2022 IEEE IFEES World Engineering Education Forum – Global Engineering Deans Council (WEEF-GEDC)

ADAPTING TO
GLOBAL DISRUPTION

CONFERENCE PROCEEDINGS

WEEF & GEDC
partnering with AEEA Conference

Cape Town – South Africa | 28 November–1 December 2022
Adapting to Global Disruption

2022 IEEE IFEES World Engineering Education Forum – Global Engineering Deans Council (WEEF-GEDC)

CAPE TOWN – SOUTH AFRICA
28 NOVEMBER – 1 DECEMBER 2022

2022 IEEE IFEES World Engineering Education Forum –
Global Engineering Deans Council (WEEF-GEDC)

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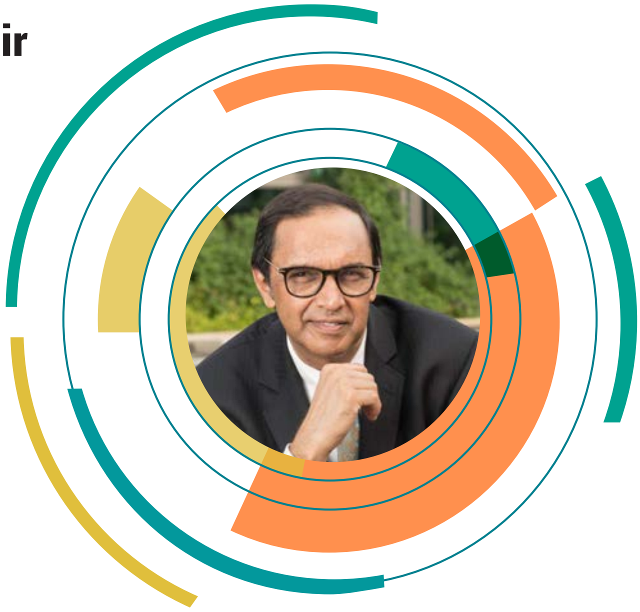
Message from the General Conference Chair



Sunil Maharaj
General Conference Chair
Vice-Principal: Research, Innovation and Postgraduate Education, University of Pretoria, South Africa

We welcome and invite Deans, professors, academics, engineering educators, industry leaders, researchers, students and governmental organizations to attend and participate in this global conference. This will give us all an opportunity to share our experiences, vision, strategy, research, products, technology and also network with engineering thought leaders from across the world. Each year, IFEES holds the World Engineering Education Forum and GEDC in different locations around the world.

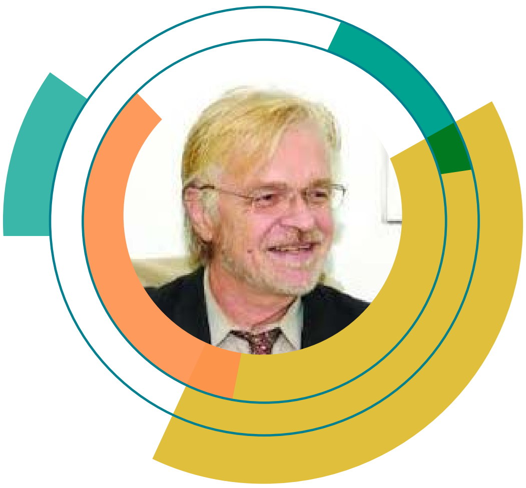
This is the largest global gathering in engineering education, involving various engineering education societies from across the various continents and includes participation from a large number of stakeholders – engineering educators, global leaders, students, industry, governmental organizations, non-governmental organizations, amongst others – who share and build fruitful and long-term collaborations and future directions during the event. The University of Pretoria (UP) as the lead organizer together with Central University of Technology (CUT), in conjunction with the African Engineering Education Association (AEEA) are collectively hosting this international conference for the first time on the African continent.

IFEES/WEEF/GEDC provides a strong platform for interaction and consultation with international delegates for the sharing of interests and expertise. We look forward to welcoming back our returning participants, corporate partners and delegates from across the globe and for providing opportunities for new partners and participants so that we can grow our networks and share our expertise and build sustainable and collaborative initiatives for a better, peaceful and safer planet.

We look forward to hosting you and thank you for your participation and support of this conference and trust that you find the many technical research papers sessions, workshops, plenaries, keynotes and exhibitions enlightening and insightful.

I hope you also take some time to experience the splendour and diversity of Cape Town and South Africa as a whole.

Organising Committee



On behalf of the IFEES, GEDC and AEEA global community it is my pleasure to invite and welcome my colleagues and friends from throughout the world to our conference this year in special Cape Town. We deeply value your commitment to join together and take action for positive change in engineering education in this time of disruption in our profession, and in the world in which we share co-dependency today and hope for the future tomorrow. I am grateful to our organizing and local committees, our corporate partners and professors, academic and governmental leaders and students for joining us . We are committed to focus on diversity, sustainability and the engagement of our new generation of leaders. We will come together after some long time apart. We take pride in our diversity and work for peace in our unity. We adopt purpose for our plans for action and celebrate the good of what we have achieved and will do so in the future.

Conference Co-Chair

Hans J. Hoyer
GEDC Executive Secretary and IFEES Secretary General

Conference Co-Chair | Student Activities

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Advisory to WFEO President

IFEES Technical Activities

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University of Stellenbosch, South Africa

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University of Pretoria, South Africa

Workshops Chair

Lelanie Smith

University of Pretoria, South Africa

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International Federation of Engineering Education Societies

GEDC
Global Engineering Dean's Council

African Engineering Education Association
AEEA

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University of Pretoria
Yunibesithi ya Pretoria

Central University of Technology, Free State

Message from the Technical Programme Committee

Chair: Deborah Blaine

University of Stellenbosch, South Africa

On behalf of the Technical Programme Committee, it is our pleasure to present the proceedings of the WEEF & GEDC 2022 Conference, partnering with AEEA. These proceedings present original research and innovative pedagogical practices implemented by authors from across the globe, as well as potential directions for engineering education researchers and practitioners through various position papers.

Authors were invited to submit a 500-word structured abstract, reporting scholarly research connected to the theme of the conference: Adapting to Global Disruption - Meeting the challenge with integrative, holistic, and sustainable engineering. All abstracts went through a double-blind peer review process by at least 2 reviewers. The Technical Programme Committee held an online workshop and provided recorded instructions in order to guide reviewers in the review process. Reviewers were required to provide structured, formative feedback by commenting on the review criteria relating to (1) relevance of the presented research to the field of engineering education (background and motivation), (2) clarity and relevance of problem statement and research aim, (3) clear description and suitability of the theoretical and analytical research frameworks (methodology), as well as data collection and analysis methods, (4) discussion of findings through logical argument, with reference to published research and implications for the field of engineering education, and (5) suitable language and style. Based on the outcome of the abstract review process, authors were invited to submit their work as a full research paper, with minor or major revision, as a poster presentation, or were deemed not relevant for the conference theme and focus. Out of the 166 abstract submissions, 86 were invited to be developed into full research papers with minor revision, 63 were invited to be presented as posters or provisionally accepted for full research paper submission pending significant revision, and 15 were rejected as focused on themes not relevant to the conference.

All full paper submissions went through an additional double-blind review process, with at least two reviewers providing independent reviews of the submissions. A similar approach to the review process was taken, where the full papers were evaluated against the same set of criteria used for the first round of abstract submissions. Based on the outcome of the full paper reviews, the full submissions were either accepted as full papers with minor revisions for inclusion in the conference proceedings, provisionally accepted as full papers pending significant revision that aligned with the feedback provided by the reviewers or accepted as poster presentations to the conference. Poster presentations are not included in the proceedings but are presented at the conference. Authors were required to provide a rebuttal with the resubmission of the provisionally accepted full papers that required significant revision, detailing how the reviewer feedback had been incorporated into the final submission. The technical programme committee reviewed these submissions in order to determine whether the feedback had been sufficiently addressed and whether they were acceptable for inclusion in the proceedings. Those resubmissions that did not meet the required scholarly standard, were rejected as full papers but invited as poster presentations. Out of the 78 full papers submitted, we accepted 64 for inclusion in the proceedings. The authors who contributed these studies represent more than 32 different higher education or research institutions in more than 14 countries around the world.

I would like to extend my heartfelt gratitude to the Review Panel, comprised of 108 reviewers from 23 countries around the world, who reviewed the abstract and full paper submissions. The timely and constructive feedback from reviewers contributed to improving the quality of the papers. I am also extremely grateful for the commitment of the Technical Programme Committee: Dr Helen Inglis (University of Pretoria), Dr Rangith Kuriakose (Central University of Technology, representing AEEA), Dr Lelanie Smith (University of Pretoria), Prof Arthur (James) Swart (Central University of Technology), and Prof Karin Wolff (Stellenbosch University). Their dedicated effort and thoughtful engagement ensured the integrity and quality of the process of publishing these proceedings. Finally, I would like to thank the team at ConfTool for their professional and immediate support throughout the review process. Their product and technical support ensured the integrity of the review process and made it so much easier.

I hope you enjoy reading through the proceedings, and that these papers open new ways for you to think about engineering education research and teaching.

Local Organising Committee

Funso Falade
University of Lagos, Nigeria

Janine Koeries
Scatterlings PCO, South Africa

Daniel Naicker
University of Pretoria, South Africa

Alfred Ngowi
Deputy Vice Chancellor, Central University of Technology, South Africa

Christopher Njaravani
University of Pretoria, South Africa

Technical Programme Committee

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University of Pretoria, South Africa

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Lelanie Smith
University of Pretoria, South Africa

James Swart
Central University of Technology, South Africa

Karin Wolff
University of Stellenbosch, South Africa

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University of Pretoria, South Africa

Yashin Brijmohan (Student conference)
Advisory to WFEO President

Henry Alinaitwe (AEEA)
AEEA Vice-President, East Africa

Soma Chakrabarti (IFEES)
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Michigan State University, College of Engineering, USA

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SPEED President

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Conference Operations Chair

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IFEES International Communications and Administrative Manager

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John Mitchell (UK)
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Homero Murzi (USA)
Tagwa Ahmed Musa Mohamed (Sudan)
Luis Manuel Sanchez Ruiz (Spain)
Jiabin Zhu (China)

Theme

Adapting to Global Disruption:
Meeting the challenge with integrative, holistic, and sustainable engineering

For years the WEEF & GEDC conferences have been invaluable forums where educators, students, engineers and industry representatives have gathered to prepare for a future of global disruption. The past two years have accelerated the global reality as the Covid-19 pandemic has firmly planted us in a state of global disruption. We are no longer preparing: we are here, in the midst of disruption, coming together to reflect on our contexts. The themes of the 2022 WEEF & GEDC conference, collocated with the AEEA 2022 conference, can be represented by these questions:

- How have we adapted to global disruption?
- How do we create stable environments that are less vulnerable, more resilient to global disruption?
- How do we meet this challenge of global disruption that is bound to be the status quo for the foreseeable future?

If we approach these challenges in an integrative (multidisciplinary, interinstitutional, cross-cultural, inclusive, diverse, trusting and ethical) manner, we will create holistic learning and engineering environments (that meet the cognitive, affective and systemic needs of society, students, academia and industry) which will create sustainable (safer, peaceful and cohesive planet) solutions for our future.

Topics

Integrative

Diversity and Inclusion

- Gender
- Identity
- Multicultural education
- North/South
- Decolonisation

Industry and Engineering Education

- Work integrated learning
- Mentoring

Engineers and Society

- Society and culture
- Ethics in engineering
- K-12 STEM outreach
- Global engineer
- Peace engineering

Holistic

Development of Engineering Educators

- Scholarship of teaching and learning
- Digital fluency

Well-being

- Mental health

Teaching and Learning Approaches

- Online/virtual/hybrid student engagement
- Active learning/project-based learning
- Gamification
- Assessment

Knowledge and Curriculum

- Programme design and renewal
- Accreditation
- Graduate attributes

Sustainable

Sustainable Development Goals

- Health and well-being
- Quality education
- Gender equality
- Climate change

Future of Engineering and Engineering Education

- Fourth Industrial Revolution
- Artificial intelligence
- Machine learning
- Digitisation
- Data driven education
- Automation and machine safety

Keynotes

Xavier Fouger, Dassault Systèmes

Bio: An Industrial Engineer, former Science Attaché for the French embassy in Vienna, Xavier joined Dassault Systemes in 1990. He created Dassault Systèmes' Learning Lab for educational research with universities, funded by US and European agencies on the use of digital technologies in education and the development of lifelong learning for the Industry Renaissance: social innovation, precision agriculture, Internet of Things, Virtual Twins, Additive Manufacturing, Collaborative Robotics, SmartFarm/Factory/City/Building and Systems Engineering. A founding member of the International Federation of Engineering Education Societies and the Global Engineering Deans Council. He currently develops industry-inspired learning centres, educational government programs and collaboration with engineering education societies. A fellow of the American Society for Engineering Education and of the European Society for Engineering Education.

Learning Ecosystems at the edge of the Metaverse

As the planet faces the historic imperative of a green transition, engineers more than ever will use virtual representations to imagine and, above all, to create smarter solutions in all human activities. Enabling this evolution requires digital skills to connect virtual universes with reality. The presentation explores fundamental competencies and practical means that emerge in different places of the world to develop them in engineering students. Among such means are global ecosystems in which African countries can invent new roles for their youth and their economies.

Ruth Graham, Higher education consultant

Bio: A Mechanical Engineer by training, Dr Ruth Graham specialised in aeronautical fatigue, working with BAE SYSTEMS for a number of years. In 2002 she moved to Imperial College London and later became Director of the EnVision project, which sought to transform the undergraduate education across all nine departments in the Faculty of Engineering related to autonomous technology and climate change. Outside work, she uses her skills, creative thinking and leadership to support initiatives designed to increase participation of underrepresented groups in Science and Engineering. Ruth has worked as an independent consultant since 2008. Her work is focused on fostering change in higher education across the world, helping to improve teaching and learning worldwide.

The Future of Engineering Education: Building on from the lessons of emergency online teaching

Speakers

Michael Milligan, ABET (Gold Sponsor)

Bio: Michael is the Executive Director and Chief Executive Officer of ABET, the global accreditor of over 4,000 college and university programs in applied and natural science, computing, engineering and engineering technology. Prior to joining ABET in 2009, Milligan was a systems director at the Aerospace Corporation, leading a team at the NASA Goddard Space Flight Center. Milligan served over 24 years as a career U.S. Air Force officer working in operations, education, international research & development, and technology acquisition. Milligan earned his Ph.D. from the University of Texas at Austin, his M.S.E. from the University of Massachusetts at Lowell, and his B.S. from Michigan State University — all in electrical engineering. He also earned an M.B.A. in Business Administration from Western New England College, is a registered Professional Engineer (PE) in Colorado and Maryland, and a Certified Association Executive (CAE).

Topic:
Changes to Programmatic Accreditation Globally and the Impact on Sustainability

Marco Rossi, MathWorks

Bio: Marco is a member of the MathWorks Academia Team and supports lecturers and researchers in the use of MATLAB and Simulink for teaching and research. Since 2020, Marco has spearheaded curriculum development projects in South Africa, Turkey, Hungary, and many other universities throughout Eastern Europe. Marco graduated with a Master of Science in Aeronautical Engineering from La Sapienza in Rome. He later worked as an Assistant Researcher at TU Dresden in Germany, where in 2019 he obtained a PhD in Mechanical Engineering due to his work on modeling and simulation of soft materials. Marco has taught several courses during his academic experience including statics and intelligent materials.

Topic:
Preparing Engineers for the Growing AI Workforce

Panel sessions

1. Advancing Diversity, Equity and Inclusion (DEI) through Academia/Industry Collaboration

- How do we change the equation to increase diversity, equity, inclusion and access in Engineering?
- Thought leaders in Academia and Industry explore real cases and success stories to show how academia/industry collaboration can open up access to encourage greater diversity, equity and inclusion in engineering to prepare students for the jobs of tomorrow.

MODERATOR:
PJ Boardman, Global Director STEM Outreach and Workforce Development, MathWorks

Renetta Tull
Vice Chancellor of Diversity, Equity and Inclusion, UC Davis

Loreto Margarita Valenzuela Roediger
Dean of the School of Engineering, Pontificia Universidad Católica de Chile

Adri van Nieuwkerk
Research, Teaching and Learning, Opti-Num Solutions, South Africa

Collins N. Vaye
PhD student, Florida International University

2. "Engineering for Good" – Peace and Humanitarian Engineering

- As highlighted in some recent reports on the "State of Engineering for Global Development" prepared by Engineering for Change, there is an increasing number of programs in engineering education that can loosely be called E4G. These programs, which are both undergraduate and graduate and which are both curricular and extracurricular, have names ranging from "Global Development Engineering" to "Peace Engineering", "Contextual Engineering" to "Humanitarian Engineering" and more. A key aspect of such programs is that they integrate concepts from engineering, humanities, social sciences, policy, finance, and health.
- Panelists will share their knowledge of these programs and start a global conversation about these themes.
- The goal is to identify the common and essential FBOKPs for integrating E4G into engineering education and other disciplines.

ORGANISERS AND MODERATORS

Kevin Moore, Executive Director, Humanitarian Engineering, Colorado School of Mines, USA (left)

Ramiro Jordan, Associate Dean of Engineering for International Programs, University of New Mexico, USA (right)

PART 1

Spyros Schismenos
University of Technology Sydney, Australia

Tagwa Ahmed Musa
Sudan University of Science and Technology, GEDC Executive Committee Member

Pali Singh
Bhagwan Parshuram Institute of Technology, Delhi, India

PART 2

William Bill Oakes
Director of EPICS, Purdue University

Ann-Perry Witmer
Research Scientist, Illinois Applied Research Institute

Sri Yash Tadimalla
General Secretary, SPEED University of North Carolina, Charlotte, USA

Panel sessions

3. Innovative Engineering Education Curricula

- Panelist introduction and reflection on their experience in Innovation of Curricula.
- Staff identity change management.
- How do you manage large classes and high student to staff ratios?
- Accreditation – does it support or inhibit innovation of the programme?

CHAIR:
John Mitchell, Vice Dean Education, UCL Engineering and Co-Director, Centre for Engineering Education

David Attipoe
Engageli

Manuel Indalecio Zertuche Guerra
Dean of the School of Engineering and Sciences, Tecnológico de Monterrey, Mexico

Paul Gilbert
Quanser

Aida Olivia Pereira de Carvalho Guerra
Aalborg Centre for Problem Based Learning in Engineering Science and Sustainabilit

Ruth Graham
Higher education consultant

4. Geopolitical Challenges for Global Engineering Education Societies

- One of the key goals for engineering education over the past decade has been preparing our students to operate in an increasingly globalized environment.
- A world where they must interact with colleagues from different countries and cultures seamlessly in order to address borderless lofty challenges such as the UN Sustainable Development Goals as well as the mundane challenges of global supply chains for manufacturing. But how well do we as representatives of engineering societies who choose to operate and collaborate under the umbrella of IFEES do in meeting these same challenges?

FACILITATOR:
Bevlee Watford, Associate Dean, Academic Affairs Director, Center for Enhancement for Engineering Diversity College of Engineering – Virginia Tech

Stephanie Farrell
International Federation of Engineering Societies

Funso Falade
University of Lagos AEEA President

Laura Romero
The Latin American and Caribbean Consortium of Engineering Institutions

Masahiro Inoue
Japanese Society for Engineering Eduction

Panel sessions

5. Micro-credentials: Challenges, Opportunities and the Path Forward

- Micro-credentials, the smaller learning units than a degree, often help achieve the learning outcomes and skills development useful for today's job market. Additionally, these provide flexible options for learners who are working as professionals, creating the pathways to degrees.
- While regional recognitions and frameworks are in place or being worked on, mobility of such recognitions with standardized learning and assessment criteria are yet to be developed.
- We will hear from the industries on what they need from the universities in such programs to prepare learners for the workforce, what credentials they accept; as well as from the accreditation board on what quality assurance the universities must provide and finally, from the universities on their strategy to implement a micro-credentialing system and their understanding on how these may lead up to degrees.

FACILITATOR:
Soma Chakrabarti, Education Resources Team Leader, ANSYS Granta Education Division, Cambridge, UK | President, IACEE

Jessica Silwick
CFO and COO, ABET

Jennifer Bradford
Business Strategy Manager, Siemens Digital Industries Software, GEDC Executive Committee Member

Ramiro Jordan
Associate Dean of Engineering for International Programs, University of New Mexico

Michael Fors
Executive Leader, Corporate Division and Business Unit Development, Boeing

Matthias Gottlieb
Technical University of Munich

Radhika Gunaji
Student Representative

6. Rising to the Top" – A Conversation with women engineering leaders and the authors of the book series on their professional and personal journeys

- Inspired by Tagwa Musa's real life professional and personal journey, a book series on women engineering leaders was born in 2019. With four volumes already published and two others in preparation, the series has gained immense popularity among engineering leaders and students. We bring six authors of various volumes of the book and a student organization representative in a panel where they discuss their challenges in professional lives .Panelists will share their knowledge of these programs and start a global conversation about these themes.

MODERATORS

Soma Chakrabarti, Education Resources Team Leader, ANSYS Granta Education Division, Cambridge, UK President, IACEE (left)
Tagwa Musa, Sudan University of Science and Technology, Sudan (right)

Stephanie Farrell
Rowan University, USA

Loreto Margarita Valenzuela Roediger
Pontificia Universidad Católica de Chile, Chile

Juliana Pallangyo
Geni Energy Consulting Firm, Tanzania

Sushma Kulkarni
Rajarambapu Institute of Technology, India

Renetta Garrison Tull
University of California Davis, USA

Ghada Mohamed Amer
Misr University for Science & Technology, Egypt

María Laura Polo González
SPEED, Colombia

Panel sessions

7. IFEES Panel discussion: Belonging Transforms

- Inclusion, Diversity, Equity, and Accessibility (IDEA) to STEM Education is key to the transformation of society and the progression of engineering education worldwide.
- The International Federation of Engineering Education Societies (IFEES) developed this session to identify key insights and best practices in developing an extensive environment of belonging.
- The discussion will consider the spectrum from recruiting AND retaining a more diverse pipeline of talent into the field to developing products and solutions that are environmentally and socio-economic aware.
- The session will consider concepts like empathy in engineering, design for disability, rural engagement along with what makes future engineers feel included or excluded.
- With this diverse unveiling of global experiences, participants will learn how engineering can serve as a platform for social change.

FACILITATORS:

Renetta Tull, Vice Chancellor of Diversity, Equity and Inclusion, UC Davis (left)

Debby Blaine, Stellenbosch University, IFEES ExCo (centre)

Dora Smith, Senior Director, Global Academic Program from Siemens Digital Industries Software and VP of D&I for IFEES (right)

William Bill Oakes
Director of EPICS at Purdue University

Disaapele Mogashana
University of Cape Town

Inês Direito
Senior Research Fellow at UCL

8. Emerging Roles for Engineers

- The old ways of educating Engineers, and keeping them upskilled upon graduation, are being called outdated and are being disrupted. The 4th Industrial Revolution sprints along, continually changing the way Engineers will work in the future, through accelerating cloud-based technologies. New Engineering specialties are emerging as a result. These emerging roles and skills must not be denied, as corporations that hire graduates are expecting universities to keep up with this new revolution. For example, new roles and skills in aerospace include new ways to accomplish Systems Engineering and Electrical Engineering. New roles include Product Safety Engineer, Software Engineer, and Guidance, Navigation, and Control Engineer. Such implications may include infusing skills in all degree programs, the creation of new degree programs and inclusion of new specializations within degree programs. In continuously working with the private sector, internships for students and professors may be explored. Apprenticeship programs, to give graduates more hand-on, job-ready skills, may be a part of a solution. Finally, partnering with private sector companies to create joint certificate programs may keep alumni upskilled as technologies and skills accelerate and change.

FACILITATOR:
Michael Fors, Leader of Corporate Division Development in Boeing's Leadership, Learning & Organizational Capability (LLOC) Team

Greg Benn
Boeing

Klaus Hengsbach
Phoenix Contact

Marcello Nitz
Instituto Maua de Technologia, Brazil

Raheel Pathan
Student Representative

Panel sessions

9. The Status and Strategic Impact of Accreditation

- Accreditation elicits a variety of responses based on perception and experience with accreditation bodies. The role and focus of these bodies are to ensure clear guidelines between what industry expects and what the standards and expectation of a professional engineer is and what Engineering Programmes are expected to facilitate and develop. The questions are, is this what is experienced on the ground-level and does accreditation drive or inhibit engineering education innovation?

FACILITATOR:
James Warnock. Adjunct Director for Professional Development at ABET

Martin Manuhwa
VP WFEO

Didier Nyembwe
ECSA

Yan Yean Chin
FEIAP Secretary General

10. Progressing Engineering Education Research and Practice in Africa: historical milestones, global influence, plans and future roles

- This panel explores the history and current status of Engineering Education practice and research on the African continent. Panellist will discuss the progress made, challenges experienced and opportunities moving forward. Conversations are circled around capacity building on the continent.

FACILITATOR:
Yashin Brijmohan. WFEO

Wahid Azizi
(Partnerships in Africa – RAE)

Esther Matemba
Engineering Education Advisor- Lassonde Educational Innovation Studio,Lassonde School of Engineerin

Bruce Kloot
University of Cape Town (UCT)

Alfred Ngowi
Deputy Vice-Chancellor of Research, Innovation and Engagement Central University of Technology, Free State

Yacob Astatke
Assistant VP for International Affairs Morgan State University

Rovani Sigamoney
Engineering Programme Specialist at UNESCO

Panel sessions

11. Race to Net Zero

- Elsevier is supporting the GEDC and the Industry Forum as a sponsor and contributor in their mission to enable university-industry collaboration to address significant global challenges well identified by the UN SDGs. This panel is about the race of the world to "Net Zero". More specifically it will cover the detailed challenges of the corporate world in terms of Engineers skills need and the impact on academia, both in research but more so in Engineering Education, with a specific view on Africa. Last but not least we want to give the student perspective a voice on how the next generation of Engineers can support with their impact on Social and Environmental Responsibility and their view on the way sustainability is taught in engineering degrees to meet those objectives.

FACILITATOR:
Jan Quint, EMLA Region Elsevier

Bryan Davies
General Manager,
Engineering Solutions,
Elsevier

Sampson Mamphweli
Director CRSES,
Stellenbosch University

Francisca Trigueiros
VP of Ed, ESTIEM
(student representative)

Leadership Forum

Engineering Education in Africa Beyond 4IR:
What actions are needed?

Imraan Patel, Deputy Director-General: Research Development and Support, Department of Science and Innovation

Bio: Employed since 2006 at the Department of Science and Innovation, he is currently a Deputy Director-General responsible for research development and support. He is a current member of the board of the Water Research Commission and a past board member of MINTEK, TIPS, and SASSCAL. At DSI, he is responsible for strategically driving a portfolio of investments and policies that enable the leveraging of science, technology, and innovation. This includes investments in human capital development and knowledge production, science engagement, the basic sciences, open science, research infrastructures, and science missions.

Lidia Brito, UNESCO Director for Southern Africa and Representative to SADC

Bio: Dr Lidia Brito is a forest engineer with a Master's and Doctorate in Forest and Wood Science from Colorado State University, USA. She joined UNESCO in November 2009, and in 2014 she was appointed UNESCO Regional Director for Sciences in Latin America and the Caribbean region (UNESCO Montevideo Office). As of 2022, she is leading the UNESCO team in Harare as the UNESCO Regional Director for Southern Africa

Tawana Kupe, Vice-Chancellor and Principal, University of Pretoria

Bio: Professor Tawana Kupe has been the Vice-Chancellor and Principal of the University of Pretoria since January 2019. He holds BA Honours and Master's degrees in English from the University of Zimbabwe, as well as a DPhil in Media Studies from the University of Oslo in Norway. In December 2019, Prof Kupe received an honorary doctorate from Michigan State University in the US, and another from the University of Montpellier in France, in October 2021.

Sabine Dall'Omo, Chief Exective Officer, Siemens South and East Africa

Bio: As one of Africa's most influential women in engineering, Sabine Dall'Omo has consistently put her best foot forward and broken boundaries in this male-dominated field. She currently serves as the Chief Executive Officer (CEO) and board member for Siemens in South Africa, following a successful career at the company for over thirty years.

Workshop sessions

1. Dassault Keynote Workshop

Plenary Workshop

Part 1: The "Learning Factory": New products, processes & business models with a digital platform
To increase graduates' professional action skills for their industrial career as well as to equip them with necessary tools to exploit existing potential due to innovative digitalization technologies, the system – Learning Factory Werk150 (the factory of ESB Business School) – offers an excellent opportunity. The workshop provides examples of curricular training in learning factories for master students within industrial engineering study programs at the ESB Business School, Reutlingen University.

Part 2: International collaborative learning for sustainability and employability
One way to increase industry competitiveness is to prepare students for a design thinking process in which prototyping and iteration loops give them the experience of digitalization for the real world. This intervention provides practical details of such approach at Durban University of Technology and Cape Peninsula University of Technology. It articulates with an international program and with sustainability considerations.

Part 3: Roadmaps to the digital transformation in education
Digital transformation in education can take many roads. In this presentation we will describe the pedagogical journey proposed by Dassault Systèmes to academic institutions around the world, and specifically in Africa. It highlights how effectively digital collaboration contributes to an inter-disciplinary teaching approach, which is engaging for students, gratifying for teachers and relevant for national economies.

COORDINATOR:
Xavier Fouger, Dassault Systèmes

Vera Hummel
Director "Werk150",
Reutlingen University.
Guest lecturer, Stellenbosch University
PART 1

Laurent Marche
Durban University of Technology, Franco-South African 3DEXPERIENCE Edu Academic Center
PART 2

Raoul Jacquand
Public services and Africa Business Development VP, Dassault Systèmes
PART 3

Frederic Douphy
Africa Business Development, Dassault Systèmes
PART 4

2. First approach and vital points to successfully produce peer-to-peer lecture films

The objective of the workshop is to challenge the idea that lecture video production is very time consuming and requires significant effort. There are good and easy ways to visualize content without becoming a future film editor. PowerPoint is a simple and yet powerful tool to produce high quality content and good short lecture videos. Using peer-to-peer student-created short lecture videos is an approach that has shown success and its implementation as a teaching and learning tool is directly related to the students' learning outcome.

FACILITATOR:
Anna Pfennig, HTW Berlin, Germany

Workshop sessions

3. An Approach to Holistic Systemic change towards Innovative Curricula

With increasing complexity of graduate attributes, engineers as academics are often unsure or unable to keep up with innovative technologies and innovative assessment practices that are published in Engineering Education Research. This workshop explores the change of roles for academics towards preparing graduates for the 21st century. We also consider creative and innovative approaches to support the development and measurement of complex graduate attributes.

FACILITATORS:

Lelanie Smith
University of Pretoria

Karin Wolff
Stellenbosch University

Helen Inglis
University of Pretoria

4. Maximizing Impact with Community Engaged Learning

The goal of the session is to actively involve participants in the exploration of community-engaged learning on a theoretical and practical level to maximize positive impact to students and community partners. A research-informed model will be used to guide participants to explore existing or potential projects or programs in a new light to enhance benefits to student learning, faculty experiences, and community impact.

FACILITATOR:

William Bill Oakes, Director of EPICS at Purdue University

5. How to Disseminate Entrepreneurially-Minded Best Teaching Practices Through the Scholarship of Teaching and Learning (SOTL)

The scholarship of teaching and learning (SOTL) is a powerful tool to disseminate knowledge about entrepreneurially-minded teaching interventions. This workshop focuses on supporting engineering instructors to augment their promotion and tenure objectives with SOTL opportunities. Equipped with SOTL tools and know-how, faculty can simultaneously elevate student learning and satisfaction while advancing their professional and academic career goals. The intended audience is engineering instructors (who are not formally trained in conducting engineering education research). The workshop topic fits well with the conference theme, "Adapting to Global Disruption," given the emphasis on entrepreneurial thinking which was necessary for many businesses to survive the pandemic. Participants will leave the workshop with a roadmap for conducting and disseminating scholarship of teaching and learning (SOTL) best practices through conference proceedings and journal manuscripts focused on entrepreneurially-minded teaching practices.

FACILITATOR:

Lisa Bosman, Purdue University

Workshop sessions

6. A workshop on Developing Spatial Thinking for Engineering Student Success

The ability to visualize in three dimensions is a cognitive skill that has been shown to be important for success in engineering and other technological fields. For engineering, the ability to mentally rotate 3-D objects is especially important. Unfortunately, of all the cognitive skills, 3-D rotation abilities exhibit robust gender differences, favoring males. The assessment of 3-D spatial skills and associated gender differences has been a topic of educational research for nearly a century; however, a great deal of the previous work has been aimed at merely identifying differences. For nearly three decades, Sheryl Sorby has been conducting research aimed at identifying practical methods for improving 3-D spatial skills, especially for women engineering students. Her current research focuses on the role that spatial thinking skills play in engineering design and problem-solving. This workshop details the significant findings obtained over the past several years through her research and identifies strategies that appear to be effective in developing 3-D spatial skills and in contributing to student success, and allows participants to engage with the programme material first-hand under the guidance of Sheryl.

FACILITATOR:

Sheryl Sorby, The Ohio State University

7. Engineering Education Research in Africa - Building capacity within a community of practice

This workshop explores how to build capacity through an under-resourced organically emerging community of practice. We ask reflective questions about the shared contextual challenge and opportunities of collaboration to explore on the African continent and in relation to the wider global north community. The workshop is facilitated by the founders of two emerging communities of practice: EERN-Africa is an emerging community of practice with more than 90 participants from 22 countries in Africa; and the Engineering Education African Fellows Group consisting of Diasporan Africans pursuing advanced degrees in engineering education. Both networks' members range from experts to developing Engineering Education Researchers and also include Engineering Educators. This workshop is open to all WEEF/GEDC2022 attendees to connect with the members in this emerging community to expand its effort towards capacity building in EER on the continent.

FACILITATORS:

Esther Matemba
Engineering Education Advisor-Lassonde Educational Innovation Studio, Lassonde School of Engineering

Lelanie Smith
University of Pretoria

Moses Olayemi
Purdue University

8. Using ATLAS.ti to collect, manage and analyse literature in research projects

ATLAS.ti is a powerful computer-assisted qualitative data analysis software (CAQDAS) that facilitates analysis of textual and media data in any discipline and for diverse research topics. In addition to assisting with analysis of data, the tools of ATLAS.ti can also be applied to the literature review process particularly when access to library and university facilities is limited due to the global challenge of COVID-19. The workshop consists of both instruction and hands-on exercises in ATLAS.ti. By the end of the workshop, it is hoped that participants will have the conceptual and practical tools necessary to use ATLAS.ti to assist organise, manage and analyse literature related to their current or future research projects. This workshop is designed for postgraduate students, early-career researchers and well-established scholars not familiar with Atlas.ti and how it might be used to assist with literature review. It will be applicable to participants in any discipline.

FACILITATORS:

Ekaterina Rzyankina
University of Cape Town

Zach Simpson
University of Johannesburg

Workshop sessions

9. Voices from the Heart: A trauma-informed and wisdom-inspired approach to wellness and thriving in engineering education

The work of education innovation is stressful, challenging, and at times isolating. We carry our battle scars like armors, full of anxiety and striving, forgetting to reconnect with our people, our history, and our deeper selves. In this workshop, through the practices of intention setting, embodiment, and wisdom council, we are invited to breathe, to pause, to reconnect and be held, and to let our true creativity emerge.

FACILITATORS:

Kai Zhuang
York University

Dimpho Radebe
University of Toronto

10. What is our responsibility to act, and advocate for systemic change within engineering education and practice?

Engineers Without Borders UK and South Africa are part of a global movement of 26 organisations who work across 55 countries, with 200 staff impacting more than 4 million people, by advocating for a stronger focus on the ethical, social, environmental and cultural aspects of engineering. Engineering graduates entering the workplace will address sustainability and global challenges, well beyond the horizon of the Sustainable Development Goals (SDG). Preparing future and current engineers requires disruption to traditional education pedagogies and approaches, to develop the knowledge, skills and attitudes needed to enable globally responsible outcomes and tackle the complex challenges of the future. Critically reflect on the current and future role of engineers, and explore Engineers Without Borders UK's prototype competency framework that looks at what is required to prepare engineers in addressing the world's most challenging issues.

FACILITATORS:

Jonathan Truslove
Education and Skills Lead at Engineers Without Borders UK

Robyn Clark
Engineers without Borders

Irshaad Vawda
Engineers without Borders

Emma Crichton
Engineers without Borders

Workshop sessions

11. Sustainability Assessments, using Ansys Granta EduPack

"Sustainability" is not a simple parameter that can be quantified and optimized in an engineering design. Even the simplest proposal for a "sustainable" development has many facets. What material and energy resources will it require? What impact will it have on the environment? What regulatory constraints must it observe? Is it socially acceptable and fair? Is it economically viable? Issues of sustainable development are intrinsically complex; their assessment requires acceptance of this complexity and the ability to work with it. Individual facets can be explored in a systematic way but the integration of the facets to give a final assessment requires debate, compromise and reflection. The first session presents the 5-step method for analyzing proposals that claim sustainability as an objective, Social Impact Audit Tool, EduPack's Sustainability Package and the tools it contains. The second session involves participants more actively. The final one encourages reflection and discussion.

FACILITATORS:

Tatiana Vakhitova
Ansys, UK

Nicolas Martin
Principal Development Manager EMEA
Ansys France

12. Appropriate Evaluations of Applicants' Diversity Statements for Improved Inclusivity and Convergent Thinking

The participants will primarily be prepared as a search committee member, chair, or convener to determine how to best evaluate diversity statements, in order to enhance the selection of applicants for a more inclusive environment filled with more convergent thinking individuals. The participants will see the theoretical and practical connections between convergent thinking and diversity and inclusion. They will understand the many ways that a diversity statement helps to find the best applicants for the organizational cultures we must develop. They will see the KSAs and ideas that can be discovered or revealed in a diversity statement. Finally, they can develop appropriate rubrics for different organizational cultures for judging the strengths of diversity statements.

FACILITATORS:

PK Imbrie
University of Cincinnati

Teri Reed
Assistant Vice President of Faculty Research Development for the Office of Research University of Cincinnati

Stephanie Adams
Dean of the Erik Jonsson School of Engineering and Computer Science and Lars Magnus Ericsson Chair in Electrical Engineering, University of Texas

Karan Watson
Abura Group

Carmen Sidbury
Senior Director Research and Development at National Action Council for Minorities in Engineering

Bevlee Watford
Associate Dean, Academic Affairs Director, Center for Enhancement for Engineering Diversity College of Engineering – Virginia Tech

13. Supporting Personal and Community Mental Wellbeing: Managing Workload in Engineering Education

In the facilitator's home institution, curricular and co-curricular programming has been introduced to support student well-being and connect students to existing mental well-being supports. This programming is delivered by a variety of people within the engineering community, including engineering course instructors, engineering students, and support staff. This model was designed with the philosophy of creating a community of support – having classmates and instructors share the material and their own personal connections to the material can make it feel more accessible to undergraduate students. Using the same philosophy of a community of support, this workshop will be intended to offer participants an opportunity to examine their own style of managing their high workload. We will then discuss strategies to support our students and peers.

FACILITATOR:

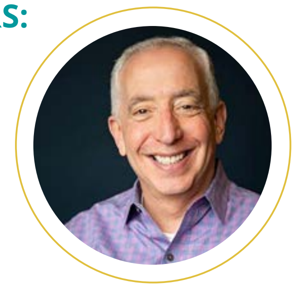
Kim Johnston, Associate Dean (Teaching and Learning and Mental Wellness) at the Schulich School of Engineering at the University of Calgary

Workshop sessions

14. The Art of Strategic Thinking and Planning

“Sustainability” is not a simple parameter that can be quantified and optimized in an engineering design. Even the simplest proposal for a “sustainable” development has many facets. What material and energy resources will it require? What impact will it have on the environment? What regulatory constraints must it observe? Is it socially acceptable and fair? Is it economically viable? Issues of sustainable development are intrinsically complex; their assessment requires acceptance of this complexity and the ability to work with it. Individual facets can be explored in a systematic way but the integration of the facets to give a final assessment requires debate, compromise and reflection. The first session presents the 5-step method for analyzing proposals that claim sustainability as an objective, Social Impact Audit Tool, EduPack’s Sustainability Package and the tools it contains. The second session involves participants more actively. The final one encourages reflection and discussion.

FACILITATORS:



Howard Teibel
President of Teibel Education Consulting

Stephanie Adams
Dean of the Erik Jonsson School of Engineering and Computer Science and Lars Magnus Ericsson Chair in Electrical Engineering University of Texas

15. Women Leadership

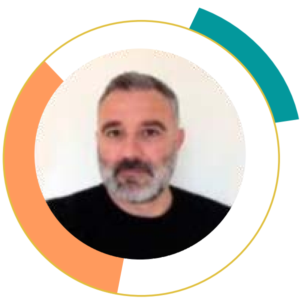
Working to increase the gender balance in decision making fora is one of the primary objectives of the new SDG 5 of the 2030 development agenda for sustainable development. Noting the significant lack of women in engineering decision making positions, irrespective of the remarkable increase of women at the entry level as faculties and instructors, this workshop is designed for female engineering professionals looking to develop and acquire the techniques and skills to drive their full potential and maximize opportunities in their career. This women’s Leadership workshop seeks to address the gender imbalance that exists pertinently in top positions of Engineering Leadership. Having more women in leadership positions may facilitate new ways of reaching consensus and may inform more gender-responsive policy. The workshop will be hands on, resulting in a self -assessment of their skills and leadership styles.

FACILITATORS:

Sushma Kulkarni
Director at Rajarambapu Institute of Technology, Maharashtra, India

Hemlata V. Gaikwad
Rajarambapu Institute of Technology

16. The IEECP – A 180º turnaround towards innovative STEAM education



The purpose of the workshop is to provide a basic approach on the need to transform STEAM education into a real pathway to authentic learning where teachers and students collaborate by defining learning goals and teaching and assessment activities that can lead to evidence the competence acquisition. Having offered the International Engineering Educator Certification Program (IEECP), accredited by the International Association for Engineering Pedagogy (IGIP), for more than 200 colleagues in different countries, this workshop will show the results of this experience and will incentive the participants to acquire new skills as engineering educators.

FACILITATOR:

Eduardo Vendrell Vidal, Vice-Rector for Studies, Universitat Politècnica de València / InnovaHiEd

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Graduates' views on the curriculum and the transition to the world of work: Skills, knowledge, and generic engineering competencies

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Abstract — **The aim of this work was to gather insights from our recent graduates (≤ 10 years since graduation) on what aspects of their undergraduate experience were useful, what skills could have been foregrounded more, what aspects could be considered for change or update, considering their experiences after graduation, as well as how their expectations met reality in the world of work. Graduates strongly indicated support for, and appreciation of, the strong technical content of the curriculum, especially process design. Core chemical engineering skills were discussed as strongly grounded in the current curriculum, along with the development of generic competencies. Further, problem solving and critical thinking, as well as personal development (working under pressure, work ethic, time management and grit) were valued. Suggestions for changes in curriculum included an emphasis on financial, economic, and business subject content, development of leadership, management and interpersonal skills, and stronger ties with, and integration of, industry into technical courses, calling for real-world practical application of knowledge and skills. However, it must be noted that insertion of additional content into an already full curriculum is inadvisable, and a more subtle approach to including the recommended ideas should be considered. In consideration of expectations, there were several cases where alumni expectations of either their relative skill level, or what the world of work is like mismatched with reality. An emerging theme from this research is that educators could do more to align expectations to smooth the transition to industry. Although large-scale recurriculation is not always possible (or feasible), existing programs can be modified to embed or integrate many of the suggestions put forward by graduates, diminishing the gap between the world of work and the curriculum, and enhancing the programme offering.**

Keywords — Curriculum reflection, chemical engineering, student experience, world of work, generic competencies

I. INTRODUCTION

The transition from the undergraduate BEng degree to the world of work is significant [1] and one that universities have a mandate to facilitate. Recent graduates can provide powerful perspectives in shaping the university's understanding of what areas of the current curriculum graduates routinely use and which skills and knowledge from their degree they find most useful. Further, they can provide insight into which skills and knowledge are underdeveloped in the degree, from their professional perspective and experience [2], [3].

Recurriculation efforts in vocational programs have considered feedback from graduates as a key input [4]. Such studies used a similar methodology to elicit insights from graduates, to inform specific changes to vocational programs in, for instance, engineering [3], [5], accounting [6] medicine [7] and veterinary sciences [8].

It is critical in a well-designed, and fit-for-purpose curriculum that a balance between technical engineering, technical non-engineering, and generic competencies be maintained [9]. Male et al [10] argue that, within the Australian content, non-technical and attitudinal competencies were rated to be as important as technical competencies. Further, Passow and Passow's [5] systematic review of competencies in undergraduate engineering programmes found that technical competence is inseparably intertwined with effective collaboration. There is further a call from many researchers for a stronger (or more explicit) link to industry needs [11], [12], as well as calls for greater emphasis on generic engineering competencies [13] – while engineering schools must also retain strong teaching of theoretical knowledge. It may be that, while technical engineering skills should remain the core focus of engineering education, recurriculation efforts might consider integrating generic engineering competencies, such as communication, leadership, finance, and economics [14]–[17]. While much research has been done globally on generic competency development [18], [19], [20], input and insights from our South African graduates could further illuminate what aspects of this skillset is most utilised in the world of work.

Various conceptualisations are used to define generic competencies [21], commonly referring to as basic, cross- disciplinary, holistic, key, soft, transferable skills (or attributes or competencies) or employability skills, which are considered necessary to thrive in the world of work. Within the context of engineering education, many studies agree that generic competencies required of young professionals include interpersonal abilities, effective communication and teamwork skills, management and leadership skills, as well as effective decision-making and problem-solving skills [18].
For this paper, we examine the survey respondents' answers to selected qualitative questions, highlighting skills they acquired during their degrees that have been useful, what changes they would suggest to the curriculum, and their expectations – and subsequent experiences – of the world of work. These questions give insights into which skills shine through the current curriculum (implicitly or explicitly), and in what areas engineering educators could consider changes.

As engineering educators, it is our role to prepare graduates for the 'real' world of work. This study feeds into other projects within our faculty [23]–[26] that consider how best to prepare students for the world of work.

II. METHODOLOGY

Ethical clearance for this study was granted under application REC-2021-21667. This paper forms part of a greater study exploring graduates' experiences of the world of work, their perceived experience of the undergraduate curriculum, and how well they feel the qualification prepared them for industry. While a previous paper focussed on our graduates' roles and skills in the world of work [22], this second paper considers which skills and knowledge our graduates valued most in the world of work, what they would change about the curriculum in light of their professional experience, and unpacks what their expectations were of the world of work compared to their experience.

The survey instrument (available online), conducted in English, followed a mixed-methods approach [22]. It included both quantitative and open-ended (qualitative) questions. Data from selected open-ended questions were included for qualitative content analysis [27], which were analysed using Atlas.ti™. A conventional content analysis approach was followed: individual responses were coded for specific concepts, which were then grouped per specific categories or themes into meaningful clusters. The advantage of such an approach is that the knowledge generated is grounded in the actual data and based on the participants' unique perspectives without imposing preconceived themes or theoretical approaches [27]. Thereafter, the responses and emergent themes were considered and regrouped into broader categories according to the existing curriculum and shortcomings to further improve the analysis and interpretation. Meaningful quotes, best illustrating the different emergent themes, were included in the discussion to support the findings.

III. RESULTS AND DISCUSSION

For this paper, three qualitative questions were analysed:

A. Highlight any skills that you acquired in your BEng degree that have been useful in your employment.
B. What would you change about the BEng (ChemEng) degree in light of your experience in the world of work?
C. Consider your expectations of the world of work when you were an undergraduate student. How does your experience in the world of work compare to that?

A. Respondents

The sampling pool included graduates of the Department of Process Engineering from 2010 – 2019 (N = 472). At the time of survey distribution, the last graduation cohort was excluded from the sampling pool due to their limited experience in the world of work. Potential respondents who were still affiliated with the Department in some capacity (e.g., current employees or postgraduate researchers) were excluded from the participant pool. Ultimately, 440 potential respondents were invited to participate via email and their responses anonymised.

Ultimately, 110 complete responses were received (25% response rate). The response rate varied between 14% and 36% of each graduating class, representing a significant response rate from most cohorts, whilst offering a representative graduate voice overall [22].

The following sections discuss the data analysis of the respective qualitative questions, with selected examples of key responses, followed by a discussion of the emergent themes.

B. Highlight any skills that you acquired in your BEng degree that have been useful in your employment.

Two major themes emerged: firstly, graduates valued what they considered to be core chemical engineering knowledge and skills, and secondly valued generic competencies acquired during their degree. Interestingly, the theme of generic competencies emerged stronger than the core knowledge and skills theme (116 unique responses versus 84, respectively). It could be argued that it is unsurprising that technical skills were not highlighted as strongly as the professional skills, since these may be considered implicit in the degree, and therefore 'assumed'.

Respondent 1320999 most eloquently encapsulated many of the key themes that emerged for this question, which are further discussed in the following sections.

"Gaining proficiency with technical writing has been very helpful. This is a big advantage we had over many other engineering disciplines. I feel that the course taught students how to manage time effectively since the workload was so high. I think the course also taught us to have grit and to persevere even when things are tough. The course forced me to have a good work ethic. I think that the course taught us the basics of chemical engineering well. If your job is very technical, it is important to understand the fundamentals. Having a sound base is important for building later knowledge on. Further, the standards were set high for the course. I hope it never gets watered down like many of the other universities in South Africa. What matters most in the workplace is to be able to learn quickly and to utilize your resources effectively. It is important to be practical and independent in your decision making."

It became clear that the respondents valued the skills and knowledge developed throughout their undergraduate degree, both implicitly and explicitly taught.

1. Core chemical engineering skills and knowledge

Unsurprisingly, considering that many of the respondents work in traditional chemical and metallurgical engineering sectors [22], these engineers valued the core knowledge and skills that form the foundation of the chemical engineering curriculum. Most respondents spoke to the value of developing process-related thinking, including process design, control, simulation, as well as process modelling and optimisation.

Respondent 1320417: *"4th year Design was by far and away the best subject that prepared me for real-life engineering."*

Respondent 1323551: *"The standard of Process control at SU is far above average and is assisting me to stand out in my work environment."*

Many respondents spoke to the value of fundamental engineering and scientific knowledge that they acquired throughout their degree and how this knowledge empowered them to develop further in their careers as engineers.

Respondent 1320999: *"I think that the course taught us the basics of chemical engineering well. If your job is very technical, it is important to understand the fundamentals. Having a sound base is important for building later knowledge on."*

Other core technical knowledge and skills mentioned in the responses included fundamental knowledge of programming and coding, fluid mechanics, mass and energy balances, heat transfer, separations processes and thermodynamics, and reactor design – corresponding well to the core knowledge areas in the curriculum. Specific technical skills mentioned by the participants also include data analysis, software literacy, and research.

2. Generic competencies

Participants overwhelmingly valued the generic competencies acquired throughout their degrees. Many of these competencies were implicit in the curriculum, rather than explicitly taught in stand-alone modules.

The strongest theme that emerged from this question related to communication; the value of developing technical report writing and professional communication skills (35 unique responses).

Respondent 1320472: *"The report writing skills learned at SU appear to be particularly valuable and distinguish SU process engineering graduates."*

Respondents valued how this degree developed their approach to problem solving (24 unique responses), project management (17 unique responses), critical/analytical thinking (15 unique responses) and their work ethic (16 unique responses), and how this fostered independent learning (3 unique responses) and teamwork (6 unique responses) in the workplace.

Participant 1322453: *"Problem solving. Problem solving. Problem solving. Report writing, working really hard and staying calm under pressure. I am not a typical chemical engineer and don't really use all the technical/theoretical skills, but I use my general understanding of the various fields to manage people."*

It was evident that our graduates value and make use of the skills and knowledge acquired throughout their degree, both in traditional chemical engineering industries and other non-traditional fields.

C. What would you change about the BEng (ChemEng) degree in light of your experience in the world of work?

146 unique responses were coded, which could be, for the most part, grouped into five major themes. 15 respondents commented that the curriculum needed no adjustment, while a few respondents mentioned that helping graduates find employment could be emphasised.

Another related question, *"What elements of your work were not sufficiently covered in your BEng (ChemEng) degree?"* was included in the survey. These responses were also considered whilst analysing the current question and were included in this section rather than repeated, as similar and overlapping themes emerged.

1. Suggestions for changes to technical and specific knowledge and content

Most notably, the addition of knowledge and skills related to financial management, project economics, or business/commercial content – specifically relating to managing large, complex projects with significant budgets (as such projects are inherent to the engineering industry, across multiple sectors) – were called for.

Respondent 1326677 suggested to *"[i]ncorporate more discussions on risk and opportunity assessments as this is a key driver of ALL businesses-regardless if it is purely technical, engineering operation or finances".*

Many respondents spoke to this theme, and it appeared to represent a significant need for consideration in the current curriculum.

Respondent 1320826: *"Financial elements. All jobs are based around economics or financial return. We were not exposed to enough financial management."*

Respondent 1325272: *"Being able to understand that all of engineering is motivated commercially is quite important. Engineers want the best technical solution but economics (even on a small-scale) is important and usually this is a very large part of the motivation for change."*

32 respondents suggested changes to technical knowledge content, including recommendations for software-related skills and knowledge (AutoCAD, Python, general programming, AI, and machine learning) as well as several suggestions for specialisation or advanced modules in selective fields (particularly during final year), such as minerals processing, water treatment design, and environmental engineering:

Respondent 1327187: *"Split the final year into a choice of "specialist' or interest fields like Control, metallurgy, Bioprocessing etc and then focus on those subjects rather than force everyone to have a LITTLE of everything. I'd rather walk out of university a specialist than a generalist."*

These suggestions were however closely related to the respondent's particular interest, technical field, or profession, and the subsequent need in their immediate environments, and was unsurprising. Participants might rather be directed to short courses or postgraduate programmes focussing on advancing those particular knowledge areas and skills.

2. Suggestions for changes to teaching and learning approaches

Graduates' responses were generally positive towards the degree and teaching and learning approaches.

As Respondent 1321026 elaborated: *"I had a great experience at Stellenbosch and feel that I was very fortunate to have had exceptional lecturers who mentored me, taught me how to think more critically, and somehow managed to make 5 years' work digestible within 4 years."*

Graduates made several valuable suggestions for changes to teaching and learning approaches. Most notably, they urged a greater focus on real-world application throughout the degree. One practical application of this suggestion could be a shift towards more project- or problem-based instruction (PBI) throughout the curriculum. Although this is currently included in some advanced modules, it could be expanded where appropriate. For instance:

Respondent 1320459: *"SU covers the basic theory and modelling very well. But practical application is lacking. I would have like to have a small project each year to get more time to understand the development of a project, real world challenges with construction and control. Troubleshooting of actual designed systems."*

This respondent's suggestion on 'troubleshooting actual systems' was an excellent one, which could truly benefit students whilst exposing them to real-world industry examples. A potential drawback of this approach is that its success is dependent on buy-in from industry partners.

Respondent 1323898: *"I wish we had had more practical experience. Not only naming valves, but being able to identify, select and technically specify the types of actuators. Not only calculating pressure but having a point of reference as to what that physically looks like."*

While this is a valuable suggestion, we must remain cognisant of the role of the university and training received during the undergraduate degree, and what is expected to be covered during initial employment as an Engineer in Training (EIT).

Respondent 1320467 suggested that *"it could be beneficial to prepare students for the creatively demanding workplace by introducing more open-ended projects which require lateral thinking."*

The role of creativity in science, technology, engineering and mathematics education is well documented [29], [30], but is potentially under-emphasized in our current curriculum. Open-ended projects and problems are currently included, while creativity might admittedly be lacking. Students need scaffolded learning opportunities throughout the curriculum to prepare them for open-ended problems requiring creativity in the workplace.

In terms of negative feedback, there was concern over student overload, lack of work-life balance, and the quantity of content potentially resulting in *"quantity over quality"* (Respondent 1323457).

Respondent 1324752: *"Make it a 5 year course. Cramming all the work into 4 years creates an unrealistic expectation of your work-life balance in the world of work that is not required all the time."*

Teaching and learning approaches evolve and change over time and are dependent on various factors, including the lecturers and their teaching styles, the nature and content of the modules, modes of evaluation, and more. The nature of assessment approaches and the general approach to the curriculum offering is continuously improving and developing, and these suggestions are worth considering in recurriculation efforts.

3. Suggestions for development of generic engineering competencies and non-engineering skills and knowledge

Another major theme that emerged from the qualitative data included suggestions within the development of generic competencies.

One such suggestion – which emerged as a major theme – was project management. Currently, the project management module is presented to all final-year engineers (across all degree programmes) in the faculty. As such, the focus of the curriculum is more generalised to be applicable to all programs and might lack some specificity for chemical engineers. Thus, considering the feedback received from our graduates, it might be worth considering a specialised project management module for chemical engineers, although there are benefits to running an integrated course with all engineering students. Furthermore, as financial modelling and analysis, as well as people management, form such an integral part of project management, it might make sense to include such content (called for by many respondents) in a project management module. Conversely, project management is already an over-full module, and the addition of extra content would be difficult.

Respondent 1320425: *"Project management as a subject did not prepare me in the right way for project management in the working world. The subject is a good idea but the emphasis on all the memorization rather than more practical experience might be the wrong approach."*

Further, within the theme of professional skills development, respondents called for a greater focus on the development of interpersonal, communication, leadership, and teamwork skills. Although the current curriculum has a significant focus on (technical) communication, the emphasis from the feedback was on interpersonal skills development and how it relates to people and project management.

Respondent 1320467: *"[I]t could also help having leadership and team building workshops to instil a sense of comradery. This may be counter-intuitive, as universities traditionally aim to develop individuals as individually competent, but establishing a framework for building trust as a team is sometimes more important than building performing individuals. Success is actually a medley of both individual and social performance."*

Respondent 1324442: *"Engineers always have to work with people. It is important to also understand how to do that effectively."*

Respondent 1321145: *"Definitely add a couple of leadership courses in... Most of the engineers I know are in a form of leadership, and were vastly underprepared for this role."*

Respondent 1321463: *"I was not prepared for a client facing work, where any problems will be directed to you to deal with by a diplomatic approach."*

Clearly, our graduates believe that there is a need for further development of professional skills, and specifically interpersonal skills, in the curriculum. Creating opportunities for group work in modules is not enough; these are already included in several modules and are clearly not transferring the much-needed competencies and skills. Recurriculation must consider including explicit skills development in this arena, and should align students' expectations of the crucial, inherent daily use of these skills in their future careers.

4. Suggestions for greater integration with industry

Many respondents suggested that students would benefit from greater interactions with industry, and more practical exposure to real-world applications of the theory.

Respondent 1320446: *"More experience with industry, more collaboration with industry, visiting lecturers or speakers from industry. In my time at SU, there was little collaboration with the outside world except for a few site visits. Students were learning in a university bubble, with little translation to real world application."*

Respondent 1322002: *"More practical experience is needed. Students need to be able to see what people do on the plant (production) and how design and troubleshooting works..."*

A greater integration with industry, and further interactions with industrial partners (for instance, through guest lectures), is recognised as valuable and is a point well taken from the graduates' feedback.

Currently, our four-year undergraduate program does include a compulsory module where students are required to do vacation work for at least six weeks at an engineering company. However, students' experiences at these companies are varied and dependent on a number of factors, including the sector and company itself. Further, students have the option to spend an internship year at an industry partner between their third and fourth years of study. While this valuable internship year could speak to the gap identified by the graduates, the uptake is comparatively low. More could be done to emphasise this opportunity and its value to students.

5. Suggestions for greater exposure to industry practices

Respondents recommended greater exposure to the detailed knowledge required in industry and corporate practices. For instance, health and safety standards and training, how one prepares a tender, Environmental Impact Assessment requirements, compliance to legal aspects in project design and management, and quality control.

Respondent 1322002: *"Prepare students for real work by going through legal specs and client specs. Get the latest design specs from companies such as Sasol, Engen, Shell etc and incorporate compliance of those specs into design work."*

Many respondents further called for greater exposure to industry-specific practices, such as site operations and optimisation, utilities, CAPEX proposals, plant construction and commissioning, and legal requirements. This begs the question: what is the purpose of an undergraduate degree, and what is the role of initial employment as an EIT? Many graduates incorrectly expect that the above-mentioned practical knowledge – that should rightfully be developed in industry – should be included in the undergraduate curriculum. It is thus important to align students' expectations for their level of competence as graduates, differentiating between what is learnt as an undergraduate student, and the continued training that occurs in employment. Students should embrace the notion of life-long learning as an engineer; preparing them for a continuous learning curve as they enter industry could positively shift experiences thereof. As such, some suggestions are not feasible for inclusion in the undergrad curriculum:

Respondent 1322934: *"What I struggled with most was the practical aspect of engineering. Real world applications are very different from the P&IDs we are used to as chemical engineer undergraduates. Also, better understanding both electrical and mechanical engineering basics are important to work better with other engineering disciplines to deliver sound solutions to customers."*

Respondent 1323120: *"The practical nature of the real world. Initially, I approached real-world problems and projects in the theoretical manner that worked at university. This did not suffice, since there are far too many variables to take into account, and I failed miserably. Knowing which assumptions to make and how to apply the theory in practice, is crucial, and I did not have that skill."*

D. Consider your expectations of the world of work when you were an undergraduate student. How does your experience in the world of work compare to that?

One's experience of the world of work is closely aligned with one's job satisfaction, specific role, and sector. Further, one's experience thereof is determined by various factors, such as line managers, team environments, duties, and responsibilities. Thus survey responses, such as these, are highly coloured by individual experiences, which may not be a direct reflection of the curriculum and program or the degree they hold. Nonetheless, the following does provide valuable insights into the lived experiences of our graduates.

Unsurprisingly, most respondents indicated that their experiences of the world of work were vastly different from their expectations. Nonetheless, and gratifyingly, many graduates felt adequately prepared by the degree.

Respondent 1323642: *"...I believe that the undergraduate alone at Stellenbosch University prepared me well to enter the world of work. My expectations during my undergraduate studies aligned very well with what I am doing now."*

Interestingly, the most prevalent theme that emerged from this question was – as previously noted – the importance of interpersonal communication, teamwork, and people skills and how these form an integral part of their core work responsibilities, regardless of their role or sector.

Respondent 1320552: *"I work on operations, where communications and collaboration is critical. I think many people underestimate the* *importance of this and think that the technical ability will take them all the way. How one communicate the technical analysis and project plan, and deal with a wide spectrum of different people with different backgrounds and education plays a equal role than the technical ability."*

Respondent 1320455: *"Initially well aligned with skills, but as I progressed to more senior roles it quickly become about people, risk and financial management, none of which was taught in major modules or outcomes of modules."*

Some respondents reiterated the fact that real-world engineering emphasises economics, financial considerations, and commercial aspects, and that these knowledge areas are not sufficiently covered in the curriculum.

Another interesting theme that emerged was that graduates expected more challenging technical engineering work. Only few graduates go on to work at, for instance, design houses – places where a deep, fundamental day-to- day knowledge of all technical aspects of chemical engineering is needed. In fact, some respondents found that the world of work was mundane (and boring!) in comparison to what they were exposed to at university or what they were expecting the world of work to entail. Some respondents indicated that working was much less stressful than studying, alluding to the intensity of the undergraduate programme.

Respondent 1320999: *"In university, I thought that I would be using a lot of the theoretical knowledge (spend heaps of time on simulations and modelling). In reality, there is rarely time for full studies and building extensive models. Having a sound theoretical base helps a lot, but one must be able to apply it practically and cost effectively. When I was a student, I underestimated how important people skills are. It is of great importance to be able to win over operators and experienced supervisors to consider your inputs and ideas."*

Some respondents also acknowledged that the degree imparts not only technical knowledge, but importantly, a mode of thinking and problem solving that is particularly valuable across all industries in (and outside) the engineering sector.

Respondent 1321439: *"...but the thinking skills I developed were crucial in my success in my roles so far and I definitely wouldn't have chosen to study anything else if I could redo the University process."*

Respondent 1320594: *"I do think a lot of my success through this has been the work ethic Stellenbosch installed into me and the ability to solve problems quickly and efficiently."*

Many graduates experienced the industry as more saturated than expected – from both the perspective of entering the world of work after graduating, but also when looking for opportunities to move to a new position. Some graduates noted that they expected to be highly sought after directly after graduating and did not expect to look for employment for a few months. This is however a normal course of events, and students' expectations should be aligned with this reality.

Respondent 1323690: *"First, I think most undergraduates over- rate themselves and think that they will be headhunted out of university. That is definitely not the case. I think emphasis should be placed on how to structure your CV and market ourself for the position you want to get... I also thought there would be more engineering opportunities in R&D in South Africa, but unfortunately that was not the case."*

Respondent 1320476: *"It was hard to find a job initially, even though the Chem Eng degree really is an excellent degree. I think more emphasis and help provided (industry connections and getting employers and recruiters to campus etc) to final year students would really help."*

Themes that emerged that were less prevalent, but still worth mentioning, include: the importance of a self-starter attitude, the role of lifelong learning in becoming an engineer, and the expectation of remuneration being misaligned in the South African industry. Also, some respondents found the world of work more practical and physical than they expected. The nature of the work was also often more interdisciplinary than they expected.

Respondent 1320417: *"...you actually still have a large learning curve and even the people with 20+ years experience still do not know everything..."*

Respondent 1324930: *"I thought people knew what they were doing, but working now I realized that everyone is still figuring things out as they go along"*

IV. CONCLUSIONS

This survey provided useful feedback about our curriculum and insights into what skills, knowledge, and competencies our graduates valued in the undergraduate curriculum and the world of work. Most respondents were positive and satisfied with the degree and the programme. However, many useful suggestions were made that could be considered in future recurriculation efforts.

The process of recurriculation is inherently complex, requiring balancing credits, graduate attributes, generic engineering competencies, and consideration of a plethora of systematic factors and constrains, such as industry regulators, institutional procedures and regulations, and staff buy-in. However, the process of reflection and improvement using graduates' inputs provide a valuable starting point. Easily implementable changes within the current framework are however possible, without major recurriculation of module content, particularly in light of graduate feedback.

Suggestions for recurriculation could be themed under specific content and knowledge, teaching and learning approaches, development of generic competencies, as well as greater integration with, and exposure to, industry practices.

Most notably, respondents highlighted the need for content related to interpersonal, communication, and people skills, as well as people management and leadership skills. Another significant theme was the need for competencies relating to economic, project finances, financial modelling and management, cash flow analysis, and risk analysis.

For teaching and learning specifically, there was a significant call for more links to industry activities and application, and real-world applications. Graduates also suggested including more problem- and project-based instruction and open-ended problems to develop creativity. While there is a call for further applied work, there is also a call for greater focus on the teaching of fundamentals.

Finally, it was apparent from the responses that the programme could do more to align students' expectations of (1) the reality of the world of work (and what will be expected of them as EITs in traditional engineering sectors, at least), (2) the role of their undergraduate degree and what they can expect to know as graduates, and (3) what they can expect to learn and continue developing as they enter the world of work. Such alignment of expectations could easily be implemented in various ways, including both curricular and co-curricular adjustments and interventions, without major recurriculation, and could positively impact their experiences of the world of work.

The use of graduates' perspectives has proven invaluable in considering the curriculum and structuring our approach towards recurriculation. Many suggestions were made that will assist in improving our programme offering.

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REFERENCES

[1] E. E. Stiwne and T. Jungert, "Engineering students' experiences of transition from study to work," vol. 23, no. 5, pp. 417–437, Nov. 2010,

[2] M. Sankaran and A. K. Rath, "Assessing undergraduate engineering programmes using alumni feedback," J. Eng. Educ. Transform., vol. 34, no. Special Issue, pp. 733–741, Jan. 2021

[3] G. Saunders-Smits and E. de Graaff, "Assessment of curriculum quality through alumni research," Eur. J. Eng. Educ., vol. 37, no. 2, pp. 133–142, May 2012,

[4] H. Heydenrych and J. M. Case, "Researching graduate destinations using LinkedIn: an exploratory analysis of South African chemical engineering graduates," Eur. J. Eng. Educ., vol. 43, no. 5, pp. 693– 705, Sep. 2018,

[5] H. J. Passow and C. H. Passow, "What Competencies Should Undergraduate Engineering Programs Emphasize? A Systematic Review," J. Eng. Educ., vol. 106, no. 3, pp. 475–526, Jul. 2017,

[6] S. Yu, N. T. Churyk, and A. Chun-C. Chang, "Are students ready for their future accounting careers? Insights from observed perception gaps among employers, interns, and alumni.," Glob. Perspect. Account. Educ., vol. 10, pp. 1–15, 2013,

[7] D. I. Clemmer and W. E. Bertrand, "A model for the incorporation of alumni-faculty feedback into curriculum planning.," Am. J. Public Health, vol. 70, no. 1, pp. 67–69, Jan. 1980

[8] D. A. D. C. Jaarsma, D. H. J. M. Dolmans, A. J. J. A. Scherpbier, and P. Van Beukelen, "Preparation for Practice by Veterinary School: A Comparison of the Perceptions of Alumni from a Traditional and an Innovative Veterinary Curriculum," J. Vet. Med. Educ., vol. 35, no. 3, pp. 431–438, Sep. 2008,

[9] M. H. Forbes, A. R. Bielefeldt, J. F. Sullivan, and R. L. Littlejohn, "Divergent requirements for technical and non-technical coursework in undergraduate engineering programs," Int. J. Eng. Educ. ISSN-e 0949-149X, Vol. 33, no. 1 (Parte A), 2017, págs. 162-174, vol. 33, no. 1, pp. 162–174, 2017,

[10] S. A. Male, M. B. Bush, and E. S. Chapman, "An Australian study of generic competencies required by engineers," Eur. J. Eng. Educ., vol. 36, no. 2, pp. 151–163, May 2011,

[11] C. Dorfling, K. Wolff, and G. Akdogan, "Expanding the semantic range to enable meaningful real-world application in chemical engineering," South African J. High. Educ., vol. 33, no. 1, pp. 42– 58, Apr. 2019,

[12] R. Grady and J. Pratt, "The UK Technology Transfer System: Calls for Stronger Links Between Higher Education and Industry," J. Technol. Transf. 2000 252, vol. 25, no. 2, pp. 205–211, 2000,

[13] A. J. Fletcher, A. W. A. Sharif, and M. D. Haw, "Using the perceptions of chemical engineering students and graduates to develop employability skills," Educ. Chem. Eng., vol. 18, pp. 11– 25, Jan. 2017,

[14] K. J. B. Anderson, S. S. Courter, T. McGlamery, T. M. Nathans-Kelly, and C. G. Nicometo, "Understanding engineering work and identity: a cross-case analysis of engineers within six firms," Eng. Stud., vol. 2, no. 3, pp. 153–174, Dec. 2010,

[15] S. Male, M. Bush, and E. Chapman, "Identification of competencies required by engineers graduating in Australia." Apr. 29, 2021,

[16] S. A. Male, M. B. Bush, and E. S. Chapman, "Perceptions of Competency Deficiencies in Engineering Graduates," Australas. J. Eng. Educ., vol. 16, no. 1, pp. 55–68, Jan. 2010,

[17] J. Trevelyan, "Transitioning to engineering practice," Eur. J. Eng. Educ., vol. 44, no. 6, pp. 821–837, Nov. 2019,

[18] M. Girotto and A. Oliveira, "Undergraduate students' perceptions of the development of generic competences and their relevance to the engineering profession," Eur. J. Eng. Educ., pp. 1–22, Aug. 2022,

[19] S. A. Male, M. B. Bush, and E. S. Chapman, "Understanding Generic Engineering Competencies," Australas. J. Eng. Educ., vol. 17, no. 3, pp. 147–156, Jan. 2011,

[20] G. Besagni, F. Inzoli, T. Ziegenhein, and D. Lucas, "Computational Fluid-Dynamic modeling of the pseudo-homogeneous flow regime in large-scale bubble columns," Chem. Eng. Sci., vol. 160, no. November, pp. 144–160, 2017,

[21] M. Tight, "Twenty-first century skills: meaning, usage and value," Eur. J. High. Educ., vol. 11, no. 2, pp. 160–174, Apr. 2021,

[22] R. W. M. Pott and M. De Jager, "A decade of chemical engineering graduates: Their roles and skills in the world of work," Proc. 2021 World Eng. Educ. Forum/Global Eng. Deans Counc. WEEF/GEDC 2021, pp. 124–131, 2021,

[23] C. Winberg et al., "Developing employability in engineering education: a systematic review of the literature," Eur. J. Eng. Educ., vol. 45, no. 2, pp. 165–180, Mar. 2020,

[24] R. W. Pott, K. E. Wolff, and N. J. Goosen, "Using an informal competitive practical to stimulate links between the theoretical and practical in fluid mechanics: A case study in non-assessment driven learning approaches," Educ. Chem. Eng., vol. 21, pp. 1–10, Oct. 2017,

[25] M. Tadie, R. Pott, N. Goosen, P. Van Wyk, and K. E. Wolff, "Expanding 1st year problem-solving skills through unit conversions and estimations," in IEEE Global Engineering

Education Conference, EDUCON, 2018, vol. 2018-April, pp. 1035–1043,

[26] K. E. Wolff, C. Dorfling, and G. Akdogan, "Shifting disciplinary perspectives and perceptions of chemical engineering work in the 21st century," Educ. Chem. Eng., vol. 24, pp. 43–51, Jul. 2018,

[27] H. F. Hsieh and S. E. Shannon, "Three approaches to qualitative content analysis," Qual. Health Res., vol. 15, no. 9, pp. 1277–1288, Nov. 2005,

[28] M. Q. Patton, "Qualitative research and evaluation methods. Thousand Oaks," Cal. Sage Publ., vol. 4, 2002.

[29] D. H. Cropley, "Creativity in engineering," Multidiscip. Contrib. to Sci. Creat. Think., pp. 155–173, Jul. 2015,

[30] D. H. Cropley and A. J. Cropley, "Fostering Creativity in Engineering Undergraduates," vol. 11, no. 2, pp. 207–219, 2010,

Technical papers

Evaluation of a holistic framework for leadership training of engineering students

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Abstract — **Leadership training for engineering students is generally understood to be a compilation of several categories of skills and competencies. In this paper, a simple framework is presented to incorporate all of the skills under three categories – cognitive, interpersonal, and intrapersonal. This framework is demonstrated with the help of the newly-established Seidel Leadership Institute at New Mexico State University. With cohorts of students selected based on specific criteria, the Institute provides a set of opportunities for students to engage in outside their curricular requirements and schedules. Results from research-based surveys suggest that the Leadership Institute helps engineering majors improve in their self-assessments of relevant skills, and it can also impact their attitudes about the engineering profession and the role of service as a professional engineer. The data also suggest that it is important to have hands-on experiences for students so they can have opportunities to practice and apply what they learn, as this was greatly valued in the feedback. Findings show promise for smaller, cohort-based programs to positively impact engineering students as they develop important skills and attitudes outside of the classroom and prepare for the field.**

Keywords — Interpersonal skills, Intrapersonal skills, Cohort-based

I. INTRODUCTION

Leading a team of engineers in any project involves a self- directed vision, coordinating and communicating various elements of the project, and technical expertise on the project feasibility and execution. Earlier views on engineering leadership confined it to an exclusive enterprise of visioning. Walesh (2000) describes it as a traditional pyramidal and segregated organizational model, where the three functions of leading, managing, and producing, reside in three separate groups of personnel [1]. According to this pyramidal model, an organization consists of a vast majority of employees who are the doers or producers, a smaller group of employees who are the directors or managers, and a still smaller group – often a single person – who is the leader symbolized as the top of the pyramid. This model implies that leadership is a career goal that an individual accomplishes only after passing through the production and management stages. This traditional view is superseded by a shared responsibility model, which accepts that every single individual in an organization has all the three capabilities – leading, managing, and producing, in varying degrees. The relative proportions of leading, managing, and producing vary among individuals, but the model allows for synergistic build-up of the strengths of all individuals. A successful organization, therefore, allows individual competencies along with freedom, initiative, creativity, productivity, and responsibility to be coordinated synergistically.

Subsequent studies sought categorization of various skills and personality traits needed in leadership [2], [3]. Different dimensions of leadership are explored by researchers. As examples, the Social Change Model of leadership development documented seven Cs of Change – Citizenship, Common Purpose, Collaboration, Controversy with Civility, Consciousness of Self, Congruence, and Commitment [4]; while the Emotionally Intelligent Leadership Model categorized twenty-one capacities to be developed in the three categories of Consciousness of Context, Consciousness of Self, and Consciousness of others [2].

The current study deals with the development, implementation, and evaluation of a simple yet comprehensive framework for leadership training of engineering students. The goal is to develop a set of simple attitudes which would propel one to acquire the necessary skills or capacities identified by others. Subject knowledge, visioning/self-directed will, and synergistic interaction, are recognized in this framework as the three skills of equal importance. Any one of these three in the absence of the other two might be useless if not dangerous:

- Subject knowledge without will is impotent; without synergistic communication, it is only cerebral without any possibility of practical realization.
- Visioning and exercising administrative will without a synergistic purpose is useless; without topical/subject knowledge, it is misguided and ill-advised.
- Synergistic communication without a purposeful will is futile; without subject knowledge it is only chatter.

Interestingly, many researchers involved in designing higher education zoomed on a threefold division of skills or competencies “Figure 1”. The National Research Council (NRC) of the National Academies published an extensive study in 2012 to identify transferable knowledge and skills in the 21st century [5]. With the goal of synthesizing the vast body related to the teaching and learning of such skills, NRC categorized these competencies into three categories: cognitive, intrapersonal, and interpersonal. The competencies listed under these categories are [6]:

- The Cognitive Domain includes three clusters of competencies: cognitive processes and strategies, knowledge, and creativity. These clusters include competencies, such as critical thinking, information literacy, reasoning and argumentation, and innovation.
- The Intrapersonal Domain includes three clusters of competencies: intellectual openness, work ethic and conscientiousness, and positive core self-evaluation. These clusters include competencies, such as flexibility, initiative, appreciation for diversity, and metacognition (the ability to reflect on one's own learning and make adjustments accordingly).
- The Interpersonal Domain includes two clusters of competencies: teamwork and collaboration. These clusters include competencies such as communication, collaboration, responsibility, and conflict resolution.

The cognitive, intrapersonal, and interpersonal domains outlined by the NRC correspond to the subject knowledge, visioning/self-directed will, and synergistic interaction, respectively. Although each of the domains involves extensive number of skills and competencies, the broad three-fold division serves to keep the framework simple to implement in leadership training.

The three domains described above call for a congruent set of attitudes for the three vertices "Figure 2". Learners should recognize that knowledge is trumped by behavior, and their quality of existence in the group is characterized by how they relate with the group and not necessarily by how intelligent they might be. This involves among other things, replacing 'I' with 'we.' Attitudes about the objective world ought to consider it as a set of relational realities. Knowledge of the objective world should be extended to seeking an understanding of relationships among things and people; exploiting nature should be substituted by learning from, and living with, nature. The attitudes on the very process of learning, congruent with the other two sets of attitudes, are to seek synergistic and interdisciplinary learning, to develop a habit of group learning, and to constantly synthesize and see unity in diversity.

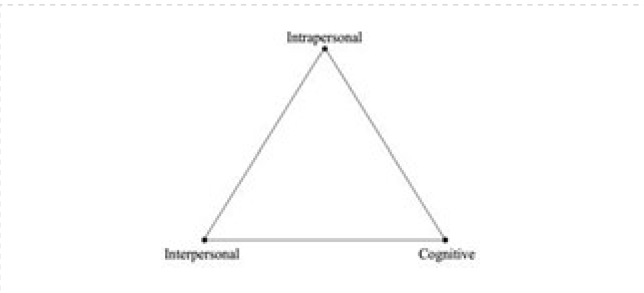

FIGURE 1: *Categorization of necessary competencies recognized by the National Research Council*

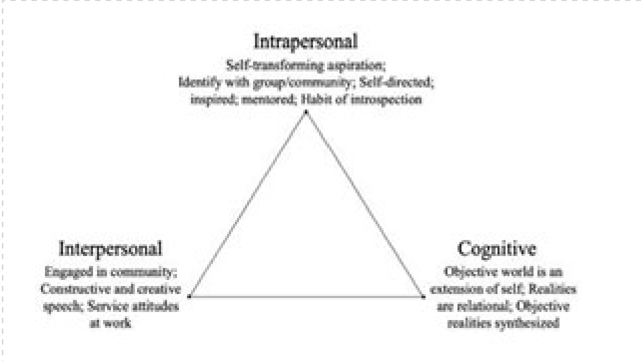

FIGURE 2: *Attitudes necessary for the cognitive, intrapersonal, and interpersonal competencies.*

The newly-established Seidel Engineering Leadership Institute at the New Mexico State University College of Engineering allowed us to implement this framework and train cohorts of students in the development of attitudes necessary to acquire intrapersonal skills and interpersonal skills. The expectation is that these two sets of skills are concurrently acquired with the cognitive skills from regular academic curricula. The purpose of this paper is to summarize the implementation of the leadership training framework described above, and to provide students' experiences, feedback, and self- assessment. The Institute was designed to involve cohorts with small groups of students; therefore, the sample sizes are too limiting to allow for formal and thorough statistical analyses. However, students' self-assessment of their own skills and attitudes before and after the leadership training allowed an understanding of the relative impact and importance of various components of the training.

II. IMPLEMENTATION OF THE FRAMEWORK

To implement the training framework described above, a call is issued at the beginning of every academic year to solicit student interest in the program. An important objective of the training program is that it does not interfere with the academic progress of students in their program curricula. The regular academic coursework is directly responsible for the cognitive skills, and it is crucial that the interpersonal and intrapersonal skills complement those skills without competing for time with them. The challenge therefore is to provide flexibility in students' meeting times and in the submission deadlines of their work and yet to incorporate rigor and set fair expectations.

A. Applicant Eligibility Criteria

Students wishing to participate in the Leadership Institute are required to commit to the two-year program and should be entering their junior year of engineering studies. They must have a GPA equal to or greater than 3.0. They should be U.S. citizens (per the donor's request). They must submit a one-page essay answering the following questions:

- What does leadership mean to you?
- What leadership roles do you think engineers can fulfill?

B. Program Participation Requirements

Participating students are required to keep a journal of their observations throughout the two-year program. They attend workshops and seminars presented by different career experts including members of the Engineering Advisory Council who are accomplished and recognized leaders in engineering industries, academia, or national laboratories. Additionally, they are exposed to discussions with non-engineering students and faculty.

Each semester, students are asked to complete a reading assignment. The group discusses the books and students provide a paper at the end of each semester reflecting on the readings. The following books have been used for the four- semester readings:

- "Service-Learning: Engineering in Your Community", by Marybeth Lima.
- "A Whole New Mind", by Daniel H. Pink.
- "Emotionally Intelligent Leadership: A Guide for College Students", by Marcy Levy Shankman and Scott J. Allen.
- "Citizen Engineer", by David Douglas and Greg Papadopoulos with John Boutelle.

Students are asked to demonstrate skills development through participation in community engagement or service, such as the refurbishment of a fallowed community garden on the NMSU campus that the group took on this past spring. These projects require them to use engineering design steps, work as teams, and learn about the real-world issues they may encounter in their careers as engineers.

Another component of the program is entrepreneurship, led by NMSU's Arrowhead Center, dedicated to promoting entrepreneurship and innovation and create economic opportunities. Students are introduced to a problem in one of NMSU's global challenges (water, agriculture, clean energy) that also affects the local and regional communities. They form teams and brainstorm ideas for innovative solutions to the problem. They complete a business model to present during the final workshop.

All participants are required to complete a rubric-based assessment before and after Engineering Leadership Institute participation. The evaluation is a mixed methods approach to evaluate students' progression in:

- Cognitive skills: Critical thinking, deep knowledge, analytical/rational, objective reality.
- Interpersonal skills: Initiative, motivation, vision, passion, ethical behavior, time management.
- Intrapersonal skills: Connect, interact, communicate, contextualize.

III. RESEARCH QUESTIONS

It is recognized that the regular academic coursework in students' curricula outside the Leadership Institute is designed to improve skills in the cognitive domain. Hence, intrapersonal and interpersonal domains are the primary foci to determine the impact of the Institute. Specific research questions of interest to the Institute are primarily related to these two domains:

- Does the Institute impact student assessments of their skills and attitudes in intra- and inter-personal domains? Are their attitudes about the importance of engineers' responsibilities and engagement in society impacted?
- Where do students feel they have improved the most in their perspectives when asked to reflect on their training experiences? What components of the Institute are most impactful?

IV. METHODOLOGY

A. Participants

The pilot 2021 cohort had nine students, and the second 2022 cohort had seven students. All 16 students are engineering majors. Demographic information is presented in Table 1 and is aggregated for both cohorts.

TABLE 1:

	Hispanic	White	Female	Male
Total Students	11	5	8	8

B. Data Collection

At the start of the Institute as juniors, students completed a survey which assessed their interpersonal and intrapersonal abilities along with their attitudes about service and the role of engineers/engineering (pre survey). At the end of the program as seniors, students answered the same questions (post survey) and provided feedback about their experience. Questions were both closed and open-ended. For the 2021 cohort, the pre survey was done in person, and for their post survey and all 2022 surveys, data were collected online using REDCap (Research Electronic Data Capture), a secure, web-based software platform designed to support data capture for research studies [7], [8]. Each survey took around 20 minutes to complete.

C. Instruments

To assess Institute impact, survey items were selected from reliable and valid instruments that represented the Interpersonal and Intrapersonal categories of NRC competencies. They include questions from:

- The Engineering Professional Responsibility Assessment Tool [9]: Questions asked students to reflect on the role they think engineers have in addressing society's challenges and needs, their perceived responsibility and interest in service and helping society, and their own and the engineering profession's ability to positively impact change in the world. These questions address both interpersonal and intrapersonal domains "Figure 2".
- The STEM Interpersonal Communication Skills Assessment Battery [10]: Questions focused on student assessments of their ability to plan and identify their objectives when

communicating, giving/receiving feedback, and utilizing feedback they receive to help them improve in these areas. These questions are largely related to interpersonal domain.

- Leadership items selected from Metz, Cuseo, and Thompson's (2013) book in the area [11]: Questions asked students to assess their leadership practices and understanding of leadership, which are related to the intrapersonal domain.
- Students were also asked if they understood the mission of the University, and how the mission of the Leadership Institute related to the University mission as a whole.

Each response option was coded according to the instrument scale, which ranged from five to seven choices. All scales ranged from Strongly Disagree to Strongly Agree, which were coded from one to five, one to six, or one to seven, depending on the scale, with Strongly Disagree always given a value of one. Means for pre and post scores for both cohorts combined were calculated accordingly. With this coding methodology, the engineering Professional Responsibility Assessment Tool response range was one to seven, the STEM Interpersonal Communication Skills Assessment Battery range was one to six, and the leadership and mission questions ranged from one to five. Internal consistency using Cronbach's alpha (1951) was calculated for each assessment at the pre and post administration [12]. In the pre survey, the Engineering Professional Responsibility Assessment Tool yielded 0.82, the STEM Interpersonal Communication Skills Assessment Battery yielded 0.69, and Leadership questions yielded 0.76. In the post survey, in the same order, alphas were 0.74, 0.86, and 0.80, respectively. Overall, these suggest acceptable reliability and that each set of survey items measure the same underlying concept.

D. Results

There were several changes from pre to post averages across the scales, particularly in students' agreement that they know how to plan a well-crafted message and identify the objective of their message (interpersonal communication), that engineers should use their skills to solve social problems and that they can have an impact on solving problems that face their local community, and that they take time to self-examine their leadership strengths and weaknesses (intrapersonal). Students also had stronger agreement that they can articulate the mission and vision of the Engineering Leadership Institute to others and how it relates to the broader NMSU mission. The relatively small number of students limits the use of extensive statistical tests; however, results suggest that students did demonstrate attitude change from the start to the end of the Institute experience, and provide good understanding of the relative impact of various training components. Averages for selected items are presented in Tables 2 to 5.

TABLE 2: *STEM Interpersonal Communication Skills Assessment Battery Averages – Pre to Post*

When communicating with others, I know how to...	Mean	
	Pre	Post
Plan a well-crafted message.	4.9	5.3
Identify the objective of my message.	5.1	5.5
Identify the desired outcomes of my communication interaction.	5.1	5.4
Use the feedback received as a learning tool.	5.4	5.6

TABLE 3: *Engineering Professional Responsibility Assessment Tool Averages – Pre to Post*

Question	Mean	
	Pre	Post
I can have an impact on solving problems that face my local community.	6.1	6.4
Engineers can have a positive impact on society.	6.8	6.8
It is important to me personally to have a career that involves helping people.	6.4	6.3
Engineers should use their skills to solve social problems.	5.8	6.4
I believe that extra time spent on community service is worthwhile.	6.3	6.4

TABLE 4. *Leadership Self-Assessment Averages – Pre to Post*

Question	Mean	
	Pre	Post
I have a clear understanding of what “leadership” means.	4.3	4.5
I take time to self-examine my leadership strengths and weaknesses.	4.1	4.4
I'm an honest and ethical leader.	4.5	4.8
I am a reflective leader who regularly reviews what I do to continually improve what I do.	4.2	4.3

TABLE 5. *Understanding of NMSU and Institute Mission Averages – Pre to Post*

Question	Mean	
	Pre	Post
I'm aware of the mission of NMSU, and I can clearly and persuasively articulate the mission of my campus to others.	3.8	4.1
I can articulate the mission and vision of the Engineering Leadership Institute to others and how it relates to the broader NMSU mission.	3.8	4.3

Open ended feedback asked students to identify which skills they have improved the most and what components were most impactful for them as they reflect on change over the two years. In terms of where students think they improved the most, students mainly cited their communication skills because they had the hands-on opportunities to apply them:

"My leadership and interpersonal skills have definitely improved from my time in the cohort. I think my interpersonal skills improved the most because there were plenty of opportunities where I could practice them".

"My communication skills like talking to people above me and also giving presentations to lead a group".

Students were also given the opportunity to identify what Institute components were most impactful for them, and they cited several areas, with guest speakers and service projects listed most frequently:

"I think my peers would agree with me when I say it was the guest speakers. Being able to hear from people that already have had that success in engineering is motivation in itself. Again this also helped with my confidence as an engineer because I always gravitated to asking guest speakers about their struggles and being able to see that these people went through similar or worse struggles in school or in the workplace really made me feel like I was at least on even footing".

"I think the most impactful component is hearing from the guest speakers. Their stories and journeys are very inspiring".

"The component that made the biggest impression was our community service with the community garden as it allowed us to work together".

Students also described how the reflection journal was useful with helping them think more about their development; sample feedback from one student is:

"I enjoyed writing the reflection papers as it gave me a sense of what I improved on and what I accomplished that year/semester".

E. Implications

Results suggest that the Leadership Institute shows promise in helping engineering majors improve in their self-assessments of interpersonal and intrapersonal skills, and it can also impact their attitudes about the engineering profession and the role of service as a professional engineer. In both the closed and open-ended feedback, students reported improvement in their communication and leadership skills in particular, citing hands- on opportunities to practice these as key in their growth. These results suggest that it is important for leadership training programs to provide students with opportunities to practice and apply what they learn, as this was greatly valued in the feedback. The relatively small number of students in the study does not allow for extensive statistical analyses but the Institute is designed for smaller cohorts so they can get to know each other well and practice opportunities in small group settings, which are challenging in larger programs. Student feedback is clearly encouraging, and the training framework merits implementation at other institutions.

It is also worth acknowledging that this Institute took place during the Covid-19 pandemic. This meant that for each cohort, they experienced half of the Institute while navigating the uncertainty of the time, with the first cohort experiencing the second half under these restrictions and the second cohort experiencing the first year of the Institute during the height of the pandemic. Despite this, there were promising changes across many of the constructs of interest, suggesting this type of program can positively impact students even during the extreme circumstances that the pandemic created. The Institute served as a way to provide structure and to help bring students together during a time when everyone was separated. The program also has flexibility but with clear expectations to help engineering students develop skills and attitudes that will serve them well upon graduating, and this can be adapted at different institutions and settings as well.

REFERENCES

[1] Engineering Your Future: The Professional Practice of Engineering by Stuart G. Walesh.

[2] Emotionally Intelligent Leadership: A Guide for College Students by Marcy Levy Shankman and Scott J. Allen, Jossey-Bass, 2008.

[3] Leadership for a Better World: Understanding the Social Change Model of Leadership Development by Susan R. Komives, Wendy Wagner, and Associates, National Clearinghouse for Leadership Programs, Jossey- Bass, 2009. Page 50.

[4] A Social Change Model of Leadership Development (Version III), Higher Education Research Institute (HERI), 1996, Los Angeles: University of California, Los Angeles, Higher Education Research Institute.

[5] Education for Life and Work: Developing Transferable Knowledge and Skills in the 21st Century, Committee on Defining Deeper Learning and 21st Century Skills, National Research Council, James W. Pellegrino and Margaret L. Hilton, Editors. 2012.

[6] Education for Life and Work: Developing Transferable Knowledge and Skills in the 21st Century, Committee on Defining Deeper Learning and 21st Century Skills, National Research Council, James W. Pellegrino and Margaret L. Hilton, Editors. 2012. Page 4.

[7] Harris, PA., Taylor, R., Thielke, R., Payne, J., Gonzalez,, N., Conde, JG. (2009). Research electronic data capture (REDCap) – A metadata-driven methodology and workflow process for providing translational research informatics support. Journal of Biomedical Informatics. 42(2), 377-381.

[8] Harris, PA., Taylor, R., Minor, BL., Elliott, V., Fernandez, M., O'Neal, L., McLeod, L., Delacqua, G., Delacqua, F., Kirby, J., Duda, SN. (2019). The REDCap consortium: Building an international community of software partners, Journal of Biomedical Informatics. [doi: 10.1016/j.jbi.2019.103208]

[9] Canney, NE., & Bielefeldt, AR. (2016). Validity and reliability evidence of the engineering professional assessment tool. Journal of Engineering Education, 105(3), 452-477.

[10] Wilkins, K. G., Bernstein, B. L., & Bekki, J. M. (2015). Measuring communication skills: The STEM interpersonal communication skills assessment battery. Journal of Engineering Education, 104(4), 433–453.

[11] Metz, G., Cuseo, J., , & Thompson, A. (2013). Peer to peer leadership: Transforming school culture. Dubuque, IA: Kendall Hunt.

[12] Cronbach L. J. (1951). Coefficient alpha and the internal structure of tests. Psychometrika, 16, 297–334. [doi:10.1007/BF02310555]

Technical papers

Nature connectedness and discursive spaces: Understanding student responses to sustainability education

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***Abstract* — Considering the significant impact of engineering on the environment, educational curricula for engineers should, as a minimum, include courses on sustainability transitions. The Deep Transitions (DT) framework, however, argues that transitions will only be achieved if education is accompanied by the reshaping of students' ideological assemblages, through which sustainability becomes normative. The DT perspective raises two fundamental questions for engineering educators; is the student/lecturer interface appropriate for attempting such changes and if it were to be suitable, how could its extent be articulated and assessed? In this study, the concept of nature connectedness, already described in the field of environmental psychology, is explored as a means of understanding directionality and transition. Students completed a class exercise relating to choices on energy technology, and then participated in a qualitative study to understand their responses. Although the students acknowledge that the classroom is a discursive space, in which new bodies of meaning can be created, the intervention had little impact on their extent of nature connectedness. Changing the latter remains a challenging, if impractical, task for engineering educators.**

Keywords — Discursive space; nature connectedness; energy transition; pedagogy

I. INTRODUCTION

The work of engineers has a significant effect on the environment. It is therefore important that environmental education is part of their tertiary education curriculum, and that they graduate with an awareness of, and preferably a sincere commitment to, environmental sustainability, as articulated by the sustainability development goals (SDGs) [1].

Making sustainability normative to human behaviour is, however, a challenge for engineering education, requiring ongoing experimentation and pedagogical reflection. In this article, the results of a single intervention with a cohort of post-graduate students, are reported and discussed. The intervention was designed within a "Deep Transitions" framework, which emphasises that the transformation of socio-technical systems can only be realised when we adopt and act in accordance with a new, universal set of rule-systems or meta-regimes [2, 3].

Change at this fundamental level implies the acceptance of a new directionality of behaviour and decision-making, where sustainability is the starting point and not a 'side-show' of human activity [2, 4]. This perspective considers that we require changes not only to institutions (used in the meaning of the social sciences), but to the way in which we think and hence act, or what may be called our ideological assemblages [5]. Ambitious though it may seem, the intervention of this study was designed with the intention of such an outcome.

The conceptualisation is based on two important propositions, namely that the student/lecturer engagement is an opportunity for cognitive change due to its specific context and the openness of a student's discursive framing, and that nature connectedness can be used as a measure of the extent cognitive change, and particularly, changes to meta-regimes or ideological assemblages. Nature connectedness is a validated term which is used within the field of environmental psychology to describe the human/nature relationship in which a person considers that their sense of well-being is directly linked to nature and is part of their identity [6]. It can also be applied as a quantitative measure, the Connectedness to Nature Scale, of this convergence in identity between and individual and nature, and validated assessments to measure the index has been developed [7].

Assessing the validity of both propositions has been to some extent part of this research. In other words, the study design was abductive, with simultaneous development of the theoretical position and its use in an exploratory framework. The research question itself (is it possible to make transition thinking normative for engineering students?) arose from previous attempts to raise the awareness of post-graduate students to climate change. The results of this initial attempt, which was overly aggressive in its design, suggested that a novel approach, based on the theoretical frameworks of discursive institutionalism [8, 9] and nature connectednes [10] could be more influential.

In the following sections, the background to the key topics, a description of the research method, the results, and the discussion thereof, are given. The article concludes with the main learning points and suggestions for further research.

II. BACKGROUND

The imperative of climate action is now widely reported and acknowledged [11, 12]. However, multiple theories of change have been proposed, including the transformation of individual behaviour [13], the redevelopment of manufacturing systems [14], radical changes to institutions and policies [15], reforming the financial sector and the development of green financing [16] and redirecting government expenditure [17]. Whether the change agents are individuals, acting with power and agency, or structures, people remain at the centre of these decisions, building and using windows of opportunity within which change can take place. As such, the micro-practices, a term used in the Foucauldian sense, of individual actors are highly influential [18], and although individual agency may be constrained by structure, the latter are also constructed by them [19].

The role of individual agency and behaviour in sustainability transitions relative to structures and institutions is contested in the literature. The perspectives can be grouped into three categories, namely institutional, socio- psychological and practice-based/relational, all of which accept the idea of agency as being 'embedded' in an environmental and institutional context [20]. This paper seeks to further develop the socio-psychological perspective, where agency arises from social and psychological mechanisms, and is a direct reflection of factors such as social identity, habitus and beliefs [20]. The challenge, based on this framing, is how to change the socio-psychological aspects, which is referred to as an ideological assemblage in the remainder of the article.

The student/lecturer interface is used as the laboratory for an experiment on influencing ideological assemblages. The interface is unique in the sense that it is a discursive field characterised by a degree of cognitive flexibility. Discourse, also used in the Foucauldian sense, is itself a useful term in this discussion, referring not only to the body of knowledge, thought and communication through which we seek to impart meaning to the world, but also the means through which subjects are socially constructed and relationships of power are imposed (discourse transmits and (re)produces power). In this sense, discourse becomes a direct means of social exclusion and fixation (resistance to change).

Nevertheless, it is also considered that an individual can hold several overlapping discourses, which may be complementary or conflicting. The notion of a series of overlapping discourses, referred to as discursive fields, raises the question of cognitive flexibility and openness to change [9]. The acceptance of this flexibility leads to the idea of discursive spaces, within which actors are able to consider alternatives and change behaviour [9]. The student/lecturer interface, which I hesitate to denote as the 'classroom', is assumed in this study to be a discursive space, and hence an opportunity to build a new body of knowledge and practice in respect of sustainability. A pictorial version of the interface is shown in Figure 1.

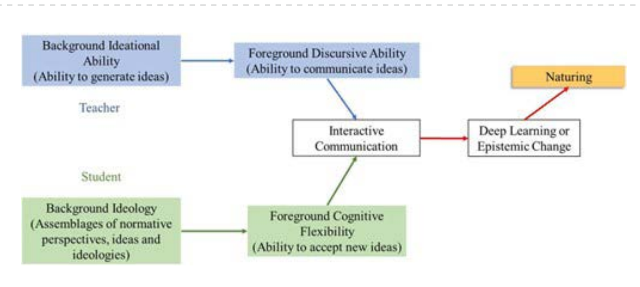

FIGURE 1: Discursive spaces and cognitive flexibility

The assessment, however, of any transition in respect of sustainability is a challenge. Even if there were to be some success, such as a greater awareness, or a direct action for change, this impact would not be apparent in the short term. As a result, this study has turned to the field of environmental psychology in answering the question of influence, and in particular, the concept/scale of nature connectedness [10]. As mentioned in the introduction, the concept describes the extent to which an individual assigns their overall sense of well- being as being coupled to nature, and is measured by the degree of overlap between two circles, the one representing 'nature' and the other 'self', as shown in Figure 2.

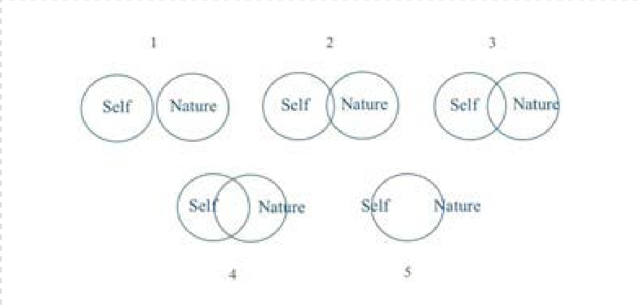

FIGURE 2: Measuring the extent of nature connectedness

III. METHODOLOGY

The project used a qualitative, exploratory approach to determine whether the responses to the class intervention were governed by the participants' level of nature connectedness. The interviewees were drawn from a group of 94 post- graduate students on the Energy Leadership Programme at the Wits Business School, of whom 53 were registered for the Masters, and 41 for the Post-Graduate Diploma. Several of the students held an undergraduate degree in engineering. Ethics approval for the study was obtained from the Human Research Ethics Committee (Non-Medical) of the University of Witwatersrand.

Given that the lectures were held in February 2021 and the interviews took place over the period October 2021 to February 2022, when South Africa was in various levels of lockdown, all the interactions were virtual. The lectures were pre-recorded and made available to the students through YouTube.

Interviews were held and recorded using Microsoft Teams. The tutorials, one of which was used for the intervention of this study, were held using Microsoft Teams.

The intervention itself involved both two groups (Masters and Diploma), but in separate events. The students were initially polled (individually and anonymously) on their perspectives of three aspects of wind vs. nuclear energy; their relative reliability, risk of significant environmental impact, and their benefit to harm ratio. They were also asked to indicate in which technology (nuclear or wind) they would choose to invest, should this be presented as binary option. The class then listened to a 20-minute podcast debate between two energy experts, one of whom was pro-nuclear, and the other pro-wind [21]. The debate was then discussed, and finally the students were again polled on the same set of question as used in the initial poll. The results were analysed quantitatively (for example, the data for the technology preference question is shown in Figure 3).

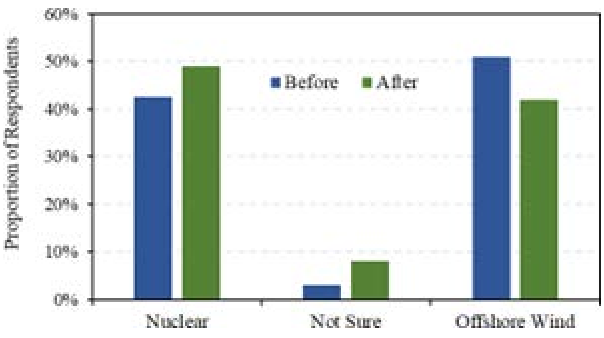

FIGURE 3: *Investment preference before and after the intervention*

The results of the intervention showed that the debate of the podcast had little significant impact, with small changes to perceptions of nuclear safety and as a result, preference for the use of nuclear in building new capacity (see Figure 3). Nuclear was considered to be higher risk, but more reliable and hence of higher benefit to risk ratio relative to wind. These outcomes were somewhat unexpected, and it was decided to explore the experience of the intervention, and the reasons for the responses, in a more detailed way using an exploratory, qualitative study.

A semi-structured questionnaire, consisting of four sections, was used to guide the interviews, covering background information of the student, experience of the virtual platform, degree of cognitive flexibility (openness to alternative perspectives), and the link between personal values such as nature connectedness and energy transitions. The transcripts were then analysed following the approaches of content analysis and interpretive phenomenological analysis [22].

Altogether 7 students were interviewed. Although many more students agreed to be interviewed, no new sub-themes or themes were emerging from the data at this point and it was clear that there was little benefit in proceeding i.e. saturation had been reached. For the work to proceed, the questionnaire needed to be re-designed so that the issue of how students understand nature connectedness could be explored in more detail. However, a re-design would have required a new application to the Ethics Committee, which would have led to further delays for the research, and possibly a change to its focus. It was decided, instead to close this study, and then re- assess how the fundamental issue of nature connectedness could be explored.

IV. RESULTS

All the participants were experienced professionals, with the average duration being about 7 years. About half of the respondents were engineers, with the remainder being accountants and managers. The interviews affirmed one of the initial propositions, namely that universities are places of learning, where the absorption of new knowledge, even if this contradicts prior knowledge, is embraced as the purpose of education, a process which cannot take place without cognitive flexibility. In the words of one respondent:

Interviewee Three (time point 12 min)
"Having gone through the course, I did discover for instance that nuclear poses less (of a safety threat). Yeah, it helped me form an educated opinion about nuclear power."

In terms of the energy transition, there was unanimous agreement that it is an imperative and that we need to keep "talking, implementing and trialling" new approaches to the challenge. Apart from the issue of climate change due to greenhouse gas emissions, one respondent also noted geopolitical impact of fossil fuels, and the resultant destabilisation of the global economy. This issue has been particularly evident in 2022 following Russia's attacks on the Ukraine.

There was mostly a positive response to the design and content of the intervention, with the students appreciative of the opportunity to hear both sides of the wind vs nuclear debate, and hence make up their own minds. The intervention was described as "effective, useful and relevant", and not belittled by its use in a virtual platform.

Interviewee Three (time point 14 min)
"The podcast, you know, brought a lot of things into perspective. They put both sides of the arguments and... I think it it's helped me, I'm educated."

Interestingly, there were mixed views about the general use of virtual platforms as a means of lecturing or engaging with the student cohort. One student noted that loss of opportunity for networking and peer-to-peer learning, whereas another student felt the virtual world to have sufficient intimacy whilst offering some flexibility:

Interviewee Six (time point 4 min)
"I think it is an adjustment from the traditional ways of learning, but I still find it quite effective. 'cause you're still interacting with the person ... you still hearing their voice, you still looking at them if they have their video on so and I just like the comfort of being. I still get to learn, and I like the flexibility that it offers. It's not protected or isolated. I see you. I hear you."

On the issue of nature connectedness, all but one of the students declared themselves to be 50/50 midway on the diagramme), citing many behavioural aspects reflecting the importance of the environment in their lives such as camping, recycling, walking in nature, gardening, and waste management. In one case, the issue of obvious environmental damage was raised:

Interview Three (time point 22 min)
"I'm in the centre of the diagram because I'm from Nigeria and I know what the effect of petroleum, discovering petroleum, and what he has costs in Nigeria in or is one of the reasons for the civil war. I spent some time in the Niger Delta and in the south of Nigeria. So I see how much environmental degradation that the exploitation of oil causes to these people. You will not ever know the extent of the damage to people and

the environment in the Niger Delta of Nigeria. The oil industry has literally destroyed people's livelihoods such as the fishermen and the subsistence farmers."

None of the interviewees reported any change to their extent of nature connectedness during the intervention or indeed, over the whole programme. One interesting insight, however, from the discussion was that the extent of nature connectedness appears to correlate with the different perspectives on who should take responsibility for energy transitions, and how it should be achieved. The lower the perceived score, the less important, in the view of the respondent, that the transition should take place initially on the African continent, and that it should be driven by personal agency rather than government regulation:

Interviewee Four (time point 18 min)
I mean at this point in time we don't have a choice (about transition). But why should we (Africa) have to change? We make the smallest contribution (to carbon emissions) and...

And later:
"You know the government needs to enforce the need to change, the need to school society, then maybe give incentives for people to do such. Everyone now puts on a mask without even thinking about it because it's been drilled into us and government is actually doing something about making sure that we have mastered it"

The study, however, cannot be definitive on this correlation, and further validation would require an additional study with a separate design.

V. DISCUSSION

There are a number of implications from the outcome of the study, even though it ended with a limited sample size. The qualitative data supported one of the initial propositions, namely that cognitive flexibility and willingness to learn are evident in the students' approaches to their studies, even if this changes their understanding of a specific topic, such as the safety profile of nuclear energy. This is, of course, an obvious result; students would not be at university if they were unwilling to learn.

However, the study did not offer any major insights into the second proposition, relating to deep learning, changes to ideological assemblages, the development of a new directionality and making sustainability normative in personal and professional lives of the students. Partly this outcome was the consequence of the study design, which was frozen in its early stages by the ethics process, when there was only a vague understanding of how the issue of nature connectedness and deep learning could be approached. Another factor was also certainly the difficulty of the realizing even an incremental change in the students' assemblages, as may be reflected by the extent of their nature connectedness.

Ideological assemblages are fundamental to identity, which itself is a construct derived from its social and cultural context [23]. Individuals think and act in accordance with their identity, which is developed from cultural norms and practices. Extending, in one may, the theoretical conceptualization of gendering, which results from a process of socialization according to dominant gender norms [23], to the idea of naturing, leads to the idea that individual relationships with nature are themselves the consequence of the process of socialization, and are difficult to change.

The principle of naturing is similar to the philosophical concept of Ukama, which acknowledges the interrelatedness of people and nature and is positioned in the literature as an African meta-theory [24]. Ukama covers not only the interrelatedness of people, as described by the term Ubuntu, but also the importance of relatedness to nature and the means, perhaps the only means of giving meaning to human existence [24].

The similarity between relatedness and connectedness suggests alternative approaches to how an educator may approach the task of guiding students towards a new value system which understands the sensitivity of complex adaptive systems (such as the earth's ecosystem) and acts in a manner that these systems remain functional. As a beginning, it is recommended that we need to "reconstitute the epistemological and ontological foundations of mainstream economics" [24 p68]. Such a task is clearly formidable!

VI. CONCLUSION

To some extent, sustainability science and engineering have maintained separate paths and epistemologies. Environmental engineering has developed as a distinct discipline and there persists a discourse of 'normal' engineering and 'green' engineering in the literature [25]. Moving forward with sustainability transitions and the SDGs will require a new directionality in engineering education, where sustainability is the starting point of engineering practice.

This directionality can only be achieved through a deep transition, in which changes are made to both meta-regimes and personal values or ideological assemblages. In this study, the results of a pedagogical intervention to influence such assemblages, and particularly the level of nature connectedness, where the latter was treated as a reflective measure of an altered directionality, are described. It is shown that the intervention had little impact on nature connectedness, with students having similar views before and after the event. One interesting theme, however, which emerged from the study, was that individuals with a higher level of nature connectedness were more likely to consider that sustainability transitions will require changes to individual behaviour.

Further studies will be needed to understand two key aspects of this study, namely how to influence the extent of nature connectedness, and whether a greater level of nature connectedness amongst engineering graduates could indeed accelerate energy and sustainability transitions.

REFERENCES

[1] S. A. Abdul-Wahab, M. Y. Abdulraheem, and M. Hutchinson, "The need for inclusion of environmental education in undergraduate engineering curricula," International Journal of Sustainability in Higher Education, 2003.

[2] J. Schot, and L. Kanger, "Deep transitions: Emergence, acceleration, stabilization and directionality," Research Policy, vol. 47, no. 6, pp. 1045-1059, 2018.

[3] L. Kanger, and J. Schot, "Deep transitions: Theorizing the long-term patterns of socio-technical change," Environmental Innovation and Societal Transitions, vol. 32, pp. 7-21, 2019.

[4] K. M. Weber, and H. Rohracher, "Legitimizing research, technology and innovation policies for transformative change: Combining insights from innovation systems and multi-level perspective in a comprehensive 'failures' framework," Research Policy, vol. 41, no. 6, pp. 1037-1047, 2012.

[5] D. Walwyn, "Mainstreaming Sustainability Transitions through Curriculum Design: Virtual Classrooms as a Means of Developing Student Awareness and Agency," in IST2021, Karlsruhe, 2021.

[6] P. Schultz, "Inclusion with nature: The psychology of human-nature relations," Psychology of Sustainable Development, P. Schmuck and W. Schultz, eds., pp. 61-78, Geneva: Springer, 2002.

[7] F. S. Mayer, and C. M. Frantz, "The connectedness to nature scale: A measure of individuals' feeling in community with nature," Journal of Environmental Psychology, vol. 24, no. 4, pp. 503-515, 2004.

[8] M. B. Carstensen, and V. A. Schmidt, "Power through, over and in ideas: conceptualizing ideational power in discursive institutionalism," Journal of European Public Policy, vol. 23, no. 3, pp. 318-337, 2016.

[9] U. Pesch, "Tracing discursive space: Agency and change in sustainability transitions," Technological Forecasting and Social Change, vol. 90, pp. 379-388, 2015.

[10] B. Restall, and E. Conrad, "A literature review of connectedness to nature and its potential for environmental management," Journal of Environmental Management, vol. 159, pp. 264-278, 2015.

[11] J. Burton, T. Caetano, and B. McCall, Coal transitions in South Africa; Understanding the implications of a 2°C-compatible coal phase-out for South Africa, University of Cape Town, Cape Town, 2018.

[12] L. Baker, J. Burton, C. Godinho, and H. Trollip, "The political economy of decarbonisation: Exploring the dynamics of South Africa's electricity sector," 2015.

[13] G. Dubois, B. Sovacool, C. Aall, M. Nilsson, C. Barbier, A. Herrmann, S. Bruyère, C. Andersson, B. Skold, and F. Nadaud, "It starts at home? Climate policies targeting household consumption and behavioral decisions are key to low-carbon futures," Energy Research & Social Science, vol. 52, no. 6, pp. 144-158, 2019.

[14] A. Nurdiawati, and F. Urban, "Towards Deep Decarbonisation of Energy-Intensive Industries: A Review of Current Status, Technologies and Policies," Energies, vol. 14, no. 9, pp. 2408, 2021.

[15] E. Tyler, and K. Hochstetler, "Institutionalising decarbonisation in South Africa: navigating climate mitigation and socio-economic transformation," Environmental Politics, vol. 30, no. sup1, pp. 184- 205, 2021.

[16] R. Galvin, "Yes, there is enough money to decarbonize the economies of high-income countries justly and sustainably," Energy Research & Social Science, vol. 70, pp. 101739, 2020.

[17] D. R. Walwyn, "Turning points for sustainability transitions: Institutional destabilization, public finance and the techno-economic dynamics of decarbonization in South Africa," Energy Research & Social Science, vol. 70, pp. 101784, 2020/12/01/, 2020.

[18] M. Bevir, "Foucault, power, and institutions," Political Studies, vol. 47, no. 2, pp. 345-359, 1999.

[19] L. Fuenfschilling, and B. Truffer, "The structuration of socio-technical regimes—Conceptual foundations from institutional theory," Research Policy, vol. 43, no. 4, pp. 772-791, 2014.

[20] S. Huttunen, M. Kaljonen, A. Lonkila, S. Rantala, A. Rekola, and R. Paloniemi, "Pluralising agency to understand behaviour change in sustainability transitions," Energy Research & Social Science, vol. 76, pp. 102067, 2021.

[21] Naked Scientist, "Is nuclear power necessary?," Naked Scientist, C. Smith, ed., The Naked Scientist, 2021.

[22] V. Singh, and D. R. Walwyn, "Influence of Personal Epistemology on Research Design: Implications for Research Education," Journal of Research Practice, vol. 13, no. 2, pp. 2, 2017.

[23] J. Butler, "Performative acts and gender constitution: An essay in phenomenology and feminist theory," Theatre Journal, vol. 40, no. 4, pp. 519-531, 1988.

[24] M. Swilling, The Age of Sustainability: Just Transitions in a Complex World, Oxon: Routledge, 2019.

[25] P. Glavič, "Updated Principles of Sustainable Engineering," Processes, vol. 10, no. 5, pp. 870, 2022.

Technical papers

Learning from failure: Development of a culture of failure scale for higher education

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***Abstract* — Benefits of a failure friendly culture, e.g., learning from failure, are widely known in occupational settings. Validated scales have been developed to measure organizational failure culture and individuals' mind-sets on failure. While research on learning from failure exists in secondary education, scales for higher education are lacking. To support both higher education engineering instructors and students, this contribution aims to develop a Culture of Failure Scale to assess students' and lecturers' handling of failures in engineering higher education settings. This data-driven approach helps inform instructors about aspects of educational settings that are safe and conducive to learning and supports their students to develop a mind-set where failures are seen as a source for improvements and learning. Exemplary application of the developed scale is shown by assessing the failure culture in different groupings, e.g., gender, between two participating German and US institutions.**

Keywords — culture of failure, learning from failure, learning environment

I. INTRODUCTION

An important step of the Engineering Design Process (EDP) is the evaluation of generated solutions against given requirements [1]. As an iterative process the identified fulfillments of requirements as well as nonconformities (or failures) are integrated into further design iterations. In this context, fulfillments and failures can be seen as equivalent sources for the purpose of obtaining high-quality solutions or products. This equivalency can also be found in other iterative value creating methods, e.g., the Scrum framework where inspection (toward agreed goals) and adaptation (of deviations) are two of the three framework's empirical pillars [2]. What all these value-creating iterative methods have in common is the approach of *learning from failure*. It therefore seems only appropriate that the approach of learning from failure can be found in quality management standards, too, e.g. [3], where lessons learned from failure are listed explicitly as an internal source for organizational knowledge.

Thus, learning from failure can be considered as an important engineering competence. The individual engineer needs a mind-set which identifies failures as learning opportunities and not as to be avoided. Creating such a positive mind-set cannot be the responsibility of a single individual only. Rather, it is up to teams and organizations to create a failure-friendly environment.

An approach to realize such an environment is to create a failure-friendly or positive failure management culture. A system of shared norms, values, and common practices, where negative failure effects (e.g., loss of time, faulty products, quality loss, injuries, or even disasters) are still in focus, but where also positive failure effects (e.g., learning, innovation, and resilience) are promoted [4], [5]. The basic assumption of a positive failure culture is that failures are inevitable, yet helpful. Therefore, it is necessary to reduce the impact of negative failure effects while highlighting potential positive ones [4]. In contrast, a failure prevention culture implements a zero-failure tolerance by disregarding benefits of failures [4].

From a psychological perspective, individuals experience and behave completely differently in both environments. In a zero-failure tolerance environment, failing involves the risk of negative consequences coming from supervisors and peers. In extreme cases, the fundamental attribution error can cause an unjust attribution of the failure to one's own personality traits, competencies, or intelligence and underemphasize situational explanations. This leads to strain and fear of failure and will most likely result in a negative mind-set of individuals leading to covering up failures as well as a higher risk of additional or secondary failures. [4], [6]

In a positive failure culture, failures are accepted as human. Positive failure effects are valued and used strategically to reduce the negative failure effects. These positive effects of failures are multifarious as a systematic overview about empirical findings in [7] shows. For example, if failures are known to be inevitable, their occurrence is expected. Consequently, the preparation for failures is high and routines to deal with failures are already implemented. This preparedness leads to a superior failure detection and superior capabilities in controlling damages due to failures or failure cascades. On an organizational level, those failure process related positive mind-set effects are supplemented by superior profitability, safety performance, innovation capabilities and learning. [7]

An example for superior profitability gives the empirical findings of [4], where organizational performance is operationalized as survivability, goal achievement, and return on assets. In summary, the economic effects and key figures clearly speak in favor of a positive failure management culture. According to the benefits of a positive failure culture, different scales have been developed to measure the Culture of Failure in occupational settings, e.g., the Error Orientation

Questionnaire (EOQ) on individual level [8] or its adaptation for measurements on organizational level [4].

Especially, learning from failure has been identified as an important positive failure effect and at the same time a central prerequisite for the better preparedness for and superior handling capabilities of failures, as well as economic benefits [7]. Reference [7] summarizes findings regarding learning from failure. Learning from failure enables individuals and organizations to gain knowledge about (a) the failure made, (b) the system in which the failure occurred, and (c) how to deal with failures in general. The latter includes not only the development of failure-related action competencies of individuals and organizations, but also individual coping skills related to negative emotions, thoughts, and beliefs that result from failures. The learning itself happens on different pathways covering (a) cognitive, (b) emotional, (c) motivational, and (d) behavioral aspects of failing. From (a) a cognitive perspective, failure attracts attention, which includes a change from an automatic processing to a conscious, deeper-level one. This enables metacognitions needed to find a failure correction. These contain activities of identifying the failure cause, finding a solution, and evaluating its effectiveness, as well as revising faulty task strategies or knowledge. From (b) an emotional perspective, failures can evoke anxiety, anger, shame, or guilt. This leads to coping with these negative emotions demanding cognitive resources needed for failure handling and learning. From (c) a motivational perspective, failures can have a demotivating effect connected with frustration, self-doubt, and dissatisfaction. However, if failure is handled successfully, motivation, task interest and learning show to increase. To reduce negative and distracting impact on learning from failure-related, negative emotions or demotivation, a positive failure mind-set is needed, where failures are seen as a natural part of (learning) processes. From (d) the behavioral aspect, a (psychological) safe mind-set, where negative consequences are not feared, will increase the likelihood of failures being reported and failure details being shared openly. In summary, this will lead to improved and richer mental models of the failure-related task and knowledge of individuals and shared in the organization. [7]

The impact of learning from failures has caught the attention of the educational sector looking to assess positive failure culture, e.g., resulting in a validated, multi-dimensional psychometric scale for secondary education [9]. However, a validated psychometric scale for higher education, which differ significantly from primary and secondary education [10], is still lacking.

Based on the above literature research and existing Culture of Failure Scales for secondary education and occupational settings, we developed a Culture of Failure Scale for application in higher education. This tool supports both higher education instructors and students to assess students' and lecturers' handling of failures in higher education settings. This enables the development of interventions to change the existing failure culture into a failure-positive one. The development of the item-pool for higher education was oriented on the dimensional structure of the existing scale for secondary education [9], covering the educational dimensions (a) *learning orientation,* (b) *failure friendliness*, (c) *norm transparency,* and (d) *fear of failure*. Additionally, items covering extremely negative behavior like abasing reactions of peers and lecturers to students failing were included, as well as items and aspects from occupational failure culture scales [4], [8]. In developing the instrument, adopted items were rewritten to match higher education settings, e.g., homework and promotion, which are atypical for higher education settings. Additional items that show to impact a student's higher education, were formulated and added to ensure comprehensive analysis.

II. METHODOLOGY

A. Survey description

In its preliminary form, the first development of this instrument was issued in English and German to engineering students of two participating universities *University of Maryland, Baltimore County (UMBC)* and *Hochschule Bonn- Rhein-Sieg, University of Applied Sciences (H-BRS)* using an online platform. This included mechanical engineering undergraduate and graduate students at the UMBC and mechanical, electrical, and sustainable engineering undergraduate and graduate students at the H-BRS. The English and German items' versions were developed simultaneously by each native speaking researcher ensuring consistency in the content.

The preliminary instrument consisted of two parts. The first part consisted of nine demographic items serving as sampling variables for forming potential comparison groups. The sampling variables contained items about the participants' university, major, gender, and age. Four items covered participants' characteristics associated with their culture, e.g., former occupational experiences, individual school history, or ethnical/migration background.

The second part of the survey formed the Culture of Failure Scale and consisted of 55 items. The scale covered the four literature-based, preliminary dimensions of a Culture of Failure in Higher Education (a) *learning orientation*, (b) *failure friendliness,* (c) *norm transparency*, and (d) *fear of failure*. All items were answered by a five-point Likert-scale with the anchors 1= strongly disagree, 2= disagree, 3= neutral, 4= agree, and 5= strongly agree. As each dimension consisted of a different number of items, the interindividual raw-value of a participant was calculated by the mean of all answered items of each dimension. The 55 items were presented as five matrix-items consisting of 11 items each. These 11 items were always covering all four dimensions. Each matrix-item was presented on a single survey page. To reduce bias based on the presentation order of the items, the order of the five matrix- items as well as the order of the 11 items inside each matrix- item were randomized for each participant. In order to improve reading comprehension, negatives were omitted from tasks that refer to negative aspects of dealing with failure, such as blaming or humiliating others. To reduce possible response bias, some items were reverse worded. In both cases these items required a re-coding prior to further analysis.

The dimension (a) *learning orientation* was a student's interindividual self-report on how they deal with their own failures as well as observed failures of others (mostly peers) on a cognitive level. The sub-scale consisted of 17 items covering the three aspects (a1) *attitude towards failures*, (a2) *failure related achievement motive*, and (a3) f*ailure related self-reflection*. An example item for the interindividual attitude towards one's own failures is *"I see failures as an opportunity to learn."* and towards failures of others is *"I can learn just as much from the failures of others as I would my failures."*. Items like *"I always try to understand why I failed."* ascertain the failure related achievement motive. The failure related self-reflection was operationalized by items like *"Making failures during class have already helped me to gain a deeper understanding of a topic."*. In general, high values in this sub-scale are preferable as they show a positive Culture of Failure.

The dimension (b) *failure friendliness* consisted of 20 items. This sub-scale described the higher education setting as a thriving learning environment without (b1) *negative response to failures* neither from instructors nor peers. Instead, instructors and peers react with patience and support without blaming a student for failing. Additionally, instructors should (b2) *act as positive role-models* in dealing transparently with their own failures. Furthermore, instructors should (b3) not only correct students' failures but *use failures as a source* for helping the students to reflect and encourage deeper learning. An example item for (b1) negative response to failures in class from peers is *"My peers laugh at me when I fail."*, which needs to be re-coded prior to further analysis. A positive instructors' response example item is *"My instructors react understandingly to failures."*. An example item for (b2) instructors who handle their own failures transparently is the item *"My instructors deal openly with their failures."*. The usage of failures as an opportunity to learn (b3) is shown in the item *"My instructors discuss my failures in a way that I understand why they occurred and how I can prevent them."*. As in dimension (a) learning orientation, high values are preferable in this sub-scale.

The dimension (c) *norm transparency* consisted of nine items. The sub-scale was a student's self-report on how well the valid social rules and norms in higher education settings are known or identifiable. With items like *"Sometimes I don't understand why I or others are being criticized."* or *"I often don't know what behavior is expected of me."* low consent to the mostly reverse worded items is preferable prior re-coding.

The dimension (d) f*ear of failure* consisted of nine items. The sub-scale covered the interindividual perceived strength of feeling negative emotions, e.g., fear or embarrassment, as a result of making a failure in class or study group. An example item is *"I dread the reactions of my peers when I fail in class or study groups."*. Comparable to Yerkes–Dodson law, mean values are preferred in this sub-scale. Too low fear of failure results in not having corrective experiences, due to lacking seriousness in the higher education setting, while too high fear of failure results in performance loss, due to only focusing on failure prevention.

B. Survey procedure

The survey was implemented on the web survey platform *Unipark* hosted by the H-BRS. Participants in the aforementioned disciplines received an URL to the survey via email. Prior to beginning the survey, participants were provided with the details of the study to include handling and usage of the collected data. Once consenting the participants filled out the demographic items followed by the newly developed Culture of Failure Scale for Higher Education. The survey ended with an acknowledgment for participation and contact details.

C. Sample description

In total, 72 students from the engineering departments (mechanical, electrical, or sustainable engineering major) of the two universities UMBC and H-BRS participated in this survey. After filtering six students, who did not answer at least one of the 55 items of the Culture of Failure Scale, the final data set consisted of n = 66 students. Table 1 shows the frequencies regarding the participants' attributes gender and course level.

64 students stated their age (one missing from each university), which resulted in a mean of M = 22.84 years (SD = 5.09 years) with a minimum of 18 years and a maximum of 53 years. Based on a box-plot analysis one outlier (53 years) and two extreme values (34 and 35 years) were participants from the US sub-sample. The age distribution of the US sub-sample (M = 22.74, SD = 6.23) and German sub-sample (M = 23.00, SD = 2.58) did not differ significantly ($t(54.868) = -0.228$, $p_{2\text{-sided}} = 0.820$, bootstrapped BCa 95% CI for mean difference = [-2.175;1.984]).

TABLE 1: P*articipants' attribute frequencies: gender & course level*

Attribute		University	
		UMBC (n = 40)	**H-BRS (n = 26)**
Gender	Male	28	13
	Female	11	13
	Not specified	1	0
Course level	Undergraduate	35	17
	Graduate	1	9
	Not specified	4	0

The US sub-sample consisted mostly of students with experience in a higher education environment (38 second- to fifth-year or above students, one first-year student and one with missing value). The German sub-sample showed with 23.1% a higher first-year frequency (n = 6). 73.1% (n = 19) were second- to fifth-year or above students. The ethnic composition of the sample showed in the US sub-sample 30 white Americans, three African/Black Americans, three Asian & Pacific Americans, two Latina/Hispanic Americans, one Foreign National/US Resident (green card) from Bangladesh, and one missing value. In comparison, 24 German students visited exclusively schools in Germany. Additionally, each one visited partly an Australian and Russian school. None of the German students immigrated to Germany on their own. Though, five students had a family migration background (parents or grandparents immigrated to Germany from the following countries: Kazakhstan, Belgium, Turkey, Greece, Netherlands, Croatia, Libya, or Jordan). 29 US students transferred directly from high school to university, six after 2- year college, one after 4-year college, and three were working full-time immediately prior to studying. All 26 German students had a general (n = 24) or subject-specific (n = 2) university entrance qualification. Three German students completed vocational training prior to studying (both students with subject-specific and one with general entrance qualification. In the US sub-sample 16 students stated to have had an internship or co-op in engineering or a related field (23 did not, one missing value). The proportion of students with internship or co-op was higher in the German sub-sample (18 had prior experience while eight did not). The observed difference between the sub-samples was significant (2-sided exact Fisher-test $p = 0.042$, $\Phi = 0.277$).

D. Scale analysis

In the aim to construct a scale to measure the Culture of Failure in Higher Education, which is in the sense of the psychological construct homogeneous and reliable, an item analysis according to the Classical Test Theory (CTT) was performed [11], [12]. This item analysis consisted of a process in which the items are evaluated to delete items not fulfilling the psychometric criteria according to CTT. In this process the psychometric values (a) item difficulty and (b) corrected item- total correlation were assessed successively. In a further step, the reliabilities and correlations of the sub-scales consisting of the final item-set were analyzed to assess the dimensional structure behind the item-set.

III. RESULTS & DISCUSSION

Initially, the results of the item and scale analysis according to CCT are presented and discussed. Finally, the resulting Culture of Failure-score is evaluated exemplarily based on the sampling variables.

A. Item analysis

1. Item difficulties

The item difficulty $P(i)$ of an item i is a numerical value between 0 and 1 which shows the probability that an item will be answered in the sense of the psychological construct it measures. Too low or too high values describe items which are answered from the majority of the participants in the same manner with low variability. An item difficulty of $P = 0.5$ shows the highest variability in response behavior. As the item difficulty is related with the ability of an item to differentiate between participants, all items below a value of 0.2 and above 0.8 should be deleted from the scale [11], [12].

This one-sided response scheme applied to seven of the 55 preliminary items. This affected abasing reactions of peers and lecturers to students failing, like humiliating or laughing at them (four items of dimension (b) *failure friendliness*; $P = [0.82;0.89]$) and cognitive aspects regarding failures (three items of dimension (a) *learning orientation*; $P = [0.81;0.91]$). Taking the US ($n(US) = 40$) and German ($n(GER) = 26$) sub-samples into account, the 55 items showed heterogeneous item difficulties (mean difference US vs. GER $\Delta M(US\text{-}GER) = 0.04$, $SD(US\text{-}GER) = 0.09$, $Min(US\text{-}GER) = -0.14$, $Max(US\text{-}GER) = 0.27$). While in the German sub- sample all six items (two more than in the total sample) of abasing reactions of peers and lecturers showed item difficulties above 0.8, only two items of abasing lecturers' reaction in the US sub-sample showed comparable high values. Considering possible linguistic differences in the items, only the two items showed in both language versions a lack of variability were deleted prior next analysis steps. Additionally, one of the items regarding cognitive failure aspects which showed the highest values for difficulty in the US sub-sample ($P(US) = 0.93$) and a difficulty of $P(GER) = 0.86$, was deleted. The resulting 52 items showed a mean difficulty of $M(P,52) = 0.59$ ($SD(P,52) = 0.15$), a minimum of $Min(P,52) = 0.21$, and a maximum of $Max(P,52) = 0.82$.

2. Corrected item-total correlations

The part-whole-corrected item-total correlation $r(i,total\text{-}i)$ of an item i is a measure how much the item i measures the same psychological construct as the other items combined *(total-i)*. Values between 0.4 and 0.7 are preferred [11]. Due to the theoretical assumption of the multidimensional nature of the Culture of Failure Scale each of the above described four dimensions were analyzed separately. Therefore, the corrected item-total correlation was calculated by correlating each of the remaining 52 items with the summative value of the other items of the same sub-scale. Table 2 gives an overview about the distribution of the corrected item-total correlations separated according to the items' sub-scale.

TABLE 2: *Items' part-whole-corrected item-total correlation*

Sub-scale	*n(i)*	*M(r)*	*SD(r)*	*Min(r)*	*Max(r)*
(a) learning orientation	16 (5)	0.40	0.17	0.09	0.65
(b) failure friendliness	18 (3)	0.45	0.09	0.25	0.60
(c) norm transparency	9 (4)	0.38	0.12	0.25	0.57
(d) fear of failure	9 (0)	0.59	0.07	0.46	0.65

Note: *n(i)* = number of items remaining after analyzing item difficulties. Values in brackets show number of items with an item-total correlation < 0.4.
M(r) = mean corrected item-total correlation.
SD(r) = standard deviation.
Min(r) = minimum corrected item-total correlation.
Max(r) = maximum corrected item-total correlation.

B. Scale analysis

1. Reliabilities

The reliability of a scale is a measure of its internal consistency [12]. It can be seen as the (sub-)scale's precision of measuring a psychological construct [11]. In this sense, a high reliability is a prerequisite of (sub-)scale's validity. Thus, all sub-scales' reliability should show a higher Cronbach's Alpha value than 0.7 [11], [12]. The dimensions' reliability analysis by calculating Cronbach's Alpha for each of the four sub-scales showed satisfying reliability values for all four sub-scales (see values in brackets in Table 3).

TABLE 3: *Sub-scales' descriptive values, correlations, and reliabilities*

Sub-Scale	*M*	*SD*	(a)	(b)	(c)	(d)
(a) learning orientation	Total: 3.50 GER: 3.46 US: 3.53	Total: 0.45 GER: 0.35 US: 0.51	(0.8)			
(b) failure friendliness	Total: 3.55 GER: 3.73 US: 3.43	Total: 0.48 GER: 0.50 US: 0.43	0.41**	(0.8)		
(c) norm transparency	Total: 3.16 GER: 3.29 US: 3.08	Total: 0,55 GER: 0.54 US: 0.55	0.33*	0.48**	(0.7)	
(d) fear of failure	Total: 2.92 GER: 3.10 US: 2.81	Total: 0.79 GER: 0.88 US: 0.71	0.53**	0.68**	0.51**	(0.9)

Note: *n* = sample size.
M = mean, *SD* = standard deviation.
Values in brackets show sub-scale's reliability in Cronbach's Alpha.
Values below diagonal show Pearson's product moment correlation.
* $p < 0.01$ (2-sided).
** $p < 0.001$ (2-sided).
Total: total sample ($n = 66$).
GER: German sub-sample ($n = 26$).
US: US sub-sample ($n = 40$)

2. *Correlations*

A correlation analysis of the resulting sub-scales using Pearson's product moment correlation showed significant medium to large correlations between r = 0.33 and r = 0.68 [13]. Details for each of the bivariate pairs can be found below the diagonal in Table 3.

C. Culture of Failure-score

The resulting sub-scale values for the total sample ($n = 66$) as well as for the German ($n = 26$) and US sub-sample ($n = 40$) are shown in Table 3. Performed Kolmogorov-Smirnov tests with Lilliefors correction (in case of total sample) respectively Shapiro-Wilk tests (in case of the sub-samples) as well as related Q-Q-plots showed no significant deviations from normal distribution. The observed mean differences between the German and US sub-samples were, with exception of the dimension (b) *failure friendliness*, not significant. Here, the mean difference ($\Delta M = 0.30$, *BCa* 95% $CI = [0.09;0.53]$) between the German ($M = 3.73$, $SD = 0.50$, $n = 26$) and the US sub-sample ($M = 3.43$, $SD = 0.43$, $n = 40$) in the dimension (d) *failure friendliness* showed a medium effect ($t(47.942) = 2.57$, $p_{2\text{-sided}} = 0.007$, Cohen's $d = 0.67$) [13].

IV. CONCLUSION

In an effort to support both higher education instructors and students, this data-driven contribution aimed to develop a Culture of Failure Scale to assess students' and lecturers' handling of failures. With a sample of 66 engineering students of two cooperating universities from Germany and the US, the first item-pool of 55 items could be successfully analyzed. Using a psychometric analysis according to the Classical Test Theory (CTT), the item-pool was reviewed and reduced to a final scale of 52 items.

As a pilot study the structure of the sample consisting of 26 German and 40 US engineering students is satisfactory. The psychometric analyses of the items showed satisfactory item difficulties for 52 items $M(P,52) = 0.59$ ($SD(P,52) = 0.15$) for a scale meant to analyze a psychological construct (here Culture of Failure) generally and not to differentiate within the extreme edges of a construct [11]. The item difficulties differed between the German and English versions slightly $\Delta M(US\text{-}GER) = 0.04$, $SD(US\text{-}GER) = 0.09$. Though, few items, e.g., abasing reactions of peers, showed a higher difference in item difficulty between both language versions. This could be caused by different interpretations of the item wording or be based on significant sub-samples' differences. Further investigations, including a qualitative analysis of the item wording, are needed. The sub-scales' reliabilities (Table 3) were consistently in the limits of satisfactory values. Though, the corrected item-total correlations (Table 2) showed that in three of the four assumed dimensions ((a) *learning orientation*, (b) *failure friendliness*, and (c) *norm transparency*) between 17% and 36% of the sub-scales' items are not in the limits of a one-dimensional (sub-)scale. This suggests that a different dimensional structure than the assumed four dimensions lies behind the items. This assumption is supported by the consistent significant correlations between the four preliminary sub- scales (Table 3). A Principal Component Analysis (PCA) and a later Confirmatory Factor Analysis (CFA), which both require larger sample sizes, should be performed in future research. This will help to gain a deeper understanding of which dimensions highly impact the Culture of Failure in higher education.

Nonetheless, the Culture of Failure Scale for Higher Education developed in this research study has demonstrated as an effective tool to assess students' and lecturers' handling of failures. This will help students and lecturers to create a safe and thriving environment that is conducive to learning and to developing a failure-positive mind-set.

In future research phases, the refined 52 items Culture of Failure Scale will be issued to a larger sample with students majoring outside engineering. This enables to verify the psychometric values above for the items and sub-scales and to perform additional factor analyses. Larger and more diverse samples will also allow multivariate statistical analyses regarding the influence of gender, former occupational experience, educational history, and ethnic/migration background. With this data-driven approach we hope to start a discussion about handling failures in higher education and especially the benefits of a learning from failure approach.

A positive Culture of Failure approach in educational settings promises a safe environment with a conducive impact to learning and retention. Additionally, it supports students to develop a failure-positive mind-set where failures are seen as a source for improvements and learning. Copies of the refined survey as well as the item randomization scheme will be issued on request by the authors of this contribution.

REFERENCES

[1] ABET, Criteria for Accrediting Engineering Programs, 2019 – 2020. Baltimore: ABET, 2018.

[2] K. Schwaber and J. Sutherland, "The Scrum Guide: The Definitive Guide to Scrum: The Rules of the Game." 2020.

[3] DIN Deutsches Institut für Normung e.V., "DIN EN ISO 9001: Quality management systems – Requirements (ISO 9001:2015); German and English version EN ISO 9001:2015," Beuth Verlag, Berlin, Nov. 2015.

[4] C. van Dyck, M. Frese, M. Baer, and S. Sonnentag, "Organizational Error Management Culture and Its Impact on Performance: A Two- Study Replication.," Journal of Applied Psychology, vol. 90, no. 6, pp. 1228–1240, 2005, doi: 10.1037/0021-9010.90.6.1228.

[5] G. J. Homsma, C. Van Dyck, D. De Gilder, P. L. Koopman, and T. Elfring, "Learning from error: The influence of error incident characteristics," Journal of Business Research, vol. 62, no. 1, pp. 115– 122, Jan. 2009, doi: 10.1016/j.jbusres.2007.12.003.

[6] J. Rupert, A. C. Homan, K. A. Jehn, and R. J. Blomme, "Diversity Composition and Team Learning: The Moderating Role of Error Culture," Group Decis Negot, vol. 28, no. 4, pp. 695–722, Aug. 2019, doi: 10.1007/s10726-019-09626-5.

[7] M. Frese and N. Keith, "Action Errors, Error Management, and Learning in Organizations," Annu. Rev. Psychol., vol. 66, no. 1, pp. 661–687, Jan. 2015, doi: 10.1146/annurev-psych-010814-015205.

[8] V. Rybowiak, H. Garst, M. Frese, and B. Batinic, "Error orientation questionnaire (EOQ): reliability, validity, and different language equivalence," J. Organiz. Behav., vol. 20, no. 4, pp. 527–547, Jul. 1999, doi: 10.1002/(SICI)1099-1379(199907)20:4<527::AID-JOB886>3.0.CO;2-G.

[9] M. Spychiger, R. Kuster, and F. Oser, "Dimensionen von Fehlerkultur in der Schule und deren Messung. Der Schülerfragebogen zur Fehlerkultur im Unterricht für Mittel- und Oberstufe," Schweizerische Zeitschrift für Bildungswissenschaften, vol. 28, no. 1, pp. 87–110, 2006.

[10] M. Schneider and F. Preckel, "Variables associated with achievement in higher education: A systematic review of meta-analyses.," Psychological Bulletin, vol. 143, no. 6, pp. 565–600, 2017, doi: 10.1037/bul0000098.

[11] H. Moosbrugger and A. Kelava, Eds., Testtheorie und Fragebogenkonstruktion. Berlin, Heidelberg: Springer Berlin Heidelberg, 2020. doi: 10.1007/978-3-662-61532-4.

[12] P. Kline, A handbook of test construction: introduction to psychometric design. London; New York, NY: Methuen, 1986.

[13] J. Cohen, Statistical power analysis for the behavioral sciences, 2nd ed. Hillsdale, N.J: L. Erlbaum Associates, 1988.

Technical papers

Systematic literature review: An investigation towards finding constructs for performance prediction of students in an online engineering course

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***Abstract* — The use of technology in the field of engineering education has been the most common intervention, especially in the post-pandemic era. Most universities have plans to continue the blended approach to education in the future. This decision has to be an evaluated decision and the analysis of a student's performance serves as an input to take the decision. The other advantage of analysis include early prediction of student performance which can help the instructors to provide timely interventions and help the students to improve their performance. Thus identification of constructs that reflect student engagement and performance in a course delivered in online mode is very essential. This literature review attempts to bring forward the constructs used by various researchers that reflect student engagement and performance. The review is situated in the context of engineering education delivered in online mode. The identification of constructs is significant and helps to build machine learning models for predicting the performance of the students. Standard Systematic Literature Review(SLR) methods defined in literature including citation searching and hand searching were carried out to identify the constructs that have been in use. A list of constructs used by researchers in the literature, that capture students' attention and per- formance are identified and presented in this review. The identified constructs include students' interaction with con- tent, students' interaction with peers, demographic factors, and the academic records of the student. These validated constructs are proposed to integrate with the Learning Management System (LMS) and use the feature for early prediction of student failures.**

Keywords — Systematic Literature Review, Student engagement, Blended learning, Learning Management System

I. INTRODUCTION

The blended mode of delivery in the field of education has become quite prominent during this pandemic era [1], [2]. The decision to continue the usage of blended mode must be evaluated. Students' academic performance can be a parameter that can help educators to make decisions towards continuing the blended mode of delivery. Thus identification of constructs that reflect students' engagement and performance in blended mode becomes more essential.

The literature presents several studies that focus on describing the impact of different factors on a student's academic performance in the context of Indian engineering education [1], [3]–[5]. Further, the complexity of the study increases when other dimensions such as blended and online modes of delivery get added.

Performance of the student depends on how well the students are provided with an opportunity to have inter- action with content, peers, and mentors [6]. Hence there is a need for operationalizing the action 'interaction' in the context of online education. Through this paper, the authors attempt to bring forward the constructs used by various researchers in the literature that have influenced student engagement and performance in the blended/online mode of education.

Online mode of education has become quite prominent in recent years. Platforms like Learning Management Systems (LMS), Massive Open Online Courses (MOOCs), and other Virtual Learning Environments (VLE) are largely used for online delivery. The amount of interaction and the kind of interaction that the students have with such environments have been proven influence the students' performance [7]–[13].

Apart from the impact of the interaction of students with content on students' performance, some other factors have also been studied intensively by the researchers. A few studies tell us about the impact of the interaction of a student with peers on the academic performance of the student [14]. The activities of the student on the discussion forums and social media platforms are considered under peer interaction [11]–[13], [15], [16]. A few authors also tell us about how demographic factors affect students' performance [5], [7], [17], [18].

The motive of this review is to identify the constructs currently used by the researchers that reflect student engagement and performance in the engineering courses delivered in blended mode.

The rest of the paper is organized as follows. Identification of methodologies adopted by researchers when approaching the problem of performance prediction is reviewed in Section II. The methodology adopted is described in Section III. The analysis of the factors identified in section 2 is reviewed in

Section IV. Section V concludes the study and provides some directions for future work.

II. DISCUSSION OF METHODOLOGIES ADOPTED BY RESEARCHERS

This review has collected and synthesized the existing works and reviews report (publications from journals conferences, invited papers, and textbooks) and identified the factors and methods used when predicting students' performance and also the evaluation metrics used by them when assessing the students [19]. The following section discusses the same in detail.

A. Factors

The factors considered to predict the performance of a student in most of the literature can be broadly classified into the following categories: content interaction, peer interaction, academic records, and demographic factors [6]. Content interaction includes the activities of the student on online educational platforms like Learning Management Systems (LMS) [7], Massive Open Online Courses (MOOC) [9], etc. Activities of the student on the discussion forums and social media platforms are considered to understand the student's interaction with peers [11], [13], [15], [16]. The previous academic records and formative assessment marks are included under the academic records [14], [20]. The domestic factors(parental in- formation, socioeconomic status, etc.), and school-related factors(geographic location of the school, school quality, etc.) are considered under the demographic factors [7], [8], [17]. Some works also propose the usage of multimodal data to understand the learner's behavior as well [21].

Content interaction, peer interaction, and academic records also form three of the four main pillars of the LMS [22]. Online platforms should be seen as a tool to increase student involvement through self-reflection rather than just a place to dump the content. Ensuring the employment of the above-mentioned pillars and proper administration, which is the fourth pillar of LMS, will increase the chances of the students succeeding academically.

B. Methods

Various kinds of classification algorithms have been used by researchers to predict the performance of a student. Algorithms based on machine learning (ML) and deep learning (DL) are the state of the art that helps the educator in multiple ways. The capabilities of these ML and DL algorithms to handle massive amounts of data, and data from multi-modalities made these algorithms the state of art [23]. They are adept at managing multi-dimensional data. As the algorithms gain experience, their efficiency and accuracy continue to increase.

Machine learning (ML) methods like the random forest, decision tree, and support vector machine [8], [11], [15], [18] have often been used to predict students' performance. Deep learning algorithms like Artificial neural networks (ANNs) and long short-term memory (LSTM) [7], [14], [20], [24]have been used by some academicians and researchers to forecast students' achievements. The danger of over-fitting with limited data is larger for DL methods, which are often more complicated [25]. Hence, ML algorithms have been used in cases where adequate data is unavailable.

C. Performance Evaluation Metrics

Most works have classified the students' performances into pass/fail/distinction based on their performance [7], [10], [17], [26]. Some of the remaining papers have predicted the performance of the student using regressors and have performed regression tasks [18].

III. METHODOLOGY

The current study adopted the steps mentioned in the SLR [27] process to carry out the literature review. In this study, the works that were published between 2010 to 2021 were considered. This used keywords and phrases like performance prediction, blended learning, and online learning, in search engines like Google scholar. Along with this, citation searching was used to find relevant literature. Citation searching refers to searching for literature cited by the sources of already referred papers as well as the sources cited by them [27]. The keywords identified here were performance prediction, learner engagement, clickstream data, peer interaction, demographic data, and course performance.

The motivation to perform the SLR was to identify the constructs commonly used in predicting students' performance. These validated constructs are proposed to integrate with the Learning Management System (LMS) of a university that was in need of evaluating the effectiveness of the newly adopted blended mode of delivery. The data(academic records of the students, the activities of the students on the online platform, etc) obtained regarding the students of the university was mostly quantitative, and hence this study primarily focused on the works of researchers who have conducted the quantitative analysis.

The information from the SLR is synthesized and represented through a literature map [28] as shown in Figure 1. The literature map is a two dimensional graphical representation method that helps to organize the learning. It has 'nodes' and 'links'. Nodes represent the 'lens' or 'main theme' and the references show the source of in- formation. From the entire collection, the relevant articles were identified and further studied for this review. Figure 2 represents the PRISMA flow diagram [29] of the literature review conducted. The flow of this diagram depicts the flow of information through the different phases of a systematic review [27]. It maps out the number of records identified, included, and excluded, and the reasons for exclusions [30].

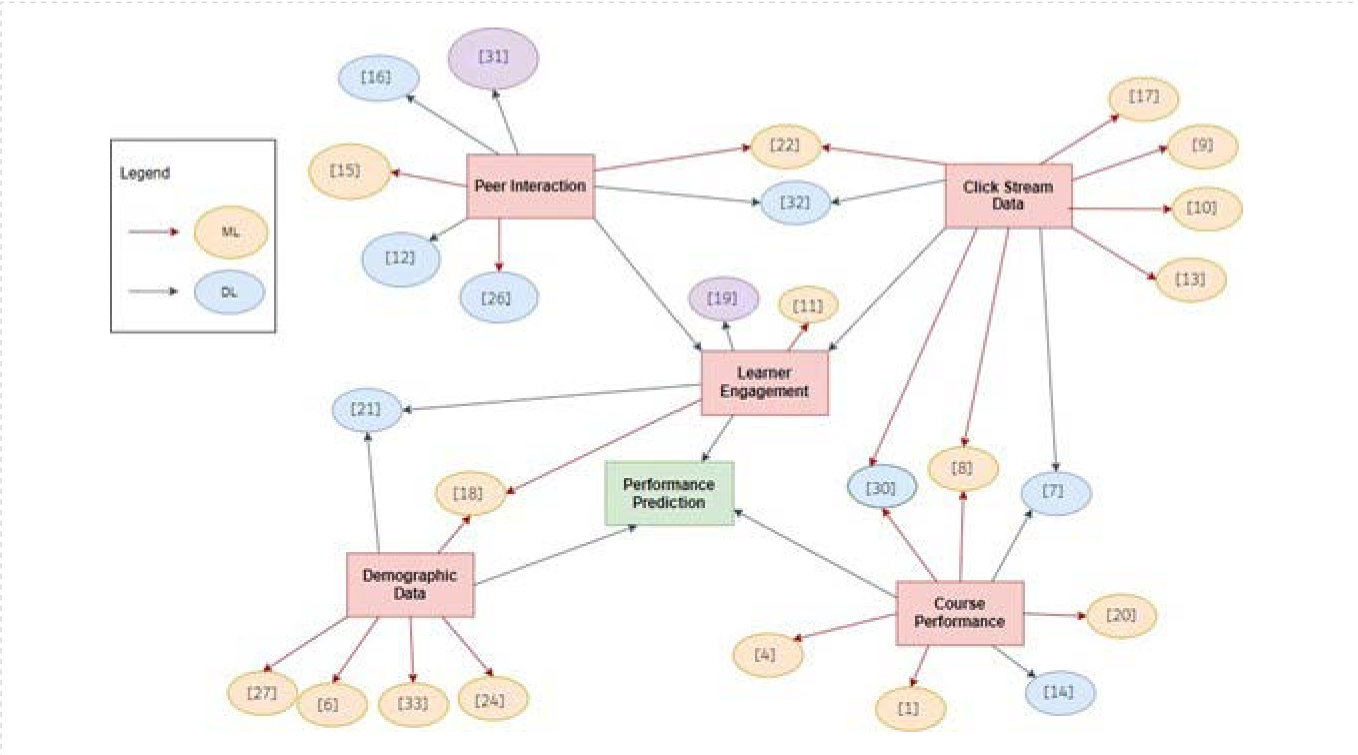

FIGURE 1: *Literature Map*

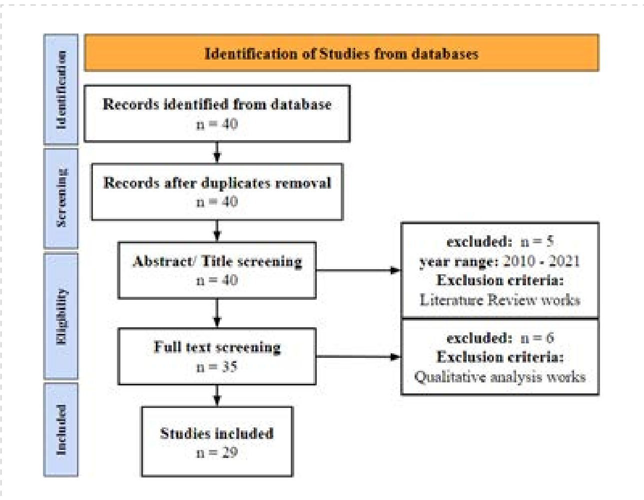

FIGURE 2: *PRISMA Flow Diagram*

Performance prediction has been studied extensively in the past for various purposes like identifying the students at risk, identifying and customizing the student learning environments, etc. The predicted values are the grade point averages (GPA), knowledge, scores, etc. Most works have used quantitative approaches and classification algorithms to classify the students into various categorical values (for example Pass/Fail).

The study limited the literature search to papers that exclusively dealt with quantitative analysis. This review looked at the aspects that these works considered and how they influenced students' performance. The researchers' methodologies and the models they trained and evaluated for prediction were also taken into consideration. The expected output was another factor that was noted from all of the research works considered.

The performance of a student is influenced by various factors. Learner engagement [9], course performance details [14] and the demographic data [17], [18] are a few of the factors considered and reviewed in our study. Learner engagement here is further categorized into peer interaction data and clickstream data, which indicates the content interactions.

The factors thus identified and obtained are further used to predict students' performance. Several machine learning and deep learning methods are used to perform the task of prediction as mentioned in the previous section. The research works that have made use of ML and DL methods are depicted using different colours in the literature map in Figure 1. Machine learning-based methods are marked with orange colour, whereas deep learning-based methods are shown in blue colour in the literature map. The literature map also has a few purple-coloured ovals, they include qualitative analysis works and literature survey papers.

IV. ANALYSIS

The literature review aimed to identify the constructs currently used by the researchers that reflect student engagement and performance. The factors, methods, and predicted outputs have been noted as a part of this review. The factors discovered in the literature can be broadly divided into four categories namely- demographic characteristics, academic records, content interaction, and peer interaction [13]. A complete discussion of these factors may be found in Table 1. In the recent past factors like the number of clicks per day, number of active days, number of resources accessed, number of videos watched and activities of students on discussion forums were commonly used and have proven to provide excellent results in predicting the performance [7], [15], [31].

TABLE 1: *Attributes commonly used*

Identified category	Attributes considered	References
Demographic factors	Gender, age, parent's educational level, parents' involvement, students study environment, school and classroom environment, possession of computers, region, family income and expenditure, nationality, birthplace.	[7], [8], [10], [11], [17], [18]
Academic records	Internal assessment marks, assignment submission marks, past performances.	[10], [14]
Content interaction	Click stream data, number of clicks per day, number of active days, number of resources accessed, number of videos watched, announcement views.	[7]–[11], [17], [31], [32].
Peer interaction	Activities of students on wiki, blog posts and twitter or any other discussion forums.	[11], [12], [15], [16], [33]

The algorithms utilized were divided into two categories: machine learning and deep learning. Table 2 lists the various Machine Learning and Deep Learning algorithms that were used in this study. In general, classification approaches are seen to be employed more frequently. Random forest, support vector machine, and decision trees are the most commonly used classification algorithms giving an accuracy of over 95% [7], [8], [11], [18], [34].

TABLE 2: *Methods Commonly Used*

Methods	Approaches	References
Machine learning	Logistic Regression, SVM, Naive Bayes, Decision Tree, Random Forest , XGBboost.	[8], [11], [15], [18]
Deep learning	Deep Neural Networks (DNN), Long short term memory (LSTM), etc.	[7], [12], [31], [32].

Various kinds of metrics were used to describe the students' performance. Mostly they were classified into pass/fail/distinction or other such categories using multiclass classification algorithms [7], [10], [17], [26]. These classifications were made on based on their final results (grade point averages or the total final marks).

V. CONCLUSION

This paper summarizes the literature and identifies the constructs that reflect student engagement and performance. The identified constructs that reflect student engagement and performance include demographic factors, academic records, and the factors dealing with the content level of interaction and peer interactions. In this post-pandemic era, the inclination toward the online and blended mode of delivery has increased. Hence, the student's interaction with content and peers mostly constitute the data obtained from online platforms. This paper not only summarizes the factors influencing students' performance but also discusses the methods used and the evaluation metrics used to evaluate the student's performance considered by the researchers.

This review primarily focuses on the research works that have used quantitative analysis methods, future works can take into account the research works that have used qualitative analysis techniques and those works that integrate both qualitative and quantitative methods. Addition- ally, studies that have employed clustering and statistical methods like regression can be taken into account and reviewed.

The understanding developed after reviewing the current trends and the conclusions provided by other researchers in the field of students' performance prediction and artificial intelligence helped the first author further their research. The data for the study collected included click stream data from Learning Management System (LMS) to understand the students' interaction with the content and collaboration made by the student on the GitHub platform to understand the students' interaction with their peers. The other sets of data included students' academic performance and demographical data.

This data was further used to train the classification algorithms. The machine learning based classifications algorithms like Random forest, Naive Bayes, Decision tree, Support Vector Machine, and XGBoost were used to predict the performance [35]. And multiclass classification was done using the decision tree classifier achieving a classification accuracy of 96%. The students were grouped into four categories including 'Excellent', 'Good', 'Aver- age', and 'Poor'. The authors are further working towards integrating these identified constructs with the LMS at the university to create a personalized learning for the students.

REFERENCES

[1] M. Vijaylakshmi, P. Baligar, K. Mallibhat, S. M. Kavale, G. Joshi, and A. Shettar, "Transition from in-person learning to technology enhanced learning in engineering education: Faculty challenges," 2021 IEEE Frontiers in Education Conference (FIE), pp. 1–5, 2021.

[2] K. Mallibhat and N. Iyer, "Program level adaptations during pan- demic: Opportunities and faculty perceptions," in EDULEARN22 Proceedings. IATED, 2022, pp. 3138–3145.

[3] P. Baligar, S. Kavale, M. Kaushik, G. Joshi, and A. Shettar, "En- gineering exploration: A collaborative experience of designing and evolving a freshman course," 2018 World Engineering Education Forum-Global Engineering Deans Council (WEEF-GEDC), pp. 1– 5, 2018.

[4] M. Kaushik, "Evaluating a first-year engineering course for project based learning (pbl) essentials," Procedia Computer Science, vol. 172, pp. 364–369, 2020.

[5] N. N. Kulkarni, M. Kaushik, and G. Joshi, "Engineering pro- fession: understanding freshman perspective," in 2016 IEEE 4th International Conference on MOOCs, Innovation and Technology in Education (MITE). IEEE, 2016, pp. 332–337.

[6] T. Anderson, "Modes of interaction in distance education: Recent developments and research questions," Handbook of distance edu- cation, pp. 129–144, 2003.

[7] H. Waheed, S.-U. Hassan, N. R. Aljohani, J. Hardman, S. Alelyani, and R. Nawaz, “Predicting academic performance of students from vle big data using deep learning models,” Computers in Human behavior, vol. 104, p. 106189, 2020.

[8] M. Hussain, W. Zhu, W. Zhang, and S. M. R. Abidi, “Student engagement predictions in an e-learning system and their impact on student course assessment scores,” Computational intelligence and neuroscience, vol. 2018, 2018.

[9] F. Bonafini, C. Chae, E. Park, and K. Jablokow, “How much does student engagement with videos and forums in a mooc affect their achievement?” Online Learning Journal, vol. 21, no. 4, 2017.

[10] K. T. Chui, D. C. L. Fung, M. D. Lytras, and T. M. Lam, “Predicting at-risk university students in a virtual learning environment via a machine learning algorithm,” Computers in Human Behavior, vol. 107, p. 105584, 2020.

[11] V. Vamshidharreddy, A. Saketh, and R. Gnanajeyaraman, “Stu- dent’s academic performance prediction using machine learning approach,” International Journal of Advanced Science and Tech- nology, vol. 29, no. 9, pp. 6731–6737, 2020.

[12] W. Zhang, Y. Zhou, and B. Yi, “An interpretable online learner’s performance prediction model based on learning analytics,” in Pro- ceedings of the 2019 11th International Conference on Education Technology and Computers, 2019, pp. 148–154.

[13] L. P. Macfadyen and S. Dawson, “Mining lms data to develop an “early warning system” for educators: A proof of concept,” Computers & education, vol. 54, no. 2, pp. 588–599, 2010.

[14] S. Hussain, Z. Muhsin, Y. Salal, P. Theodorou, F. Kurtog˘lu, and G. Hazarika, “Prediction model on student performance based on internal assessment using deep learning,” International Journal of Emerging Technologies in Learning, vol. 14, no. 8, 2019.

[15] E. Popescu and F. Leon, “Predicting academic performance based on learner traces in a social learning environment,” IEEE Access, vol. 6, pp. 72 774–72 785, 2018.

[16] C. Romero, M.-I. López, J.-M. Luna, and S. Ventura, “Predicting students’ final performance from participation in on-line discussion forums,” Computers & Education, vol. 68, pp. 458–472, 2013.

[17] P. Sokkhey and T. Okazaki, “Hybrid machine learning algorithms for predicting academic performance,” International Journal of Advanced Science and Technology, vol. 11, no. 1, pp. 32–41, 2020.

[18] S. Rizvi, B. Rienties, and S. A. Khoja, “The role of demographics in online learning; a decision tree based approach,” Computers & Education, vol. 137, pp. 32–47, 2019.

[19] A. Hellas, P. Ihantola, A. Petersen, V. V. Ajanovski, M. Gutica, T. Hynninen, A. Knutas, J. Leinonen, C. Messom, and S. N. Liao, “Predicting academic performance: a systematic literature review,” in Proceedings companion of the 23rd annual ACM conference on innovation and technology in computer science education, 2018, pp. 175–199.

[20] H. Agrawal and H. Mavani, “Student performance prediction using machine learning,” International Journal of Engineering Research and Technology, vol. 4, no. 03, pp. 111–113, 2015.

[21] M. N. Giannakos, K. Sharma, I. O. Pappas, V. Kostakos, and E. Velloso, “Multimodal data as a means to understand the learning experience,” International Journal of Information Management, vol. 48, pp. 108–119, 2019.

[22] A. J. Swart and P. E. Hertzog, “Analysing student accesses in a learning management system yields notable insights relating to student success,” World Trans Eng Technol Educ, vol. 18, pp. 111– 116, 2020.

[23] K. C. A. Khanzode and R. D. Sarode, “Advantages and disadvantages of artificial intelligence and machine learning: A literature review,” International Journal of Library & Information Science (IJLIS), vol. 9, no. 1, p. 3, 2020.

[24] B. Sekeroglu, K. Dimililer, and K. Tuncal, “Student performance prediction and classification using machine learning algorithms,” in Proceedings of the 2019 8th International Conference on Educa- tional and Information Technology, 2019, pp. 7–11.

[25] C. Janiesch, P. Zschech, and K. Heinrich, “Machine learning and deep learning,” Electronic Markets, vol. 31, no. 3, pp. 685–695, 2021.

[26] Y. Li, L. Qiu, and B. Sun, “Two ways peer interactions affect academic performance,” in Proceedings of the 4th International Conference on Crowd Science and Engineering, 2019, pp. 90–94.

[27] M. Borrego, M. J. Foster, and J. E. Froyd, “Systematic literature reviews in engineering education and other developing interdisci- plinary fields,” Journal of Engineering Education, vol. 103, no. 1, pp. 45–76, 2014.

[28] J. W. Creswell and J. D. Creswell, Research design: Qualitative, quantitative, and mixed methods approaches. Sage publications, 2017.

[29] M. J. Page, D. Moher, P. M. Bossuyt, I. Boutron, T. C. Hoffmann, C. D. Mulrow, L. Shamseer, J. M. Tetzlaff, E. A. Akl, S. E. Brennan et al., “Prisma 2020 explanation and elaboration: updated guidance and exemplars for reporting systematic reviews,” bmj, vol. 372, 2021.

[30] A. A. Selçuk, “A guide for systematic reviews: Prisma,” Turkish archives of otorhinolaryngology, vol. 57, no. 1, p. 57, 2019.

[31] M. D. Calvo-Flores, E. G. Galindo, M. P. Jiménez, O. P. Pineiro et al., “Predicting students’ marks from moodle logs using neural network models,” Current Developments in Technology-Assisted Education, vol. 1, no. 2, pp. 586–590, 2006.

[32] J. Mutahi, A. Kinai, N. Bore, A. Diriye, and K. Weldemariam, “Studying engagement and performance with learning technology in an african classroom,” in Proceedings of the Seventh Interna- tional Learning Analytics & Knowledge Conference, 2017, pp. 148–152.

[33] R. Junco, G. Heiberger, and E. Loken, “The effect of twitter on college student engagement and grades,” Journal of computer assisted learning, vol. 27, no. 2, pp. 119–132, 2011.

[34] A. Daud, N. R. Aljohani, R. A. Abbasi, M. D. Lytras, F. Abbas, and J. S. Alowibdi, “Predicting student performance using advanced learning analytics,” in Proceedings of the 26th international con- ference on world wide web companion, 2017, pp. 415–421.

[35] Y. Joshi, M. Kaushik, and M. Vijaylakshmi, “Students’ performance prediction using multimodal machine learning,” 2022 World En- gineering Education Forum and The Global Engineering Deans Council (WEEFGEDC), pp. 1–5, 2022.

Technical papers

Disruptive technologies in engineering education: A case study

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***Abstract* — Post-COVID-19 has shaped the educational system in the world, particularly in university engineering education by using a digital technology platform such as a learning management system (LMS) with an embedded virtual environment. However, students and lecturers rarely adopt and use this technology but rather prefer other platforms such as WhatsApp, YouTube, Twitter, Facebook, etc. that are not owned or controlled by the University management because they are not originally intended for teaching and learning even though they have the educational capability. This paper seeks to verify the extent to which disruptive technologies influence engineering university education. Much literature has investigated the role of disruptive technologies in recent studies, but none of them related it to the context of university engineering education in Nigeria. Activity Theory and Expansive Learning methods were used to analyse the data obtained through survey questions, and interviews on the respondent's actual practices. Out of 450 respondents involved in the studies. The survey showed that respondents tend to endorse the Disruptive Innovation theory, as the respondents justify the reasons for adopting their preferred choice of technologies, rather than following the designer's original intentions for inventing them. The survey questions and interview results showed that WhatsApp, YouTube, Zoom, Google form, and Twitter are the five topmost learning and teaching disruptive technologies frequently used by students and lecturers instead of LMS because they are easily accessible and convenient. The survey revealed that learners use a narrow range of technologies to support learning rather than those provided by their university management. Students and lecturers are not adopting LMS to support learning and teaching usage. The use of other learning technologies outside LMS has hindered the monitoring and evaluation of online education effectively by the University management.**

Keywords—Engineering education, online learning; disruptive innovation, disruptive technology; activity theory; expansive learning

I. INTRODUCTION

Disruptive technologies provide the possibility for educational activities that are different from traditional methods [1]. Federal University Oye-Ekiti, Nigeria (FUOYE) management had invested in digital technology such as LMS for teaching and learning among the Lecturers and students. However, the digital technologies provided by the university management have not achieved their purpose in terms of adoption and usage [2, 3]. This is so; because lecturers and students make use of other technologies not managed nor controlled by the university management to complement their learning and teaching [4]. Although many authors have reported that the use of digital technologies in teaching and learning would disrupt learning and teaching practices in engineering departments [5, 6]. However, digital technologies have, in practice, largely reproduced, rather than transformed and disrupted, existing pedagogical approaches [7, 8]. It is therefore expedient to explore how technologies that were not originally designed for learning and teaching purposes contribute to learning and teaching in engineering education. To provide an answer to this question, this paper assesses the role of disruptive technologies in engineering education in Nigeria [9]. This paper, therefore, discusses the role of disruptive technologies in engineering education using the faculty of Engineering in FUOYE as a case study to evaluate the role of various disruptive technologies used by students and lecturers to support learning and teaching.

A. Activity Theory and Expansive Learning

Expansive Learning Activity Theory was established for human development [10]. Activity Theory state that human actions are not directly transmitted from subject to object, but are moderated through the use of technological tools. Activity Theory is useful for this study because it provides an overall significance of technological tools in engineering education [11]. Activity Theory has been used previously to examine the effect of technologies in engineering education [12, 13]. An expanded model of human activity was developed to highlight the collaborative nature of human activity by adding social interaction to Vygotsky's original model of human activity [14, 15].

Digital technologies tools can be used to improve learning activities [2]. However, if a new technology is obtainable, over which the students have proficiency; and not the lecturer, this may require new practices within the activity system for the object of high-quality learning to be achieved, as reported by [16]. Digital technology availability in the learning environment may lead to lecturers having less control over students. The analysis is supported by Christensen's Disruptive Technology theory [17] in the sense that new technology can disrupt traditional methods and sometimes, the new technology can be used to change the old practice [18] reported by [16]. Digital technology availability in the learning environment may lead to lecturers having less control over students. The analysis is supported by

Christensen's Disruptive Technology theory [17] in the sense that new technology can disrupt traditional methods and sometimes, the new technology can be used to change the old practice [18].

B. A selective case study

This study focuses on engineering faculty in FUOYE as a case study to identify and examine the role of disruptive technologies on learning and teaching. FUOYE a selected case study is a Federal university base in Nigeria and it has recognition and reputation for excellence in teaching, learning, research, community services, educating, and mentoring future engineers who can complete favourably in a competitive global market to solve industry 4.0 related challenges. The faculty of Engineering is one of the eleven faculties of the university as shown in Figure 1, with over 3200 enrolled engineering students, which comprises 87% Undergraduate students, 12 % MSc students and 1% PhD students. There are 98 faculty tenure staff and 7 Engineering departments which are: Agriculture and bioresources, Civil, Computer, Electrical and Electronics, Materials Engineering, Mechanical, and Mechatronics Engineering.

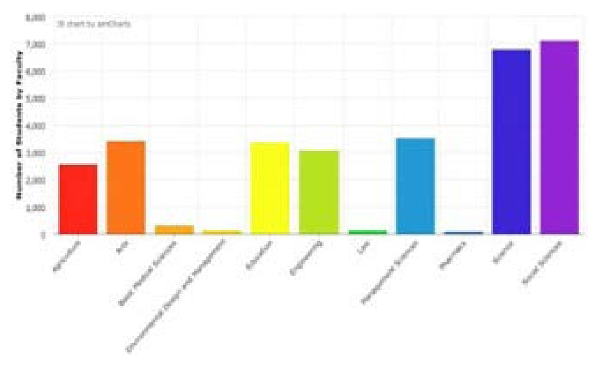

FIGURE 1: *A total number of students registered in FUOYE per faculty (Source: https://manager. ecampus.fuoye.edu.ng/analytical-dashboard, July 2022)*

II. RESEARCH METHODOLOGY

This section explains the methods followed to collect the response of students and lecturers in the engineering faculty towards the investigation of the use of disruptive technologies in engineering education. Quantitative and qualitative data were used for this study. The research methodological design is as follows:

A. Students' survey

The survey consisting of three main parts was conducted targeting only engineering students. The survey aimed at the quantitative evaluation of the student's preferences towards the use of technological tools for learning. The first stage intends to identify the different types of disruptive technologies that are available to the students for learning. The second factor is to determine the students' preferred learning technological tools while the third consideration is to investigate the reasons for the students' technology tool learning preference. The outcome of the survey study was analysed to determine the students' best preference for technological tools for learning.

B. Students' interviews

A set of interviews were conducted for the engineering students in the 7 engineering Departments who selected the five topmost technological tools for learning. The interviews aimed to gain insight into the students' reasons for selecting those 5 learning technologies.

C. Lecturers' interviews

The Interview was focused on the head of departments (HOD). The aim of the interview was to investigate the reason for the lecturers' adoption of other technologies not approved by the management for teaching. The interviews also sought the lecturers' challenges and their recommendations based on their teaching experience with disruptive teaching platforms.

D. Research Questions

The answers to the following research questions provide insight into this study:

i. What are the various types of disruptive technologies that are commonly used by students for learning?
ii. What are the students' preferred technology tools for learning?
iii. What are the reasons for the student's choice of technological learning tools?
iv. Which technology platform is preferred by the lecturers?

III. RESULTS AND DISCUSSION

This section presents the results of the surveys and interviews and their discussion.

A total of 450 responses were gathered from the students' survey questions in section 2.1, which is estimated as 14% of the entire engineering faculty population. Statistically, this is a good representation of the faculty population. Arising from the results, 87% of the respondents are undergraduate students, while 13% are postgraduate students. Students preferred choice of technology for learning and information sharing was determined by asking students to write their frequently used learning technology tools from the list of 17 identified disruptive technological tools got from the literature survey which are listed as follows: WhatsApp, TikTok, Clubhouse, Twitter, Reels, Spotify Greenroom/Spotify, Twitch, Substack, Reddit, Telegram, Polywork, Triller, YouTube, Google form, Zoom, and Instagram. The observation from the respondents shows that the following 5 disruptive technological tools were the major technological options preferred by the students: (a) WhatsApp, (b) YouTube, (c) Zoom, (d) Google form, (e) Twitter. Table 1 shows the moderate balance of the 450 respondents who selected the 5 topmost preferred learning tools across the 7 departments in the faculty of engineering.

The 450 respondents shown in Table 1, were asked to justify the reason for selecting their five learning topmost technology preferred tools from the seventeen identified disruptive technological tools. The student' quantitate responses were examined and classified into three main sets; Psychology, Technological, and Pedagogical reasons. Figure 2 depicts the reasons that influence students' selection of preferred learning technological tools. The pedagogical factor rated the highest reason for the selection of the technological learning tools with 46% this is followed by the technological factor with 30% and the least factor is psychology with 24%. The results follow the same trend as the previous studies [19] The 7 interviewed lecturers use other technological teaching tools different from the university technological provision. They supported and accepted the students preferred learning technological tools. However, they have common challenges of poor internet connection and regular electricity failure, and lack of good learning and teaching environment as limiting factors for online teaching. The study outcome is similar to the previous research reports for online education challenges [20-24].

TABLE 1: *Respondents' responses per Department*

S/No.	Department	No. of Response
1	Agric. & Bio Engineering	45
2	Civil Engineering	72
3	Computer Engineering	81
4	Elect. & Electro. Engineering	76
5	Materials Engineering	36
6	Mechanical Engineering	68
7	Mechatronics Engineering	72

Going forward, the interviewed lecturers recommended that in-house training on information and communication technology should be organised for the lecturers on how best they can prepare their lecture notes, asses students' performance and review students learning rate.

The 7 interviewed lecturers use other technological teaching tools different from the university technological provision. They supported and accepted the students preferred learning technological tools. However, they have common challenges of poor internet connection and regular electricity failure, and lack of good learning and teaching environment as limiting factors for online teaching. The study outcome is similar to the previous research reports for online education challenges [20-24]. Going forward, the interviewed lecturers recommended that in-house training on information and communication technology should be organised for the lecturers on how best they can prepare their lecture notes, assess students' performance and review students learning rate.

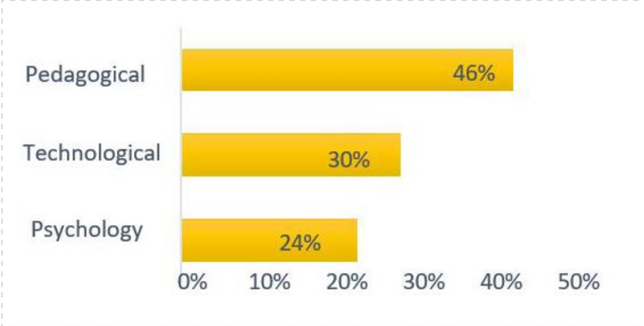

FIGURE 2: *Factors that influenced students 'choice.*
Table 2 depicts the profile of the lecturers that were interviewed.

TABLE 2: *Profile of lecturers interviewed*

Department	Department	Gender	Teaching Experience
Agric. & Bio Engineering	Professor	Male	19 years
Civil Engineering	Associate Professor	Male	16 years
Computer Engineering	Senior Lecturer	Male	10 years
Elect. & Electro. Engineering	Professor	Male	20 years
Materials Engineering	Senior Lecturer	Male	12 years
Mechanical Engineering	Assocaite Professor	Male	15 years
Mechatronics Engineering	Associate Lecturer	Male	13 years

IV. CONCLUSION

Arising from the surveys and interviews, there is no evidence to suggest that a wide range of technological tools is being used to support learning and teaching in the faculty of engineering. Instead, a small range of technologies is being used for a wide range of tasks The five topmost technological tools by students are WhatsApp, YouTube, Zoom, Google form, and Twitter respectively. As Christensen's theory predicts, people prefer to use technologies that are easy to use and cost-free. If technology is kept simple, people are more likely to make use of it. [25] justified why particular technologies attract many users. Data from the survey questions, and interviews suggested that both students and lecturers preferred easy technology tools. From an Activity Theory perspective, WhatsApp is a tool that disrupts the rules node of the activity triangle, and the division of labour node. Students and lecturers are not solely depending on LMS for learning and teaching, but preferred WhatsApp, YouTube, Zoom, Google form, and Twitter are used by both lecturers and students for teaching and learning. There are diverse technology tools for acquiring knowledge, and they are easy to use, cheap and convenient. This study identifies a disagreement between learning technologies made available by LMS, and technologies used in practice by students and lecturers. However, the use of technologies outside LMS does not provide an opportunity for the university management to monitor and evaluate learning and teaching activities.

REFERENCES

[1] J. Frizzo-Barker, P. A. Chow-White, P. R. Adams, J. Mentanko, D. Ha, and S. Green, "Blockchain as a disruptive technology for business: A systematic review," International Journal of Information Management, vol. 51, p. 102029, 2020.

[2] R. Castro, "Blended learning in higher education: Trends and capabilities," Education and Information Technologies, vol. 24, pp. 2523-2546, 2019.

[3] I. Mergel, N. Edelmann, and N. Haug, "Defining digital transformation: Results from expert interviews," Government information quarterly, vol. 36, p. 101385, 2019.

[4] M. Flavin and V. Quintero, "UK higher education institutions' technology- enhanced learning strategies from the perspective of disruptive innovation," Research in Learning Technology, vol. 26, 2018.

[5] A. Oke and F. A. P. Fernandes, "Innovations in teaching and learning: Exploring the perceptions of the education sector on the 4th industrial revolution (4IR)," Journal of Open Innovation: Technology, Market, and Complexity, vol. 6, p. 31, 2020.

[6] A. Tarabasz, M. Selaković, and C. Abraham, "The classroom of the future: Disrupting the concept of contemporary business education," Entrepreneurial Business and Economics Review, vol. 6, p. 231, 2018.

[7] J. Reich, Failure to disrupt: Why technology alone can't transform education: Harvard University Press, 2020.

[8] C. Wamsler, "Education for sustainability: Fostering a more conscious society and transformation towards sustainability," International Journal of Sustainability in Higher Education, vol. 21, pp. 112-130, 2020.

[9] N. A. Podymov, M. A. Nikoghosyan, A. N. Stolyarova, S. V. Narutto, N. A. Mashkin, S. E. Martynenko, et al., "University new educational reality in disruptive technologies context," Journal of Environmental Treatment Techniques, vol. 7, pp. 664-668, 2019.

[10] Y. Engeström, "Expansive learning: Towards an activity- theoretical reconceptualization," in Contemporary theories of learning, ed: Routledge, 2018, pp. 46-65.

[11] C. Hixson and M. C. Paretti, "Unpacking Why Engineering Faculty Members Believe Entrepreneurship Is Valuable for Engineering Education," Advances in Engineering Education, vol. 7, p. n1, 2018.

[12] R. Hite and C. J. Thompson, "Activity Theory as theoretical framework for analyzing and designing global K-12 collaborations in engineering: A case study of a Thai-US elementary engineering project," Journal of International Engineering Education, vol. 1, p. 5, 2019.

[13] C.-J. Chung, G.-J. Hwang, and C.-L. Lai, "A review of experimental mobile learning research in 2010–2016 based on the activity theory framework," Computers & education, vol. 129, pp. 1-13, 2019.

[14] K. Yamazumi, Activity theory and collaborative intervention in education: Expanding learning in Japanese schools and communities: Routledge, 2021.

[15] Y. Engeström and A. Sannino, "From mediated actions to heterogenous coalitions: four generations of activity-theoretical studies of work and learning," Mind, Culture, and Activity, vol. 28, pp. 4- 23, 2021.

[16] M. Hernández-de-Menéndez, A. Vallejo Guevara, J. C. Tudón Martínez, D. Hernández Alcántara, and R. Morales- Menendez, "Active learning in engineering education. A review of fundamentals, best practices and experiences," International Journal on Interactive Design and Manufacturing (IJIDeM), vol. 13, pp. 909-922, 2019.

[17] W. Liu, R.-h. Liu, H. Chen, and J. Mboga, "Perspectives on disruptive technology and innovation: Exploring conflicts, characteristics in emerging economies," International Journal of Conflict Management, 2020.

[18] S. J. Barnes, "Information management research and practice in the post-COVID-19 world," International Journal of Information Management, vol. 55, p. 102175, 2020.

[19] I. Abakumova, I. Bakaeva, A. Grishina, and E. Dyakova, "Active learning technologies in distance education of gifted students," International Journal of Cognitive Research in Science, Engineering and Education, vol. 7, p. 85, 2019.

[20] E. E. Rotas and M. B. Cahapay, "Difficulties in Remote Learning: Voices of Philippine University Students in the Wake of COVID-19 Crisis," Asian Journal of Distance Education, vol. 15, pp. 147-158, 2020.

[21] S. Dutta and M. K. Smita, "The impact of COVID-19 pandemic on tertiary education in Bangladesh: students' perspectives," Open Journal of Social Sciences, vol. 8, p. 53, 2020.

[22] K. A. Bello, O. A. Oyelaran, B. O. Bolaji, O. Awogbemi, O. Amu, A.O. Adeodu, et al., "Assessment of Adaptation of E- learning in Engineering Education in Nigeria universities," in 2021 World Engineering Education Forum/Global Engineering Deans Council (WEEF/GEDC), 2021, pp. 169-176.

[23] K. A. Bello, O. A. Oyelaran, B. O. Bolaji, O. Awogbemi, A. O. Adeodu, and A. Busari, "Evaluation of engineering students output during covid-19 pandemic lockdown," in 2021 World Engineering Education Forum/Global Engineering Deans Council (WEEF/GEDC), 2021, pp. 177-182.

[24] A. A. Bayor, M. Brereton, L. Sitbon, B. Ploderer, F. Bircanin, B. Favre, et al., "Toward a competency-based approach to co-designing technologies with people with intellectual disability," ACM Transactions on Accessible Computing (TACCESS), vol. 14, pp. 1-33, 2021.

Technical papers

Online and remote pedagogy: Technological innovations in an undergraduate chemical engineering module

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Abstract — **The COVID-19 lockdown adversely impacted the continuation of syllabi. Most pedagogical activities were halted as instructors lacked the knowledge, revised pedagogy, or resources to transition and continue these activities online and remotely. The study aims to outline procedures that can simulate contact lessons and assessments whilst minimizing student dishonesty and maximizing instructor mediation per Feuerstein's theory of mediated learning. Furthermore, the study aims to demonstrate the functionality of Blackboard in teaching and assessment activities. The study seeks to answer the question of what comprehensive strategies can be used to offer students an effective alternative to classroom lectures and assessments, in which student integrity is maintained, and instructor mediation is optimized? Blackboard was used as the learning management system in a second-year undergraduate chemical engineering module in 2020. Simulated lectures were created using the text-to-speech application. Discussion forums were created to allow students to address their queries and ask questions. Informal tutorial sessions were held over WhatsApp. Advanced adaptive releases ensured that students completed lectures per the outlined chronology. Tests were implemented in Blackboard using various measures to minimize student dishonesty. These measures included randomized question sets, and numerical variations in calculation questions. The "Invigilator" application was also piloted to maintain assessment integrity by recording audio and preventing communication during the tests. The results showed that students were highly satisfied with the adopted pedagogy and assessment practices in this study. The online pedagogy ensured that students effectively processed the module content with adequate mediation from the instructor and tutors. Based on these results, an empirical framework was formulated to adapt traditional contact teaching and assessment approaches to online and remote practices. Despite the end of the lockdown, online and remote pedagogical practices are still used as they save time and travel costs for students and instructors. This framework can be universally applied to optimize and streamline current strategies to ensure practical, effective, and honest assessments online and remotely.**

Keywords — online teaching; online assessment; text to speech application; Blackboard; WhatsApp; lecture simulation; revised pedagogy; Keller Plan; Feuerstein's theory of mediated learning

I. INTRODUCTION

The mandatory COVID-19 lockdown disrupted conventional pedagogical procedures, as educational institutions were not well equipped with the resources and expertise to conduct teaching and assessment online and remotely. This paper presents an evaluation of the combined technologies: Blackboard, WhatsApp and the Invigilator application to complete the syllabus of a second-year Chemical Engineering module at a South African university during the lockdown period.

Blackboard is a learning management system with global applications in teaching and learning with the advancement of technology [1]. In previous years, Blackboard was used as part of a blended learning approach in the second-year Transfer Processes module within the Faculty of Engineering and the Built Environment at the South African university. This blended learning approach involved student interactions with the lecturer through Blackboard. Students watched lectures and completed tutorials on Blackboard whilst receiving support from the lecturer and tutors during allotted lecture and tutorial times. Similarly, the module tests were conducted through Blackboard under examination conditions in a computer lab. However, post- lockdown, the module was conducted remotely, and Blackboard became the primary means of remote teaching and assessment. Furthermore, WhatsApp was used to conduct remote tutorial discussions between the tutor and the students, while the Invigilator application ensured remote assessment integrity. Technological advancements are gradually altering traditional approaches to teaching and learning [2]. Within the previous two decades, education trends have evolved towards web-based and blended instruction, where web-based instruction replaces components of face-to-face instruction [1]. Therefore, it is ironic that online education is still considered in the infancy stage [3, 4], despite several reports of great potential [5-8]. Although Blackboard has been reported as a pedagogical support tool [5, 9, 10], there is limited information detailing the creation of optimal virtual learning environments using Blackboard to simulate contact learning.

During the COVID-19 pandemic, many educators had to find alternate means of teaching within limited timeframes. Without the necessary expertise in navigating online teaching and assessment, many education institutions ceased activities until the lockdown regulations relaxed. As such, the aims of this study are fourfold. Firstly, this study aims to outline a detailed set of procedures to simulate teaching and assessment activities, including lectures, discussions, tutorials, assignments, tests, and the semester examination using Blackboard. Secondly, this study aims to develop guidelines to minimize student dishonesty in online and remote assessments using Blackboard strategies and the Invigilator application. Thirdly, this study aims to develop an empirical framework to transition from contact to online and remote teaching and learning. Finally, this study aims to critically analyze student responses to the proposed online pedagogy after a completed semester to determine its effectiveness from a student perspective.

It is hypothesized that the combined technologies can effectively simulate contact teaching and learning such that the module could be completed wholly online and remotely. This hypothesis implies that all the traditional elements of a typical university module (lectures, tutorials, and assessments) can be fully achieved using the combined technologies.

II. LITERATURE REVIEW

A. Blackboard for Online Teaching and Learning

Blackboard as a learning management system is well received and documented in the literature. Blackboard was used to create and evaluate a virtual learning environment for a nursing module [5]. Independent and self-directed learning was observed, and students appreciated the resources available on Blackboard. This finding was similar to the findings of Alenezi and Shahi [5] in which Blackboard enabled virtual lectures to save time and decrease travel expenses.

The research of Liaw [2] found perceived self- efficacy to influence students' satisfaction with Blackboard. This finding aligns to the feeling of competence and individual uniqueness associated with Feuerstein's repertoire of mediated learning [10]. Furthermore, the effectiveness of e- learning was influenced by multimedia instruction, interactive learning activities, and e-learning system quality. Building on the study of Liaw [2], the study of Heirdsfield et al. [8] determined both student and teacher perspectives of Blackboard. Like the findings of Liaw [2], students viewed Blackboard favourably concerning the accessibility of learning materials. Like the findings of Rye [9] and Teo et al. [6], students preferred interactions with each other via discussion forums. However, some instructors were reluctant to promote lecture streaming [9]. Unlike the research of Banday et al. [3], which found that lacking infrastructure bottlenecked e-learning, the study of Heirdsfield et al. [8] attributed the staff reluctance to a resistance to change. To overcome this challenge, staff training, and support were recommended [12].
The research of Hart et al. [12] found that Blackboard Collaborate enabled the effective connection of students with the educator. However, this pilot identified an initial wariness to the technology. This wariness was also found in the study of Banday et al. [3]. However, proper training coupled with the immediate application of new skills regarding the technology made students and educators more comfortable in its use.

B. Online Learning Perceptions

The research of Mishra et al. [13] and Picciano [14] recommended multi-modal approaches to achieve course content objectives during online learning during the COVID- 19 lockdown. However, funding is required for reliable communication tools, high-quality digital academic experience, and to promote technology-enabled learning [14]. The research of Radha et al. [15] found that e-learning gained popularity during the lockdown. However, this perception was limited to instances involving real-time virtual communication between students and educators. This finding is validated by the fact the intentionality of the instructor and the associated reciprocity of the student is best achieved during live lessons [10]. These findings contrast those of [9] where students appreciated online interactions via written discussion forums. This contrast could be attributed to a younger student population in the study of Radha et al. [15] that prefers contact lessons than tertiary students. Despite this, online learning can be made suitable for everyone when required [16]. Furthermore, online learning is flexible as it can be performed asynchronously.

Despite the informative findings of Mishra et al. [13] and Radha et al. [15], these studies failed to capture a South African student perspective of online learning [16]. The perspectives of [16] described the online learning challenges experienced by South African tertiary students during the COVID-19 lockdown. Not all students have laptops or internet connections, especially those in rural areas. The University of South Africa is the only South African University that aids online and remote learning by posting hard copy learning materials to students [16]. It is interesting that [16] considered the perceived inability of South African telecommunications to provide constant uniform connectivity as an injustice to students during the lockdown. Furthermore, poor mental health conditions due to domestic violence could not be overlooked. These perspectives are realistic and must be considered when implementing online teaching and assessment strategies. The pedagogy of care must be applied to ensure that students do not lag in their studies due to socio- economic issues beyond their control.

C. The Theory of Structural Cognitive Modifiability

Feuerstein theorized that adequate mediation by the teacher can improve the competence of a student by structurally modifying their cognitive abilities [10]. The theory states that mediation is required in three forms to alleviate learning deficiencies in the student: intentionality and reciprocity, mediation of meaning, and transcendence. Each of the mediated learning parameters should be implemented in modern teaching approaches.

D. Frameworks for Online Teaching and Assessment

The study of Baran and Correia [11] offered a skills development framework for transitioning to online pedagogical practices based on three support activities at teaching, community, and organization levels.

The research of Khoo and Cowie [17] presented an empirical framework to implement an online learning community. The framework depicts learning as a mediated, situated, distributed, goal-directed, and participatory activity. The study of Leslie [18] designed an online faculty development pilot course using the "Trifecta of Student Engagement," which proposes that students engage with course content, peers, and their instructor to achieve optimal engagement in a course.

The research of Picciano [14] examined online education theoretical frameworks. Upon reviewing various theories applying to online education, an integrated Multi- modal Model for Online Education was proposed, and can be consulted when developing online empirical frameworks to transition to online pedagogy in the South African context.

III. METHODOLOGY

A. Conducting Online Lessons

Adaptive release advanced was used to release content to the students in the order required to simulate contact lectures. The Blackboard lesson sequence was enabled using the adaptive release advanced tool. A comparison of the online pedagogical approaches used in this study against traditional ones is presented in Table 1.

TABLE 1: *Traditional vs online pedagogies*

Step	Traditional Lesson	Online Lesson
1	• A physical class presence is required per a timetable. • Students are seated, sign the attendance register, and listen to the instructor. • An attendance mark may be allocated.	• Students can join the class remotely per a timetable. • Students must log into Blackboard and sign the attendance register. • A mark may be allocated to encourage attendance.
2	• Students must be attentive as the educator delivers the lesson. • Lectures generally last one or two hours, with a break if required.	• Students can watch the lecture video online, look at the PowerPoint presentation slide show, read the transcripts, or listen to individual audio clips. • The video duration is around 10 minutes. • The video contains simulated speech to explain the content, allowing students to pause, rewind or forward as desired.
3	• Some students may ask questions to clarify points of uncertainty. • The lecturer may ask questions to be answered by some students to encourage engagement during the lecture.	• Questions are saved for the end of the lesson and asked using the discussion board. • The interactive discussion board allows communication between students and other students and between students and the educators. • Students participate in the discussion before proceeding to the next step. • Students must answer questions covering the lecture in the next step.
4	• Tutorial questions are issued to the students. • Students must complete the questions within a specified timeframe. • Students can clarify uncertainties from the tutorial questions with the tutors.	• Students must complete short tutorial questions, encouraging re-engagement with the lecture material if necessary. • These are followed by extended, more traditional tutorial questions. • Adaptive release advanced is used to ensure that the students perform satisfactorily in each question before proceeding to the next. • A WhatsApp group enables the students to communicate with the tutors. • Pictures of calculations and other content are sent to the tutors to seek clarification.
5	Some students may prepare for the following lecture.	Every student must answer a short tutorial question about the following lecture, encouraging independent research.

The online lesson approach is aligned with the Keller Plan of Personalized System of Instruction (PSI) [19] where students must master the learning material with tutor support and attend scheduled (virtual) lectures. Furthermore, the online lesson approach captures the intentionality and mediation of meaning aspects of Feuerstein's theory of mediated learning [10].

B. Conducting Online Assessments

Prior to the lockdown, the module was based on a blended learning approach. The module is comprised of two tests and an examination. The first test was taken online. This status quo involved students seated in the LAN and logging in to the Blackboard assessment webpage to submit their test responses under test conditions. The test questions were printed and distributed to the students along with pages for rough work. The rough work pages had to be submitted at the end of the timed session. The remote assessments (test 2 and the examination) followed a similar approach, except that questions were presented in the online assessment, rough work calculations were photographed and submitted online, and assessment integrity methods indicated in Section 3.1.2 were applied to compensate for the lack of invigilation.

C. Maintaining Assessment Integrity

In 2020, three strategies minimized student dishonesty in the online assessments. Firstly, anti- collaboration techniques were implemented on Blackboard. Secondly, questions of the higher cognitive rungs of Bloom's taxonomy were used to ensure knowledge application. Thirdly, the allocated durations of the assessments were similar to conventional contact assessments with a reasonable allowance to submit the answer files. In 2021, the Invigilator application monitored each student via their mobile devices during the online assessments. The application used random audio recordings, student identity validation, and blocked written communication applications, such as WhatsApp. The two strategies are outlined below.

1 Blackboard Techniques

Considering that the online assessments were undertaken remotely, there was still potential for student dishonesty during the assessments. The following mitigation factors were successfully implemented in Blackboard to mitigate these challenges:

- Students were required to digitally sign an integrity policy.
- Non-identical questions were issued to the students by varying the questions, such that each student would have an individual assessment.
- Only one question could be attempted at a time (using the advanced adaptive release tool) to prevent students from collaborating for the questions they could not answer. Back-tracking was also disabled to prevent students from resubmitting solutions at a later stage.
- Students had to upload pictures of their calculation workings to Blackboard before proceeding to the next question. The calculation workings were checked against the answer uploaded on Blackboard.

2 The Invigilator Application

The Invigilator application was piloted in the second semester. The application validated the student's identity by cross checking randomly requested selfies against the pictures on their identity document or student card. The application also randomly recorded audio files to detect verbal collaboration. Furthermore, the application blocked written communication applications, such as WhatsApp during the assessment.

D. Quantifying Student Perceptions to the Revised Pedagogy

Student responses to the revised pedagogy was used to quantify the delivery effectiveness. Hence, two module evaluation surveys were issued to the students. A Likert scale quantified the student responses. A score of 1 represented a strong disagreement, while a score of 4 indicated a firm agreement. Evaluation 1 contained statements relating to the module, while Evaluation 2 contained statements relating to the instructor's contributions to the module using the online tools.

IV. RESULTS AND DISCUSSION

A. Effect of the Revised Pedagogy on Student Performance

The improved student performance in 2021 relative to 2019 and 2020 can be attributed to a few factors:

- The students were more comfortable taking the assessments in their homes and therefore made fewer mistakes caused by nervousness.
- There was no need to get dressed and commute to the test venue, implying more time to prepare for the assessments.
- The students were not confined to the scheduled tutorial times. Hence, they were able to clarify their uncertainties at any time using the WhatsApp tutorial group. The entire class could benefit from any single query as the tutor's clarifications were visible to everyone. This difference is notable as a tutor's clarifications are not necessarily heard by the entire class in a contact tutorial session.
- The lecture slides for the test 2 content were revised by identifying the learning outcomes in which the students historically underperformed and improving the corresponding content. Consequently, the student performance was improved in test 2 and the examination.

B. Student Perspectives of the Revised Pedagogy

The student perspectives were quantified in the module evaluation. A 64% participation rate was recorded.

1 Evaluation 1

The overall score for evaluation one relating to the module exceeded the Department average by 10.9%. This finding indicated the effectiveness of Blackboard and can be further validated by the literature [5, 3, 9, 10, and 12].

The averages for all seven statements for this course are significantly larger than the other averages. Of significance was the student response for statement 3, which scored 91.25% (Figure 1). This finding emphasized the firm belief that a variety of learning activities helped the class achieve the module learning outcomes. In addition, the discussion boards and lecturer consultations comprised the critical elements in the multi-modal model for online education [14]. This strategy ensured that students had multiple opportunities to absorb the knowledge and that the knowledge gaps were addressed, as supported by previous research [21].

FIGURE 1: *Response to statement 3 of evaluation 1: "A variety of learning activities were used to help me achieve the module learning outcomes."*

Another notable response was that for statement 6 (Figure 2), relating to the variety of assessment tasks used in the module. Concerning Bloom's taxonomy, various assessment techniques are needed to achieve knowledge internalization and application in students [22]. Blackboard was ideal for this purpose as it offered 17 different assessment methods.

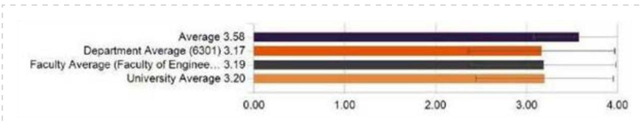

FIGURE 2: *Response to statement 6 of evaluation 1: "A variety of assessment tasks were used in the module (e.g., quizzes, short exercises, paragraphs, essays)."*

2 *Evaluation 2*

As with the results for evaluation 1, evaluation 2 exhibited a greater score than the Department (by 9.7%). This finding validated the online methodology.

The averages for all nine statements for this course were significantly larger than the other averages. The response received for statement 3 in evaluation 2 (Figure 3) was significant as it related to the tools and resources used to support online learning [3, 5, 6, 8, and 10]. The response was greater than the Department average by 9.9% and greater than the University average by 9.1%, further validating the online pedagogical approach.

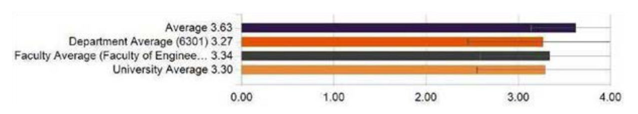

FIGURE 3: *Response to statement 3 of the second student evaluation: "The lecturer used tools and resources that supported my learning (for example, online discussion forums, WhatsApp, Blackboard Collaborate, tutorials)."*

Statement 4 of evaluation 2 related to the accessibility of the learning materials. Again, the response exceeded the Department, Faculty, and University averages. This finding validated the systematic method of creating folders to store the learning material on Blackboard in line with the learning units outlined in the learning guide. The storage of learning material in the sequence appearing in the learning guide enabled easy access to students and reinforced the chronological element of "building on" content covered in previous learning units.

Statement 8 of evaluation 2 related to the use of online tools and technology in explaining concepts. An overwhelmingly positive response was observed (Figure 4) This finding indicated the effectiveness of the online discussion forums on Blackboard. Furthermore, the discussion boards practically achieved student-student and student- instructor interactions.

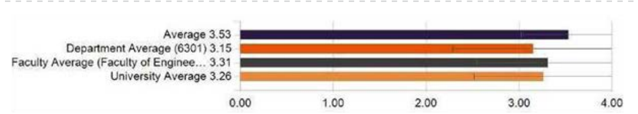

FIGURE 4: *Response to statement 8 of the second student evaluation: "The lecturer used online tools and technology to explain concepts (for example online discussion forums, WhatsApp, Blackboard Collaborate)."*

The informal WhatsApp group to facilitate tutorials could have also contributed towards the exceptional score received. This finding could be attributed to the fact that students rely on tutor assistance to excel in their studies [22]. Despite not being able to meet the tutors in person, the WhatsApp group connected them to the tutors, as aligned with previous research [23].

V. CONCLUSIONS

There is a need for a unified framework to guide the transition of traditional contact pedagogical methods in South African education institutions to online pedagogical methods to save time and money associated with travel costs. Furthermore, online pedagogical approaches can supplement traditional learning approaches by offering a greater degree of mediation to support students. Much research has been undertaken on global online teaching methodologies. However, the procedures presented in this research, ultimately culminating in the proposed empirical framework, is based on South African students' unique challenges and preferences. Despite accounting for the South African education context (as a form of decolonization), the recommended framework can be adapted to educational institutions globally. In addition, the proposed framework encompasses the best practices recommended in the literature and is aligned to future assessment principles.

The implication of this study is that the proposed framework (Figure 5) can be applied by any education institution to facilitate the transition to online education, and to any class size. If larger class sizes are encountered, then multiple WhatsApp tutorial groups can be used. Despite this research being conducted when the COVID-19 lockdown restrictions were at their peak, the findings are still applicable as many education institutions maintain online teaching and assessments as a form of voluntary social distancing.

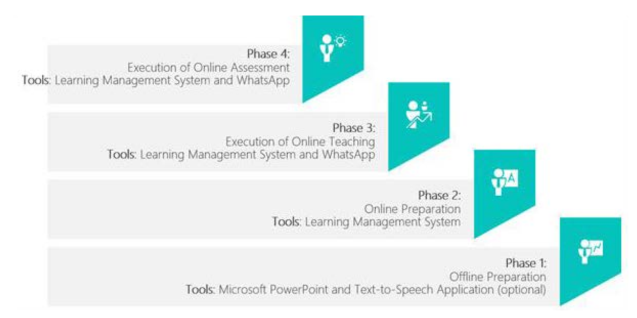

FIGURE 5: *Proposed Empirical Framework for online teaching and assessment*

For successful implementation of the proposed framework, students and educators require access to computers, the internet, the preferred learning management system, and associated technologies, such as WhatsApp and the Invigilator application. Training of staff and students on the preferred learning management system is recommended [12]. The framework comprises threefold student interactions with the learning material, other students, and the educator. Hence the proposed framework ensures optimal module engagement as per the Trifecta of Student Engagement framework [18]. The framework also comprises the key elements of the multi-modal model for online education [14]. These considerations align well with the intentionality and reciprocity and the mediation of meaning required to structurally modify the cognitive ability of students per Feuerstein's theory of mediated learning [10].

Although Blackboard was the learning management system on which this study was based, the recommended empirical framework can be adapted to institutions using other learning management systems. As such, the first two aims of this study were met. In this study, all the traditional elements of a typical university module (lectures, tutorials, and assessments) were fully achieved using Blackboard, WhatsApp, and the Invigilator application. Hence, the research question was answered.

Maintaining the quality and standard of education during online assessments is vital. Hence, the two assessment integrity measures using Blackboard strategies and the Invigilator application provide a cost-effective, and easily implementable solution. Hence the third aim of this study was met.

The success of the online pedagogical approach is characterized by students' overall satisfaction. It was notable that all students displayed an overall satisfaction with the methods used to conduct the fully online module over the semester. Hence, the fourth aim was met. The challenges and opportunities encountered in the study are not specific to engineering modules and the findings can be universally applied.

ACKNOWLEDGMENT

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REFERENCES

[1] Wells P., Fieger, P. and de Lange, P. (2005) 'Integrating a virtual learning environment into a second year accounting course: Determinants of overall student perception'. Proceedings of the AAA Annual Meeting, San Francisco.F

[2] Liaw, S. S. (2008) 'Investigating students' perceived satisfaction, behavioral intention, and effectiveness of e-learning: A case study of the Blackboard system', Computers & Education, 51(2), pp. 864–873. doi: https://doi.org/10.1016/j.compedu.2007.09.005.

[3] Banday, M. T., Ahmed, M. and Jan, T. R. (2014) 'Applications of e- Learning in Engineering Education: A Case Study', Procedia - Social and Behavioral Sciences, 123, pp. 406–413. doi: https://doi.org/10.1016/j.sbspro.2014.01.1439.

[4] Green, S. M., Weaver, M., Voegeli, D., Fitzsimmons, D., Knowles, J., Harrison, M. and Shephard, K. (2006) 'The development and evaluation of the use of a virtual learning environment (Blackboard 5) to support the learning of pre-qualifying nursing students undertaking a human anatomy and physiology module', Nurse Education Today, 26(5), pp. 388–395. doi: https://doi.org/10.1016/j.nedt.2005.11.008.

[5] Alenezi, A. M. and Shahi, K. K. (2015) 'Interactive e-learning through Second Life with Blackboard Technology', Procedia - Social and Behavioral Sciences, 176, pp. 891–897. doi: https://doi.org/10.1016/j.sbspro.2015.01.555.

[6] Teo, H. J., Johri, A. and Lohani, V. (2017) 'Analytics and patterns of knowledge creation: Experts at work in an online engineering community', Computers & Education, 112, pp. 18–36. doi: https://doi.org/10.1016/j.compedu.2017.04.011.

[7] Munusamy, S., Osman, A., Riaz, S., Ali, S. and Mraiche, F. (2019) 'The use of Socrative and Yammer online tools to promote interactive learning in pharmacy education', Currents in Pharmacy Teaching and Learning, 11(1), pp. 76–80. doi: https://doi.org/10.1016/j.cptl.2018.09.021.

[8] Heirdsfield, A., Walker, S., Tambyah, M., and Beutel, D. (2011) 'Blackboard As An Online Learning Environment: What Do Teacher Education Students And Staff Think?.' Australian Journal of Teacher Education, 36(7). http://dx.doi.org/10.14221/ajte.2011v36n7.4

[9] Rye, S. (2014) 'The educational space of global online higher education.' Geoforum. 51. 6–14. 10.1016/j.geoforum.2013.09.011.

[10] Tan, O., S. (2003) 'Mediated learning and pedagogy: Applications of Feuerstein's Theory in twenty-first century education' National Institute of Education.

[11] Baran, E. and Correia, A. (2014) 'A Professional Development Framework for Online Teaching.' TechTrends. 58. 10.1007/s11528- 014-0791-0.

[12] Hart, T., Bird, D. and Farmer, R. (2019) 'Using blackboard collaborate, a digital web conference tool, to support nursing students placement learning: A pilot study exploring its impact', Nurse Education in Practice, 38, pp. 72–78. doi: https://doi.org/10.1016/j.nepr.2019.05.009.

[13] Mishra, L., Gupta, T. and Shree A. (2020) 'Online teaching-learning in higher education during lockdown period of COVID-19 pandemic', International Journal of Educational Research Open, 2020, 100012, ISSN 2666-3740, https://doi.org/10.1016/j.ijedro.2020.100012.

[14] Picciano, A. G. (2017) 'Theories and frameworks for online education: Seeking an integrated model.' Online Learning, 21(3), 166-190. doi: 10.24059/olj.v21i3.1225

[15] Radha, R., Mahalakshmi, K., Kumar, S. V. and Saravanakumar, A. R. (2020) 'E-Learning during Lockdown of Covid-19 Pandemic: A Global Perspective.' International Journal of Control and Automation. 13. 1088-1099.

[16] Mnguni, L. (2020) 'Online learning in the lockdown is far from ideal', John McCann/ M&G, 8 April. Available at: https://mg.co.za/article/2020-04-08-online-learning-in-lockdown-is-far-from-ideal/ (Accessed: 7 December 2020)

[17] Khoo, E. and Cowie, B. (2011) 'A framework for developing and implementing an online learning community.' Journal of Open, Flexible and Distance Learning. 15. 47-59.

[18] Leslie, H. (2019) 'Trifecta of Student Engagement: A framework for an online teaching professional development course for faculty in higher education.' Journal of Research in Innovative Teaching & Learning. 13. 10.1108/JRIT-10-2018-0024.

[19] Eyre, H. L. (2007) 'Keller's Personalized System of Instruction: Was it a Fleeting Fancy or is there a Revival on the Horizon?', The Behavior Analyst Today, 8, 3, pp. 317–324. doi: http://dx.doi.org/10.1037/h0100623

[20] Massara, V. (2020) 'The Ladder Approach: Bloom's Taxonomy for Online Courses', eLearning Industry, 8 July 2020. Available at: https://elearningindustry.com/blooms-taxonomy-for-online-courses- ladder- approach (Accessed: 26 July 2020).

[21] Nisbet, J. T., Haw, M. D. and Fletcher, A. J. (2014) 'The role of tutors in peer led teaching', Education for Chemical Engineers, 9(1), pp. e15– e19. doi: https://doi.org/10.1016/j.ece.2013.12.001.

[22] Stathopoulou, A., Nikoletta-Theofania, S. and Christodoulides, G. (2019) 'A multi-stakeholder view of social media as a supporting tool in higher education: An educator–student perspective', European Management Journal, 37(1), pp. 421-431. doi: 10.1016/j.emj.2019.01.008 0263-2373

[23] Jisc (2020) The future of assessment: five principles, five targets for 2025. Available at: https://www.jisc.ac.uk/reports/the-future-of- assessment (Accessed: 25 July 2020).

Technical papers

Role of digital literacy and tools in teacher persistence in an online hands-on science training in Ghana

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Abstract — **Persistence in online education is a challenge globally. One may presume the depth of this challenge to be even higher in the context of African teacher training, due to low access to laptops, poor connectivity, and minimal digital literacy training. This paper presents results from the maiden attempt by Practical Education Network, a Ghanaian NGO, at offering its hands-on STEM teacher training in an online format. 35% of the 237 teachers targeted for the training persisted through the program– a similar or slightly higher percent than those often cited for online courses in the West. The highest drop-off rate occurred after Enrollment, at the Onboarding stage. This appeared to be less a result of poor connectivity and more a result of insufficient sensitization towards the concept of online training, in general. Most teachers who completed Onboarding persisted through to the end. They exhibited resilience and resourcefulness in overcoming digital infrastructure challenges to complete the 10 assignments and 4-5 live sessions. Strategies included uploading files to the LMS at dawn and moving to locations with stronger connectivity solely for the live session times. Lessons from this intervention can be extended to other African training organizations seeking to offer online modalities of their program.**

Keywords — persistence, online training, hands-on learning, digital literacy, Ghana, STEM

I. INTRODUCTION

The COVID-19 pandemic made remote modes of teaching and learning necessary, but significant challenges existed in realizing this in Ghana. Students across the country were out of the physical classroom for nearly 10 months. At the national level, the main intervention deployed and accessed was a TV program, Ghana Learning TV. Its efficacy may have been limited by the lack of interactivity between teachers and students [1,2]. Radio programs and zero-rating of educational content online were also facilitated by national-level education stakeholders, but they were accessed at a smaller scale than the TV program [3,4]. Radio-based interventions were utilized in multiple other parts of the continent as well [5-7].

A. Digital Literacy and Tools in Ghana

Online-based approaches for remote teaching and learning offer advantages over TV and radio. They allow for two-way communication between the teacher and the student. This enables various attributes of effective learning, such as higher levels of engagement, flexibility to adjust the learning pace, and peer learning opportunities.

The low usage of online approaches for remote teaching and learning during the pandemic in Ghana can be attributed to factors related to the level of digital infrastructure. 45% of urban Ghanaian households have access to the internet and 30% have a computer at home. These figures drop to 13% and 8%, respectively, in rural households [1]. Mobile phone availability does however reach 97% in urban and 88% in rural households. Digital literacy training is another barrier. Of a sample population between age 15-49 years, 20% of men and 5.9% of women had carried out at least one of nine specified computer-related activities, such as transferring files or sending emails, in the last three months [8]. The EdTech Readiness Index [9], which is in development, contains six pillars on which a country's readiness to adopt EdTech could be founded. Ghana and other African countries stand to score relatively low on this.

B. Persistence in Online Education

An additional challenge in online-based approaches is that persistence, the state in which learners continually participate in their educational programs to complete their degree or certificate, in online education in known to be a challenge globally. Many students enroll but drop off prior to completion. In a suite of courses offered at University of Pennsylvania through Coursera, the average completion rate ranged from 2-14% [10]. An attrition rate of 6-7 times more was seen in online than in traditional programs for a Master's program [11]. An online teacher training program in Indonesia saw 100% completion rate when offered in-person or hybrid, but only a 31% completion rate online [12]. Similar data on online courses in Ghana could not be located.

Course-side factors supporting online education persistence in the West have been found to include teaching presence, perceived ease of use [13], and alignment with interests [14]. Participant-side factors include a profile of self- direction [15] and high intellectual starting points [16]. Those who exhibit factors that indicate success in in-person education are those who may also be more likely to succeed in the online environment. External factors, such as online degree programs providing easy access to financial and technical support can also play a role in persistence [17].

Persistence in Ghanaian education has been studied from only a few factors. The familial [18] and the financial roles of female students in distance education [19] have been explored. Access to digital devices, level of internet connectivity, and digital literacy levels are prevalent challenges in the Ghanaian context, but their role in online education persistence has not sufficiently been studied. To what extent may such external factors as well as relevant course-side and participant-side factors affect persistence in online education in Ghana?

C. Practical Education Network's Intervention

Practical Education Network (PEN) is a nonprofit organization registered in Ghana since 2017. It builds teacher capacity in STEM subjects via a training program. Its approach is to utilize locally-available materials to teach hands-on activities that align with the national curriculum. This can awaken students' interest and readiness for STEM subjects and careers such as engineering. This training program had been offered fully in-person since inception, and it has been found to hold significant benefits at the student level in terms of attitudes and learning outcomes [20,21].

With the onset of the pandemic, PEN translated its existing in-person offering to a fully online modality. What had been offered as a one-day in-person training was translated to a combination of live sessions on Zoom (1-2 hours long each) and assignments posted on a Learning Management System (LMS) for the participants to conduct asynchronously. Each assignment contained a 2–3-minute instructional video for assembling and conducting one science activity. Participants sourced for materials in their local environment, replicated the activity, and posted a video of their work on the LMS. The PEN trainer facilitated the live Zoom sessions with an emphasis on peer sharing of experiences conducting said activities.

PEN sought to understand the feasibility of offering its hands-on STEM teacher training in an online modality, given the higher expected learning outcomes that could be achieved in this approach compared to TV/radio, but considering the ways in which access to digital infrastructure and existing digital literacy exposure would affect participant persistence.

With minimal existence of online offerings in the local ecosystem, could such a program be conducted successfully? This line of questioning was framed around understanding the points in the process at which the teachers persisted successfully and what strategies they may have employed in so doing. Descriptive analysis of course-side, participant-side, and external factors were done to flesh out the conclusions.

D. Research Question

The research question explored in this paper is "What factors enable teachers in Ghana to successfully onboard to and persist in an online training on hands-on STEM pedagogies, in spite of challenging contextual factors, such as minimal access to digital infrastructure and digital literacy levels?" By uncovering any enablers, barriers, and success strategies in this process, learnings can be extended to other programs seeking to offer digital modalities within the African education ecosystem.

II. METHODOLOGY

Five training groups participated in this online training pilot, which ran between 2020-2021. Each group was composed of teachers who teach at least one STEM subject and ranged from Primary 1 to Senior Secondary School 3. Key information on the groups is provided in Table 1.

Three pre-training forms: consent form, digital literacy survey and pre-survey were given to all teachers via Google Forms prior to commencing the training. The consent form provided the teachers' permissions to share their responses in this paper. The other two served as a means of collecting baseline data.

TABLE I: *Details of the five training groups engaged*

Training Cohort (Abbrev)	District; Region	Location Type	Field Partner	Funder
Presbyterian Schools in Ashanti Region (Kumasi Presby)	Various; Ashanti	Peri-Urban	Presbyterian Schools Coordinator	Private Individual
Public schools in Ahanta West (Ahanta West)	Ahanta West; Western	Rural	District Science Coordinator	Corporate
Public schools in Nzema East (Nzema East)	Nzema East; Western	Rural	District Science Coordinator	Corporation
Public schools in Greater Accra (SECF)	La Dadekotopon, Ga East and Ayawaso West; Greater Accra	Urban	District Science Coordinators	Family Foundation
Public senior high schools across Ghana (Ashesi EC)	Various; Various	Peri-Urban & Rural	None	University

Data was collected from all five trainings groups and analyzed both in aggregate and disaggregate form. The analysis was carried out in four categories, as follows.

A. Demographics

The age, gender, years of experience, leadership positions held, and educational level of participants were obtained from the pre-survey. Distribution of responses to these variables were determined in percentage form. Note that any names shown in this paper are pseudo-names assigned by the first author, based on the gender of the study participants.

B. Digital Literacy Levels

The digital literacy survey ascertained different aspects of the participants' experience and comfort level with digital tools and online education. Two questions from that tool are presented here as a descriptor of digital literacy levels. First, teachers were asked, in yes/no form, whether they had ever used a Learning Management System (LMS) prior to joining this program. Second, teachers were asked, in close-ended form, their preference for specific social media platforms. Percentages of responses were determined.

C. Persistence

Four stages were identified as key markers in the program: Recruitment, Enrollment, Onboarding, and Completion. A target number of participants for each training group was first set between PEN and the funder. PEN then provided the Field Partner a set of selection criteria to guide them in identifying relevant teachers in their jurisdiction. A teacher was considered to be Recruited if the Field Partner provided their name and contact information in the list of candidates to PEN. They were Enrolled if they proceeded to complete all three pre-training forms. They were Onboarded if they proceeded to attend the first live Zoom session – the first touchpoint where the training program was described in full. Finally, they were considered to have Completed if they attended all 4-5 live sessions, submitted all 10 assignments, and completed all pre and post training forms. Teacher persistence was determined by calculating the percentage of teachers who completed each of these stages, relative to the initial target number.

D. Factors Supporting Persistence

Course-side, external, and participant-side factors that supported persistence were ascertained by identifying themes running through the various datasets available. These include verbal statements made by participants within the Zoom recordings and phone call interviews, open ended responses on the pre and post training surveys, and comments made on assignment submissions. Dominant themes were determined by coding the qualitative responses and identifying those that appeared most frequently. Additionally, a descriptive picture of participants who successfully persisted was provided through three example teachers and their strategies.

III. RESULTS

A. Demographics

220 teachers who teach STEM subjects (science, math and ICT) were recruited from 10 out of the 16 regions in Ghana to participate in PEN's maiden series of online teacher trainings. Their ages were largely between 18 and 50 years. Some served solely in a teacher capacity, and some additionally held leadership positions in their schools. 57% of the cohort of teachers recruited were males and 43% were females. Their years of experience ranged from 1 to more than 16 years, with the largest category (36%) having between 6 to 10 years. 60% of the teachers were Bachelor's degree holders, 26% had a Diploma in Education, 13% also had a Master's Degree, with 2% having a certificate in education - the lowest certification. 92% of the teachers answered "Yes" to having received professional training to become a teacher.

B. Digital Literacy Levels

79% of teachers enrolled in PEN's online teacher training had never used an LMS before. This provides a nearly direct indication of the number of these participants who had engaged in any online training, and it is a small minority of them who have.

Figure 1 shows teachers' preference for various social media platforms. This can be interpreted as describing those which they were comfortable using. Nearly all (99%) preferred the use of WhatsApp, followed by about half (53%) for Facebook. Less than 20% chose Instagram, Twitter, or LinkedIn. Other social media platforms such as Telegram, Duo and Google Hangouts were of very low (3%) familiarity and usage by the teachers. Although smartphone usage amongst teachers in Ghana is high, this result serves as another indication of low exposure levels towards online professional development.

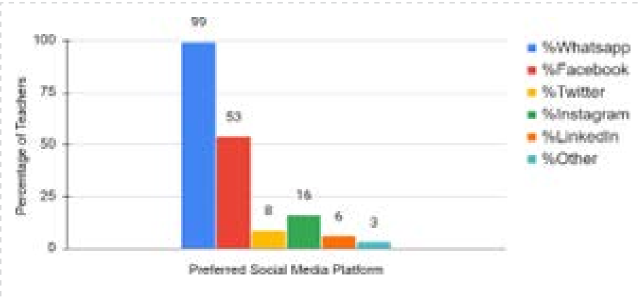

FIGURE 1: Teacher preference with social media platforms

C. Persistence

Figure 2 details the four key stages and the percentage of teachers who completed them. Overall, teachers did drop off from the beginning (Recruited) to the end (Completed). Of the 237 teachers targeted, 220 (93%) were recruited. Of this sub- set, 194 (82% of the original target) completed all pre-training surveys and were thereby enrolled. The highest drop-off rate occurred at the next stage. 41% of the original target attended the onboarding session. Most of the teachers who made it to this stage continued through the full content of the training, with 35% of the original target attending live sessions, submitting all assignments, and completing training surveys.

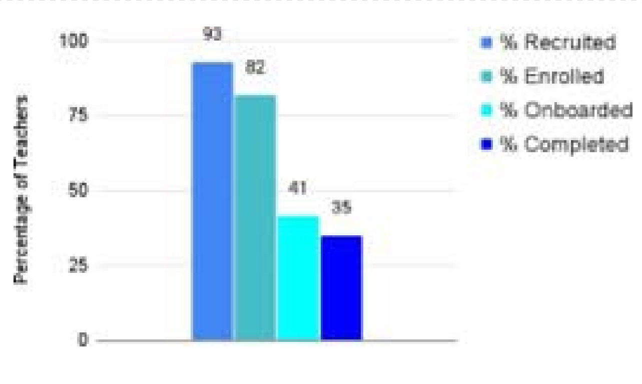

FIGURE 2: *Teacher persistence through each of the 4 stages of PEN's online teacher training program*

Figure 3 shows the same persistence data, disaggregated across the five training groups. A high level of variation is seen between the different training groups. Persistence ranged from 6% in the Nzema East group, which had low engagement from their District Science Coordinator, to 100% in the Kumasi Presby group, which had high engagement. The latter is evidenced by the Regional Director for the school chain attending one of the live Zoom sessions herself and motivating her teachers to participate fully. A quote from one member of that training group reveals the impact that had on him

"Initially to be frank with you I nearly dropped back when [the program] started because of a few challenges but as [Regional Director] said...when you face challenges and you are able to push on to find solutions to them it's good... trying to do the activity that you have given to us, it has really boosted me and given me more energy in the subject."- Male Science Teacher, Kumasi Presby

The District Science Coordinator for Ahanta West was very enthusiastic, which can be seen in the >100% rates in the Recruitment and Enrollment stages. He tragically passed away before the Onboarding, explaining the low persistence (12%) there.

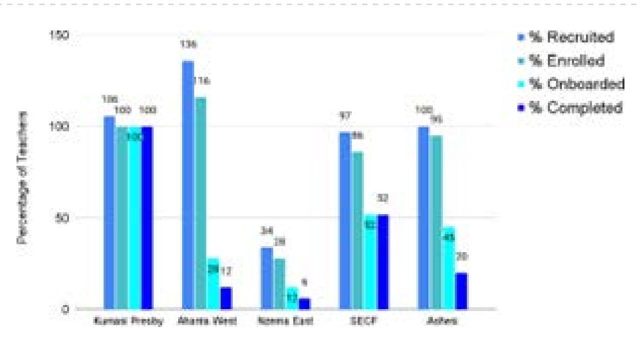

FIGURE 3: *Teacher persistence disaggregated by training group*

D. Factors Supporting Persistence

Teachers who persisted shared impactful testimonies about the positive effect of the training. They gained significant knowledge and skills to improve the teaching and learning of STEM subjects.

"Sometimes when it is time for science lessons, it becomes so dull...because we do not have any approach to get the practical way of teaching this lesson. But this time it is not that." – Female Science Teacher, Greater Accra Region

They also cited this as a key development opportunity for developing their digital literacy skills:

"This training is not only teaching us practical science. We have also learned educational technology using the phone."- Female Mathematics and Science Teacher, Greater Accra Region

1. Course-side Factors:

It was observed that frequent follow-up phone calls with teachers improved live session attendance. PEN staff used these to provide one-on-one support on the use of Zoom and the LMS and solicit convenient days and times for the live sessions to be scheduled.

Assignment submissions were requested to be of minimal file size while still providing enough evidence to ascertain the work completed. Participants were asked to upload a maximum 30 second video, which helped upload times to be reduced.

"The videos were a lot easier to upload because of the 30 seconds adjustment to keep the videos short"- Male Science Teacher, Ashanti Region

2. External Factors:

Grant funding was raised to offer the training for free to teachers and provide reimbursement for materials and data usage to those who completed the program. This served as an enabler for persistence since teachers did not need to concern themselves with financial implications of participating.

3. Participant-side Factors:

Teachers who persisted between Onboarding and Completion took the initiative to find creative strategies for persisting. These manifested in diverse ways. The profile of three sample teachers who persisted are shown in Figure 4. A desire to improve themselves and their work served as a recurring theme in their motivation.

IV. DISCUSSION/CONCLUSION

In spite of significant challenges in access to digital infrastructure and literacy, many Ghanaian STEM teachers exhibited incredible resilience and resourcefulness to persist through an online training offered during the COVID-19 pandemic. 35% of the 237 teachers targeted persisted through this roughly 3-month training. This is a higher persistence level than that quoted by many online courses offered in the West, where digital infrastructure and literacy are higher.

The stage with the largest drop-off rate (dropping from 82% to 41%, on average) was that of Onboarding, in which Enrolled teachers had to attend the first live session on Zoom to receive orientation. Per the authors' observations, the key challenge faced here had less to do with digital infrastructure than effective participant mobilization.

Effective participant mobilization includes participant sensitization on the concept of an online training itself. Without prior participation in or exposure (personally or indirectly through peers) to online training, it was difficult for some to attach import to it.

A proposed solution is to more deeply engage local stakeholders in communicating the training form and relevance. This is the same strategy which must be employed in onboarding teachers to an in-person training- District Science Coordinators deliver physical invitation letters and place multiple calls through to the teachers, reminding them of the training date. The temptation in this mode was to rely solely on digital communication of this new program, via WhatsApp, but that appeared to be insufficient. From the breakdown of persistence data by training group, it is seen that where the Field Partner was an effective mobilizer, persistence was higher.

Pseudo-name: Madam Emefa Asempa (Female)
Age: 40-49 years
Subject(s) Taught: Integrated Science
Location: La Dadekotopon, Greater Accra Region
Level Taught: Lower Primary School
Key challenge faced: She missed all of the live sessions due to gaps in communication
Strategies used to overcome the challenges: Watching the session recordings at a convenient time; Meeting with colleagues to discuss topics covered in the sessions
Quotes: *"I had to get in touch with another colleague in another school to make him a resource person to train me for more insight into the topics discussed and the activities performed". "The fact that my students were enjoying the hands-on activities and the new ideas they were bringing in class gave me the drive to complete the training."*

Pseudo-name: Madam Adwoa Mansa (Female)
Age: 30-39 years
Subject(s) Taught: Integrated Science and Mathematics
Location: La Dadekotopon, Greater Accra Region
Level Taught: Upper Primary School
Key challenge faced: Difficulty in uploading assignments
Strategies used to overcome the challenges: Changing locations for stable internet connectivity; Uploading videos at dawn; Learning from her son how to edit videos
Quotes: *"Uploading my assignments were always challenging. I have to try several times to upload a video." "The training was interesting... I learnt a lot and [am] still using the techniques learnt in my teaching."*

Pseudo-name: Mr. Kofi Manu (Male)
Age: 30-39 years
Subject(s) Taught: Intergrated Science and Chemistry
Location: Tatale-Sanguli, Northern Region
Level Taught: Senior High School
Key challenge faced: Poor internet connectivity
Strategies used to overcome the challenges: Changing locations for stable internet connectivity; Paying more to use the data from Togo (he lives on the border between Ghana and Togo)
Quotes: *"Once I had to move to Yendi which is more than 50km away from Tatale to join a live session." "Training was dear to me. I was looking at the impact I will make on my students, to demystify science to them, so when I had this opportunity, I said I would not let it pass and it actually paid off".*

FIGURE 4: *Examples of teachers who persisted and strategies employed*

The Kumasi Presby group, which operated with strong support from the coordinating entity, achieved 100% persistence. The Ahanta West group, whose District Science Coordinator tragically passed away in the early stage of the program, achieved only 12% persistence. The urban/rural divide can also help explain the difference in persistence rates, as the urban group (SECF) had a more gradual decline than the rural groups (Ahanta West, Nzema East, and select members of Ashesi EC).

Most teachers who completed the Onboarding stage made it through to the Completion stage (dropping from 41% to 35% of the initial target, on average). Once teachers understood what the training offered and became sensitized to the format in which it would take place, most of them persisted through the coming months to complete the program. In doing so, those teachers demonstrated creative strategies to overcome digital infrastructure challenges. Some highlights were captured in the form of three example teachers, and their strategies included uploading assignments at dawn, moving to locations with strong connectivity during live sessions, and soliciting help from their kids to support with video editing. For teachers who recognized that this program would support their professional development and enhance the efficacy of their teaching, they committed to persist.

Those who persisted benefited significantly. They learned and replicated 10 hands-on activities using local materials, and they learned to use Zoom and Google Classroom, which for many was their first time to do so. It is worth noting that participants were able to complete the training using their smartphones alone. Laptops should therefore not be viewed as necessary requirements for online training in the continent.

Future work should further elucidate and quantify the role of key factors influencing Ghanaian teacher persistence in online training. This will hold utility for African training organizations broadly. Online modalities offer a lower-cost and wider-reach option for disseminating training than the traditional in-person approach. Online teacher training therefore has a significant role to play on the continent, and lessons from this pilot study, especially around engagement of strong coordinating partners and sensitization of teachers to the online training concept, should be extended to deploying similar interventions effectively.

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REFERENCES

[1] E. Agbe, and C. Sefa-Nyarko, "Ghana's education response during the COVID-19 crisis: EdTech to the rescue?," Case study, EdTech Hub, 2020.

[2] Institute for Educational Planning and Administration, "Is Ghana learning TV by the Ghana Education Service in response to COVID-19 effective?", iepa.ucc.edu.gh. https://iepa.ucc.edu.gh/news/gl-tv-ghana-education-service-response-covid-19-pandemic-effective (accessed Aug. 22, 2022)

[3] The World Bank, "Ghana: Online education for delivering learning outcomes during the COVID-19 school closure", worldbank.org.https://www.worldbank.org/en/results/2022/05/16/afw-ghana-online- education-for-delivering-learning-outcomes-during-the-covid-19- school-closure (accessed Aug. 22, 2022)

[4] Global Partnership for Education, "Ghana: Ensuring education for all children in times of COVID-19", globalpartnership.org. https://www.globalpartnership.org/blog/ghana-ensuring-education-all- children-times-covid-19 (accessed Aug. 22, 2022)

[5] Government of Sierra Leone, "COVID-19 education emergency response plan", Ministry of Basic and Senior Secondary Education, Sierra Leone, May, 2020.

[6] Z. Flood, "How Africa's tech innovators respond to the coronavirus pandemic",AlJazeera.com., https://www.aljazeera.com/economy/2020/4/15/how-africas-tech-innovators-respond-to-the-coronavirus-pandemic (accessed Aug. 22, 2022)

[7] F. Kisakye, "Digital pilot program transforms learner's lives in N. Uganda", observer.ug. https://observer.ug/education/66969-digital- pilot-program-transforms-learners-lives-in-n-uganda (accessed Aug. 22, 2022)

[8] UNICEF, "Ghana multiple indicator cluster survey 2017/18", Ghana, Jan. 2019.

[9] S. V. Marin, C. Cobo, M-H. Cloutier and E. L-Porter, "Where is EdTech working? Leveraging data for better EdTech policies". World Bank Blogs, Education for Global Development, Sept. 20, 2021.

[10] L. Perna, et. al., "The life cycle of a million MOOC users", MOOC Research Initiative Conference, vol. 5, 2013.

[11] B. Patterson and C. McFadden, "Atttrition in online and campus degree programs", Online Journal of Distance Learning Administration, vol. 12, no. 2, pp 1-8, 2009.

[12] M. Burns, "Staying or leaving? Designing for persistence in an online educator training programme in Indonesia", Open Learning: The Journal of Open Distance and e-Learning, vol. 28, no 2, pp 141-152, 2013.

[13] Y. Jung and J. Lee, "Learning engagement and persistence in massive open online courses (MOOCS)", Computers and Education, vol. 122, pp 9-22, 2018.

[14] K. Lucey, "The effect of motivation on student persistence in online higher education: A phenomenological study of how adult learners expereicnce motivation in a web-based distance learning environment", PhD dissertation, Duquesne University, May, 2018.

[15] J. L. Howland and J. L. Moore, "Student perceptions as distance learners in internet-based courses", Distance Education, vol. 23, no 2, pp 183-195, 2002.

[16] J. DeBoer, et. al., "Bringing student backgrounds online: MOOC user demographics, site usage, and online learning", Education Data Mining, 2013.

[17] T. Stevenson, "Online student persistence: What matters is outside the classroom", Journal of Applied Learning Technology, vol. 3, no 1, 2013.

[18] B.A. Somuah, S. I. Kariuki and F. M. Itegi, "Correlation between fimalial roles and persistence of female students on distance education programmes in Ghana: through the lens of an administrator", Open Praxix, vol. 11, no 3, pp 261-273, 2019.

[19] B.A. Somuah, F. M. Itegi, and S. I. Kariuki, "Financial roles and its effect on persistence of female students in distance education programs in Ghana", Turkish Online Journal of Distance Education, vol. 19, no 4, pp 104-115, 2018.

[20] H. Beem, "Effect of hands-on science activities on Ghanaian student learning, attitudes, and career interest: A preliminary control study", Global Journal of Tranformative Education, vol. 2, no 1, pp 18-32, 2020.

[21] J. Babb and S. L. Stockero, "Impact of Practical Education Network on students in selected Ghanaian junior high school science classrooms", African Journal of Research in Mathematics, Science and Technology Education, vol. 24, no 2, pp 216-228, 2020.

Technical papers

Inclusive teaching practices: A comparative case study of integrated inclusion in different contexts

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Abstract — **There is both a compelling business case and social justice case for diversity in engineering (and other professions). Diverse teams make better decisions, and cohorts should be representative of the communities from which they are drawn (otherwise some groups are being excluded). However, in Australia the engineering profession continues to suffer from a significant lack of diversity. In this paper, we describe one attempt to address this in three Australian university contexts by seeking to create an inclusive learning environment and to cultivate students' inclusion competencies.**

Keywords — inclusion, context, practice, reflection

I. INTRODUCTION

Engineers aim to solve complex problems using their specialised knowledge, problem solving approaches and creativity. This is best achieved when problem solvers from diverse backgrounds and lived experiences can work together. In Australia, the engineering profession suffers from a significant lack of diversity and university initiatives have had little impact on the diversity of engineers completing degrees [1, Figure 2.3], suggesting there may be limited changes in the near future without further intervention. The engineering profession does not reflect the society in which it operates, nor does every engineer feel as though they belong to the profession. This lack of diversity and gap in belonging can begin to be addressed if professional engineers create inclusive environments [2]. As engineering educators, we have an opportunity to develop students' capability and motivation to create these environments, influencing the profession and the industries our graduates will work in. This paper is part of an ongoing pilot project between three Australian universities, with the broad objective of both cultivating an inclusive learning experience for engineering students, and enabling the development of students' inclusion competencies – their capability and motivation to be inclusive in their own emerging professional practice.

The project aims to intentionally teach inclusion capabilities within learning experiences in specific units of study from first year onwards. We devised this bottom-up approach, designed to complement the inclusion initiatives already existing in universities which are often top-down and lack practical implementation within units of study. Building on theories of change, practice theory and our reflective teaching practice we have proposed the 'practice loop' described in Figure 1 to develop and improve our inclusive practice and teaching [2].

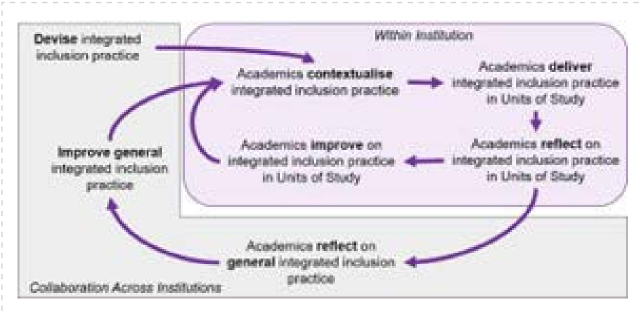

FIGURE 1: *Integrated Inclusion Practice Loop.*

Having reviewed the research and grey literature around inclusive practice, the work reported here focuses on the 'contextualise' phase of our practice loop. That is, in this paper we present lessons learnt from adapting and implementing the inclusive approach at three different institutions, guided by the following research question:

How might we contextualise an integrated inclusion practice in engineering education at different institutions?

II. BACKGROUND

The approach to integrating inclusive practice into our classrooms builds on research from [3] which highlighted the value of integrating inclusion at the level of a unit of study. They flagged that further work was necessary, but that the opportunity exists to leverage group-based project contexts in first-year engineering for such integrated inclusion unit of study design. Project-based-learning (PBL) has been presented as an opportunity to foster inclusion in a variety of contexts. There is consensus that exposure to diverse groups in a PBL setting can model inclusive practice and some authors indicate a change in attitude to social inclusion through participating in such PBL group projects [4]–[7]. A point of difference in this study is that while PBL is often reported as providing an opportunity to develop the capabilities of students so that they are more able to be included [4], [6], this project looks at PBL-based subjects as a context for developing students' abilities to be inclusive and to create inclusive environments, more in line with the transformative potential of collaborative learning identified by [7]. The integrated practice loop aims to foster an inclusion capability to develop future engineers' ability to create and maintain inclusive cultures, rather than for those who are excluded to adapt to the current exclusive environments.

As each institution has its own terminology (e.g., subject, course, paper), for clarity and consistency in this paper the term 'unit of study' is used, with a full-time student usually completing four units of study each semester.

In line with an inclusive approach to our practice, the project has been expanded to include multiple universities and educators from first and further years across engineering and Information Technology (IT), with a shared interest in integrating inclusive practice within their teaching. Over the last 18 months the research team has met regularly to problematise the concepts of inclusion and belonging in engineering, as well as related concepts such as intersectionality. The outcome of this process has been to develop a shared vision of how we can cultivate inclusion in our teaching practice.

III. APPROACH

To generate the insights presented in this paper, a comparative case study approach was used [8]. Comparative case studies go beyond examining a single case to hopefully generate more insights about "how or why particular programmes... work or fail to work" by comparing multiple instances where they have been implemented. This approach is appropriate here as comparative case studies are "particularly useful for understanding and explaining how context influences the success of an intervention" [8, p. 1]. In this paper, the cases being considered are the ***contextualisation*** of the integrated inclusion practices in large-enrolment first-year engineering or IT units of study at three different Australian institutions.

Comparative case studies can include both qualitative and quantitative data. In this paper, we will be using qualitative data from the ongoing reflective practice discussions of the team, and written reflections after the semester from each institution. The case studies have been written by authors who were directly involved in each unit of study design, with implementation based on the emerging insights noted from discussions in regular team meetings and their own experience of the units. Insights were then drawn out by other authors who work in further-year professional practice units of study, and are synthesised in the Discussion section below.

IV. CASE STUDIES

A. Overview

In this section, authors from the different universities and units of study will describe and reflect on their particular context, with the unique challenges the different contexts offer (referred to as Units of Study 1 to 4). Each will describe their motivation for participating in the project, how they have addressed inclusion and belonging up to this point, any outcomes thus far, and insights for the future.

Before those individual stories, it is important to note some overarching similarities across the different contexts. All four units of study are compulsory, large-enrolment (around 1000 enrolments each year), first-year units for engineering or IT students. Within their respective degree programs, each unit is intended to highlight the human dimensions of engineering and IT, and cultivate personal and professional skills in group- work, communication, design, and more. Although the cohorts are very large, teaching is typically in tutorial class sizes of ~30 students, taking a PBL approach with students in groups of 4-6 members working under the supervision of a tutor.

All of the units of study are aimed at providing first-year students with the foundations of what it means to be an engineer or IT professional. Students learn and apply engineering design skills whilst developing the complementary skills required to practice competently, collaboratively, ethically, and safely. The units of study utilise PBL through a partnership with Engineers Without Borders Australia (EWB), specifically using the context of the EWB Challenge. This is a mature initiative which engages thousands of engineering and IT students around Australia and internationally to respond to real-world design briefs from EWB's community partners [9]. In recent years, EWB has partnered with the Centre for Appropriate Technology and the Dawul Wuru Aboriginal Corporation, both Indigenous community organisations in northern Queensland, to deliver the EWB Challenge. Connection to land, to Country, is fundamental in Aboriginal and Torres Strait Islander cultures and the EWB Challenge in part contributes to reconciliation with Indigenous Australians, by highlighting to engineering and IT students the diversity of Indigenous cultures [10], the importance of different cultural perspectives in design, and the importance of practices like the Acknowledgement of Country, in which the Traditional Owners of the land are affirmed.

The COVID-19 pandemic has imposed particular challenges on all teaching practices, in re-creating what has historically been extremely interactive face-to-face sessions in an online environment, and supporting the development of communica- tion and group-work skills remotely Unit of Study 1

This is a first-year engineering unit of study. The learning outcomes focus on the *process* of an engineering group design project, rather than the design outcome or output; that is, focusing on developing students' professional skills rather than on just the technical design. However, seeing study and work cultures developing amongst students with embedded stereotypes and bias motivated the urgent need to address building a 'norm' of inclusive study and work culture from day one at university. A key advantage of introducing inclusive practices into first year is the mixing of all engineering disciplines in this design project. This embedded discipline diversity is a 'safer' dimension that students are more likely to openly discuss diversity about, than the more 'personal' dimensions such as gender, culture and ethnicity.

Initial inclusive teaching practices from 2020 focused on three key aspects:

'Safe space' for learning: a key activity in the first week of class with students self-identifying class 'norms' (with respect generally a central value identified).

Group-work: group formation actively taking into ac- count diversity across multiple dimensions, giving students agency to decide what group they are comfortable with; formal group charters self-developed by students to identify how unacceptable (e.g., non-inclusive) behaviours will be addressed; regular check-ins with tutors on group-work challenges, self and peer-assessment for feedback and marks- based consequences, and training tutors to identify and intervene early with group issues.

Diverse tutor teaching team: role modelling a diverse and inclusive team is critical. The unit coordinators intentionally recruited a diverse tutor team and introduced team teaching in larger classes across dimensions such as gender, ethnicity, age, background (e.g., mixing humanities, engineering, and IT tutors). Previously, tutors individually teach a class of ~30 students. By combining 2-4 classes in a collaborative classroom taught by a tutor team, this enables diversity in the tutor team to be visibly and functionally part of our teaching practice.

Informal feedback from the teaching team identified that students appreciated the activities setting up class norms early. However, it was a challenge to maintain the norms and values throughout the semester, and for students to action the norms, especially when group-work challenges arose. What has been a successful activity in the attempts for group-work inclusion is the mid-semester check-in and introducing the Lencioni model [11], which focuses on building trust as fundamental. Previous attempts to introduce group-work models earlier led to students not yet seeing the relevance. Introducing team teaching has been the most successful initiative to date, due to the diversity in tutor skills improving the teaching approaches and student learning experience. What could be explicitly measured in future is whether students notice and/or value the diverse teaching team.

B. Unit of Study 2

This first-year unit of study is taught at the same institution as Unit of Study 1. The two units are closely aligned, with the coordinators collaborating extensively on curriculum and teaching approaches. While Unit of Study 1 is for engineering students, this unit of study is for IT students, and aims to provide them with the skills they need to successfully complete their degree and to succeed in their careers. One of these skills is the ability to work in diverse teams, as this is envisaged to be necessary in a future technology workplace. Initial inclusive teaching practices from 2020 focused on two key aspects:

Diverse tutor teaching team: Together with other units, we created a dedicated, diverse team of tutors who were keen to help all our students reach their goals. This meant attention had to be paid to diversity. Perhaps the biggest asset we had was a collegiate atmosphere where ideas for encouraging students to work together were discussed in regular meetings.

Case studies and group dynamics: From past experiences, case studies were given to student groups to help them anticipate diversity problems before they occurred. Students were also given time to create a group contract which had specific questions about inclusion and working together. This contract was revisited throughout the semester.

Although diversity in our groups is far from perfect and problems still exist, we have seen a definite improvement in the understanding of others' needs. To some extent this occurs through self interest. Students are made to realise that if group members are excluded, more work will need to be done by the in-group. As standards are set from the beginning by the tutors, students become aware that including everyone is a step to achieving their goals. We have learned that establishing an environment where inclusion is expected from the beginning of the course is essential.

C. Unit of Study 3

The coordinator was motivated to develop and deploy an integrated inclusive practice after seeing students dismiss existing university diversity initiatives as not being relevant to the unit of study. Specific challenges include a particularly large cohort (>1000 students per delivery) and a corresponding large teaching team (25-35 casual and permanent academic staff). In contextualising integrated inclusion practice, the coordinator initially focused on the structure and style of learning activities. However, more recently there has been a shift to supporting the large teaching team to deliver the integrated inclusion practice. Some examples of practice include:

Group-work process: particular focus has been placed on moving students through a more appropriate group-work process. The HERDSA model [12], has replaced the Tuckman model [13] emphasising the use of group charters and expected group behaviours. This transition has seen group communication move onto central platforms such as MS Teams and away from platforms such as Facebook Messenger, where there were indicators that bullying and non-inclusive practice were becoming more prevalent. To provide better integration, the group-work set-up mimics those in industry e.g., using a Common Data Environment.

Considerations of inclusive language: whilst participation in the unit of study is intended to enhance inclusion capability and motivation, the unit also attempts to model inclusion best practice. Checks are performed to ensure that inclusive and accessible language is used in teaching materials and in the examples and case studies that the students are presented with.

Reconciliation journey: professional development sessions were run with staff to consider their relationship with Indigenous Sovereignty and how this could form part of their teaching practice. With this support, and reconciliation modules integrated into the unit of study, students had to explicitly consider Indigenous communities' perspectives, wishes, and ways of being in formulating their designs.

The coordinator has noted that there has historically been hesitation in integrating materials into units of study as it is difficult to then measure how many students have participated or engaged with those materials. As a simple example, a video played in a lecture theatre of 300 students only counts as one view on the metadata of the video. This insight has fed into the way the success of the integrated inclusion practice is being 'measured'. Instead of looking at the effectiveness of individual initiatives or practices, there are so many intersecting factors that the focus of measurement is on the overall student experience in the whole unit of study. This is important in understanding the relevance of the intervention and that there may be other factors outside of the classroom that have larger effects. This was highlighted in [3] in that inclusive practice may be taking place in only one quarter of the students' learning load and classroom impacts may be outweighed by other aspects of their lives within and beyond the university.

D. Unit of Study 4

This unit of study is in first year, first semester, with an enrolment of ~900 students. It is focused on introducing the engineering design process and laying the foundations for professional practice. The unit of study was developed and offered for the first time in 2022, following a review of the overarching degree but explicitly built from a previous version that had similar foundations. Reflection from previous offerings had led to a desire to more explicitly address inclusion and respectful group processes. Further, this unit was identified as the first opportunity in the degree for students from all majors to engage with Aboriginal and Torres Strait Islander knowledges and perspectives. The unit of study seeks to include content, case studies, and examples of the ways in which the work of professional engineers connects to Aboriginal and Torres Strait Islander people's status as First Nations owners of land and seas. In practice this occurred through invited presentations from working engineers who connected their design work to the Queensland Aboriginal Cultural Heritage Act 2005, and with a focus on stakeholder engagement in early design processes.

Tutors within the unit were offered professional development before semester commenced that included explicit activities around creating an inclusive classroom environment by prompting tutors to consider what would create a sense of belonging for them and to consider the power of images, text, and language in creating a sense of who engineers are and what they do. The limitation of this approach to fostering inclusion was that the development was optional and not all tutors attended.

The assessment associated with the unit was reframed as a professional engineering task, with the project overview incorporating explicit notions of professional conduct, including framing a requirement that group members contribute to the creation of a respectful and inclusive environment, linked to the university student code of conduct and the Engineers Australia Code of Ethics [14]. It is hoped that this linking of inclusive capability to professional competencies and conduct avoids some previous experiences in which students expressed a lack of connection between inclusion and their aspirations to be an engineer. Student negative feedback on some previous attempts to highlight the need for inclusion suggest that they align engineering with technical, rational and 'masculine' identities, and not with the need to consider the human dimensions of engineering design or practice [15]. In that sense a commitment to inclusion capability development on the part of the educator is as much about helping students unlearn what they understand engineering to be, as it is to teach them new things.

In the next offering which is in second semester, the critical reflection task will be updated to focus more on inclusion capability and reconciliation. Plans for collecting tutor reflections and developing tutor development are also under way.

V. DISCUSSION

The case studies across four units of study in three institutions provide insight into the application of the proposed practice loop and how inclusion practice can be contextualised. These cases had similar contexts as first-year, large cohort units using PBL approaches to address the EWB Challenge; however, the institutions, educators and the make-up of the student cohorts varied.

In terms of the educators reporting on the integrated inclusion practice, the case studies highlight that these implementations extend their pre-existing interest in this topic. Unsurprisingly, given their participation, these academics all saw the value in developing inclusion capabilities in their students, and had already begun to address this. For example, Unit of Study 3 indicates that there was a shift in approach from a focus on learning activities to teaching group-work capability development. This has implications for the proposed practice loop. Rather than beginning at stage 1 in Figure 1, these academics began at the stage of *reflecting on their own practice*. Their improvements and approaches were informed by discussions across institutions within this larger project, however, there was no 'external' point at which the practice was devised. This suggests a need to change the practice loop to incorporate this lived experience. Devising an integrated inclusion approach sits within institutions, with the educators themselves and in collaborations across institutions where sharing ideas informs practice: stage 1 in the practice loop should shift to reflect this boundary-spanning feature. Stage 1 is also not a *necessary* step where educators have already devised some inclusive practices and it should be indicated that it is not a requirement for implementing this practice loop (dashed line rather than solid line). It is proposed that the practice loop be updated to include this finding as in Figure 2.

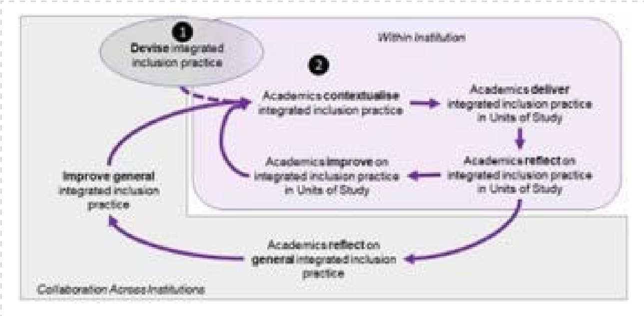

FIGURE 2: *Revised Integrated Inclusion Practice Loop.*

The case studies highlight an approach that is not explicit in the practice loop but emerges from the details of the implementation. The coordinator of each unit of study has a particular focus on modelling the inclusive practice through their teaching. Rather than simply impart knowledge on the development of inclusive practice capabilities to students, they have each operationalised this and sought to develop this capability themselves and with their teaching teams. This approach to modelling practice, rather than discussing theory, is perhaps reflective of the action-oriented nature of engineering culture. As examples of this modelling, Units of Study 1 and 2 explicitly select a diverse teaching team, Unit of Study 3 focuses on developing inclusive language, and Unit of Study 4 includes a range of voices in their guest speakers. Each unit of study identifies the development of professional practice skills needed by engineering and IT professionals as learning outcomes for their units of study, and they implement these professional skills in their own practice. None of the case studies have included approaches that measure how potentially excluded students can adapt to the expectations of the current engineering profession. Rather, this modelling of an inclusive environment is in line with the differentiated approach to inclusive practice presented here, where we aim to develop students' ability to create inclusive environments.

VI. CONCLUSION

The case studies presented in this paper demonstrated the scope, challenges, and possibilities of contextualising inclusion practice within different institutions. While the implementations varied as expected, modelling inclusive practice emerged as a key component and this was implemented as afforded by the teaching context and institution. Significantly, each academic brought their own previous interest and experience to the contextualisation of inclusive practice so that we can consider the academics who design and teach these units as part of the context itself. These insights led to an adaptation of our practice loop, where we recognise that stage 1 is not a necessary or distinct action for those academics and institutions which already value and implement inclusive practice.

The next steps in this ongoing project include obtaining student feedback to gauge their sense of belonging in their studies and in the engineering profession at large. This data, accompanied by ongoing shared reflections across the team, will be used to iteratively improve and evaluate contextualised inclusive teaching practices at our different institutions. These learnings and outcomes will be shared in future publications.

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REFERENCES

[1] I. Dobson, "STEM in Australia: The statistical patterns of university science and technology in the twenty-first century," Australian Council of Deans of Science, 2018.

[2] N. Brown, K. Whelan, L. Rhodes-Dicker, J. Lindeck, E. Cheng, T. Boye,S. Daniel, T. Bhatia, and T. Machet, "An approach for cultivating an inclusive engineering profession," unpublished, 2022.

[3] N. Brown, A. Pearson, and T. Rosenqvist, "Understanding what inte- grated inclusion looks like in a mega first year team-based engineering course," in 31st annual conference of the Australia Association for Engineering Education. Australasian Association for Engineering Education, December 2020.

[4] S. Daskou and N. Tzokas, PBL and Social Inclusion. Cham: Springer International Publishing, 2020, pp. 313–345. [Online]. Available: https://doi.org/10.1007/978-3-030-47376-1_13

[5] D. Borovic, "Developing social inclusion and 21st century skills through project based learning in the erasmus+ project "wish"," Journal of Pedagogy-Revista de Pedagogie, vol. 67, no. 2, pp. 29–46, 2019.

[6] B. R. Belland, K. D. Glazewski, and P. A. Ertmer, "Inclusion and problem- based learning: Roles of students in a mixed-ability group," RMLE Online, vol. 32, no. 9, pp. 1–19, 2009. [Online]. Available: https://doi.org/10.1080/19404476.2009.11462062

[7] V. S. Singaram, T. E. Sommerville, C. P. van der Vleuten, and D. H. Dolmans, "'Looking at the glass half full': Exploring collaborative mixed group learning as a transformative force for social inclusion in a south african higher education setting," Institutions, p. 119, 2008.

[8] D. Goodrick et al., "Comparative case studies: Methodological briefs- impact evaluation no. 9," Tech. Rep., 2014.

[9] "EWB Challenge." [Online]. Available: https://ewbchallenge.org/

[10] "Map of Indigenous Australia." [Online]. Available: https://aiatsis.gov.au/explore/map-indigenous-australia

[11] P. M. Lencioni, The five dysfunctions of a team: Team assessment. John Wiley & Sons, 2012.

[12] D. Caspersz, J. Skene, and M. Wu, Managing student teams, ser. HERDSA guide. Higher Education Research and Development Society of Australasia, 2018.

[13] B. Tuckman, "Developmental sequence in small groups," Psychological Bulletin, vol. 63, no. 6, p. 384–399, 1965.

[14] Engineers Australia, "Code of ethics and guide- lines on professional conduct," 2022. [Online]. Available: https://www.engineersaustralia.org.au/sites/default/files/2022-08/code- ethics-guidelines-professional-conduct-2022.pdf

[15] W. Faulkner, "Dualisms, hierarchies and gender in engineering," Social studies of science, vol. 30, no. 5, pp. 759–792, 2000.

Technical papers

Diversity in higher education: Practice, challenges, and strategies at University Carlos III of Madrid

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***Abstract* — Diversity is still a major concern at universities. The idea that diversity improves student learning and makes students aware of the potential of being in a diverse environment motivates many universities. However, the appropriate means to deal with a diverse community are needed. One option to deal with a diverse community is through orientation. Orientation is a much-needed action and when organized correctly it can be useful to all participants in the university community. The University Carlos III of Madrid (UC3M) has a significant commitment to diversity. UC3M takes several steps to address diversity and inclusion. Students, faculty members, researchers, and members of the administration and support staff of our university all actively participate in these activities. In this paper, the main orientation actions will be presented. Special emphasis was done on tutoring programs offered at our university, UC3M, along with the bachelor's degree studies. The results of these tutoring actions will be evaluated in terms of the satisfaction of students and tutors participating in the programs. Future actions such as the program for high-capacity students will be mentioned. Also, actions on gender equality will be included. These programs can be an inspiration to other universities and centers with students involved in engineering studies.**

Keywords — Diversity, Students, University, Higher Education, UC3M.

I. INTRODUCTION

Managing diversity is one of the major challenges in higher education institutions [1]. Nowadays, with an increasing number of students from all backgrounds in our classrooms, it is very important to make universities more inclusive. With a wider range of abilities and social, cultural, economic, and political backgrounds among students, universities have a challenge in utilizing this diversity constructively to democratize teaching-learning processes and practices and achieve other social goals [2]. Many universities are guided by the motivation that diversity enhances student learning and makes students aware of the possibilities of being in a diverse environment. It has been also claimed that diverse teams are more innovative, focus on more facts, bringing to the table different social and cultural experiences [3]. Among different universities, tutoring programs are emerging as an essential tool for addressing diversity as well as the widening gaps in educational outcomes [4, 5]. Although most universities undertake orientation activities, the way these actions are implemented can vary. For example, at Toronto University tutoring actions were improved as a strategy to help with the educational needs associated with disruptions due to the COVID-19 pandemic [4]. Princeton University offers individual peer tutoring programs to students to help students to engage the course [6].

University Carlos III of Madrid (UC3M henceforth) has a strong commitment with diversity as it has a strong focus on internationalization being one of the universities in Spain with more foreign students, from up to 32 different countries. Apart from aspects related to internationalization other aspects include geographical location, gender, age, and educational background [2]. Several actions are performed to address diversity and inclusion at UC3M. The community at the UC3M is an active part of these programs, including students, teachers, researchers as well as the administration staff.

The UC3M offers different tutoring activities for students such as programs for (i) first-year students that accompany the students in access to their bachelor's degree studies and facilitate their academic and social integration into the university; (ii) students who need support and require guidance in their academic development; (iii) academic support to high level or high-performance athletes, and (iv) students with special educational needs. The education regulations in the field of learners with special needs include physical, intellectual, sensory, and behavioral disorders, specific learning difficulties, and attention deficit hyperactivity disorder (ADHD) [7]. Special care is given to psychological and psycho-pedagogical attention. Different activities and practical resources for personal and academic development are planned. Also, personalized psychological attention is given to students.

Other activities carried out at the UC3M to favor diversity, as shown in Figure1, include actions: (i) to favor the integration of international students, coming from different backgrounds (Erasmus Exchange Programs, Carlos III International School, or YUFE alliance, Young Universities for the Future of Europe); (ii) to promote gender equality; (iii) for scholarships and grant programs to favor the access to education of students under less favoured economic situations; (iv) for cooperation and (v) for digitalization.

In this work, the main actions in diversity at the UC3M will be presented. The results of this work include data on the participation of students and teachers in tutoring programs at UC3M, allowing us to extract some conclusions about the effectiveness of these actions and an in-depth analysis of potential new strategies to deal with diversity among the students. This paper will be a framework for higher education institutions as well as all their members to help them to develop their own strategies for managing diversity.

FIGURE 1: *Scheme of the main actions on orientation and diversity at UC3M.*

II. METHODOLOGY: BACKGROUND, CONTEXT, PARTICIPANTS

The UC3M is among the best young universities in the world, present in several rankings, like the Top 50 Under Fifty, and holding various prestigious accreditations and quality distinctions [8]. The UC3M has approximately 23000 students, being similar in size to some of the major European universities, such as Paris II, Uppsala, Maastricht, Tilburg, Cambridge, and Oxford (all of which have between 14,000 and to 22,000 students). Approximately, 53,6% of the undergraduate students are women and 46,4% are men. Nearly 20% of our students receive grants from the Ministry of Education, from the Community of Madrid or from the UC3M's own funding programs [9] and around 20% of the students at UC3M are international, coming from different countries such as Venezuela, USA, UK, France, Germany, Ireland, etc.

In the Polytechnic School, there are about 6000 students participating in the bachelors' degrees in engineering, most of them taught in bilingual option (English and Spanish) or fully in English. Our degree programs have the most prestigious engineering accreditation in Europe, the EUR-ACE label, awarded by the ENNAEE (European Network for Accreditation of Engineering Education).

The purpose of this study is to introduce and evaluate the advantages of orientation programs for university students to understand their effectiveness and the satisfaction of students. This research was conducted in a young public university, UC3M. The results presented in this paper are focused on the participation of the students enrolled in the School of Engineering, in Leganés, a city in the south of Madrid. In this section, we describe the programs under evaluation and the participation in the last five years.

In relation to the methodological aspects of the programs, different actions are carried out including diffusion among participants, assignment, tutoring action, questionnaire to participants (students/tutors), evaluation of the programs by the orientation committee. In Figure 2, a scheme of the methodology is shown. Next subsections describe the different programs.

FIGURE 2: *Scheme of the methodology*

A. Programs Among Peers

One way to help first-year students is with orientation programs, which will provide a unique opportunity to know the academic environment as well as their institution [10]. During the first year, there are two tutoring options in which first-year students are accompanied by higher courses students who carry out accompanying activities. Tutoring programs also provide additional support in certain subjects and provide support to students with outstanding academic performance. They are distinguished by the closeness and credibility that promote between peers, key elements for the transmission of experience, skills, and knowledge.

The *Compañeros Program* aims to integrate new students through companionship and tutoring by students of higher courses thus facilitating their rapid and successful academic and social integration into the University. For first year students the benefits are undoubtedly clear and for those who already have experience as students as well, since their help is useful and they can obtain the recognition of 3 credits (optative ECTS). Figure 3 shows the number of participants in *Compañeros* in the last five academic years, including students, fellow-students, and teachers participating as tutors.

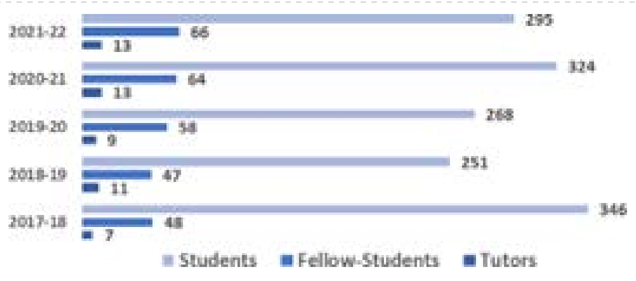

FIGURE 3: *Participants in Compañeros Program in the last five academic years.*

Approximately, around 300 students participate every year in *Compañeros* during the first semester of the first academic year. Each fellow student is in contact with 4–6 new students. The fellow students at the same time are in contact with a teacher who acts as tutor. The fellow-student and the tutor engage in a peer-to-peer relationship. According to our experience, this ratio between fellow-students/students and tutor/fellow students is optimum. Students value very positively this program considering it as a very useful way to adapt to the new life at university. Likewise, the *Buddy Program* offers international students the possibility of having support from students already enrolled in UC3M students to facilitate their access to UC3M, their university life, activities on Campus and life in Madrid. This program is organized by the International Relations Service.

The *Avanza Program* aims to provide additional support for first-year students whose academic results after the first semester have not been satisfactory. With this program, students can improve their situation in the extraordinary exams that are held in May and June. It is also aimed at students who are in a higher course and are at risk of forced abandonment of the degree due to non-compliance with the criteria of the university, according to which students have 6 opportunities to pass a course. Each student can voluntarily join a study group led by another student of the second year or higher of the same (or similar) degree. It is an important tutoring action that makes the preparation of the exams more bearable and helps them not to get discouraged that is quite usual in engineering degrees, and, at the same time, they share their experiences. Usually, the subjects that are the scope of the Program are *Physics, Algebra and Calculus*, and may have slightly different contents, depending on the degree. For this reason, in this program we try to put in contact fellow students and students from the same bachelor's degree. In Figure 4, a schematic chart showing the two tutoring options offered for first year students are presented.

FIGURE 4: *Orientation programs for first-year students, Compañeros, Avanza.*

Figure 5 shows the participants in *Avanza Program* in the last five academic years, including students, fellow-students, and tutors. In this program, the ratio between fellow-student and tutored student is around 3 students/fellow-student and the ratio fellow-students/tutor is between 1–2 students.

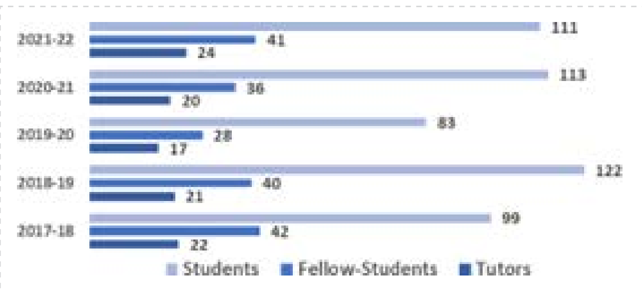

FIGURE 5: *Participants in Avanza Program in the last five academic years.*

In year 2020, there was a drop in the number of students participating in *Avanza program*, probably due to the fact that the start of the program was coincident with the beginning of the pandemic situation (March, 2020). The participation in the program increased, recovering the values prior to the year 2020 in the academic years 2020–2021 and 2021–2022 where teaching was again (partly) onsite.

B. Programs Among Student and Tutor

In higher courses or for students in other situations, there are other programs in which the role of the 'fellow-student' disappears. Here, there is not a *peer-to-peer* relationship among students. Instead, the tutoring program is developed directly between the tutor and the student. According to the current methodology, there are three programs in which the student is in direct contact with a tutor: (i) *Ecuador*; (ii) students with special educational needs and/or disability and (iii) athletes. In the following sections, these programs will be explained with more detail. In Figure 6, the main programs involving the direct contact with the tutor are summarized.

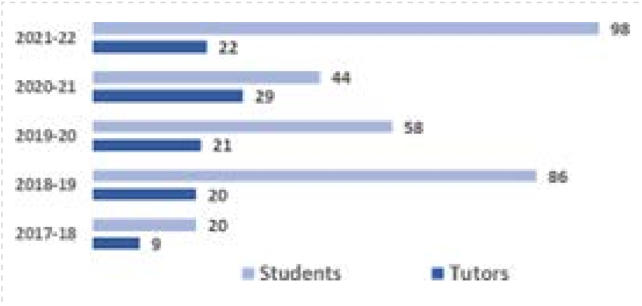

FIGURE 6: *Programs for students involving the direct orientation by a tutor.*

1. Ecuador Program

In *Ecuador Program*, students are in communication with the tutor directly during the whole program. The tutor tries to guide and advise the student in decision-making. The *Ecuador Program* aims to guide and support students who require guidance in their academic development. Participation in the program is voluntary. Students participating in this program will obtain a personalized follow-up based on their needs in key aspects such as: (a) guidance to avoid drop out; (b) guidance for academic and professional development: postgraduate studies, grants, and scholarships; (c) entrepreneurial initiatives; (d) information on the university's guidance and employment offer and services.

The Ecuador program is aimed at students who have taken at least four or more calls of exams of a compulsory or basic subject. The students enrolled in this program are in their fifth or sixth call, that is, they only have two opportunities to pass the course and stay in their degree. The program is also open to students who feel like needing support because they have any problem in their academic life, in the organization of their studies or they are not motivated. The students who participate in the program will obtain a personalized follow-up from a tutor who will analyze their academic situation to give them an orientation that helps them to satisfactorily overcome the subjects. This support is provided throughout the whole academic year. In Figure 7, the data of participants in *Ecuador*

Program in the last five academic years, including students and tutors. It is interesting to highlight the increase in the number of students participating in the program during the last academic year. In this program the ratio student/tutor is around 4-6, depending on the number of students enrolled in the program. For instance, in years 2019-2020 and 2020-2021, the number of students participating in the program was around fifty whereas in the last academic year this number was doubled. Most students participating in *Ecuador* value very positively the actions carried out and the support given by the tutors.

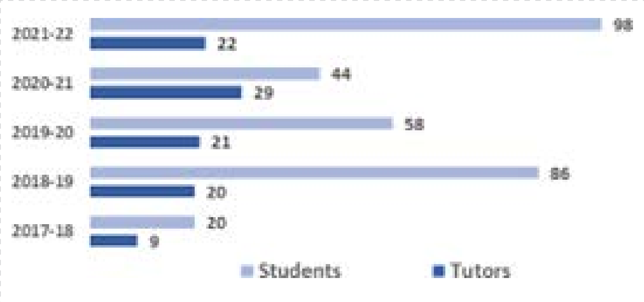

FIGURE 7: *Participants in Ecuador Program in the last five academic years.*

2. *Program of Attention to Students with Special Educational Needs and Disability (SEND)*

The Program of Attention to Students with Special Educational Needs and Disability (*SEND*) allows direct attention to students who can prove to have recognized a disability, special health condition or disorder that may limit their full and effective participation in university activity under equal conditions: (a) physical, mental or sensory disability; (b) autism spectrum disorder; (c) psychological disorders that limit normalized academic performance; (d) chronic or long-term illness that limits academic performance; (e) specific learning difficulties, in writing, in written expression, mathematical difficulty; (f) attention deficit disorder, with or without hyperactivity; (g) students with high intellectual capacity.

The objective of this program is to ensure access to studies and the development of university activity for all students on equal terms, building an inclusive university. The UC3M website of the disability program and specific educational support needs all the information of the program and the current regulations for students at UC3M is gathered. Students visiting the UC3M will have the opportunity to join this program if needed. In Figure 8, the participants in the SEND Program in the last five academic years were included. Since 2020, the number of students in the SEND program has doubled, probably as a consequence of a higher diagnosis.

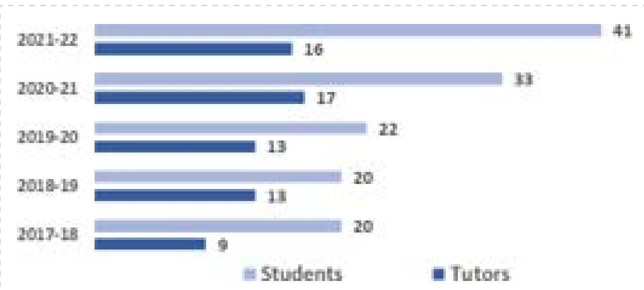

FIGURE 8: *Participants in SEND Program in the last five academic years.*

3. *High-Level and High-Performance Athletes*

High-level or high-performance athletes can have academic support is granted with the tutor and the orientation commission. Other benefits are regulated and normalized to officially accredited High Level and High-Performance Athletes, and to other students who, without having this level, have obtained a medal representing the University in the Spanish University Championships in the previous year. With this program it is intended to facilitate and achieve the effective compatibility of their studies and their training needs. All the information regarding the conditions and benefits of this program for students can be found on the website of the program of high level and high-performance athletes along with the current regulations [11]. In Figure 9, the number of participants in the high-level athletes' program are shown.

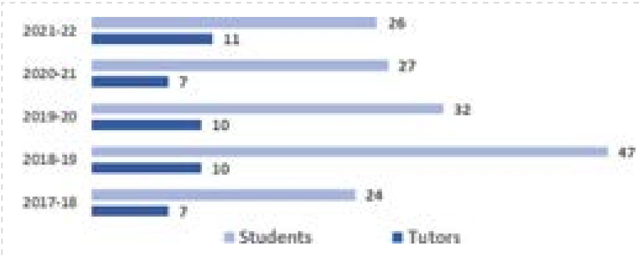

FIGURE 9: *Participants in the Athletes Program in the last five academic years.*

C. Psychological attention

1. *Psychological and psycho-pedagogical attention*

The UC3M offers personalized psychological attention. The scope is to help students to successfully overcome the difficulties and problems they may encounter throughout their studies and life at university. The psychological care service is covered during the whole academic year with a cost of less than fifty euros. During the last year, this service offered online or face-to-face attention. The first session with the psychologist is for diagnosis. Then, the student can be directed to an individual or group therapy, depending on his/her needs.

2. *General courses and workshops*

The Student Orientation Center offers several workshops that address interesting and practical resources and tools to favor students' personal and academic development: mindfulness, stress management, emotional intelligence, communication in sign language, resolution and resilience, adaptability to change, prevention of addictions, love, and sexuality. All of them have credit recognition. Most of the courses offered were face-to-face, but after the COVID-19, online courses were also considered.

D. Scholarships and Financial Aid Support

The UC3M has a program of financial aid for students with good academic performance who are in special economic situations, derived from unforeseen causes. The purpose of this scholarship is to give students the opportunity to continue with their studies in the event of an unfavorable sudden economic situation.

E. Promotion of STEM education and Gender Equality

The UC3M has several programs for the promotion of STEM education among children and teens. For example, the program *Technological Fridays* or *STEM Fridays*, in which secondary school students can participate in training programs and research workshops with teachers in UC3M laboratories. The UC3M participates in *Technovation Girls* competition, a framework for the promotion of science and technology among girls. Also, mentoring actions are done between undergraduate students from UC3M and secondary school students. For students in their final year (bachelor or master) the UC3M is involved in different mentoring programs such as the Mentoring Program with the Royal Academy of Engineering in the project Women and Engineering (*Proyecto Mujer e Ingeniería*), since 2016. Another mentoring program is the one promoted by AIRBUS in the framework of the *WomenNetworkSpain*. Finally, it is worth mentioning other actions for the visibilization of women in Science and Technology such as those carried out in the context of the Cátedra Telefónica of Women and Technology.

III. RESULTS

The efficiency and the efficacy of the tutoring actions were assessed by means of evaluation questionnaires carried out at the end of each program. There is also an open question about the positive aspects of the program and suggestions for improvement (see Table I).

TABLE 1: *Example of evaluation questionnaire*

Evaluation Questionnaire for Students in Ecuador Program			
Campus and center:	Gender:	Bachelor Degree:	Course:

- How many times have you met (face-to-face or online)?
- What communication systems has your tutor used to guide you?
- What have you done in the meetings with your tutor? Explain briefly.
- Information and registration for the program
- Closeness, communication, and willingness to help from your tutor
- Advice and practical information offered by your tutor
- Usefulness of the program in helping you to better approach exams or/and failed subjects.
- Degree of overall satisfaction with your tutor
- Overall assessment of the *Ecuador* Program
- Were you part of a teamwork with colleagues in your same situation?
- If yes. How many times have you met?
- If you have had them, rate from 1 to 5 the degree of usefulness of these meetings with your colleagues
- Did you pass the subjects for which you enrolled in the program?
- Would you recommend this program to your colleagues?
- Which are your suggestions to improve next editions of the program?

The evaluation questionnaires were done to all the participants in the program, students, fellow students, and teachers involved in each case. In 2021-22, approximately 900 students participated in the tutoring programs and about 90 teachers collaborated as tutors voluntarily. In Figure 10 and Figure 11 are shown the average satisfaction of students and tutors respectively, participating in the different tutoring programs.

FIGURE 10: *Students satisfaction with the different tutoring programs.*

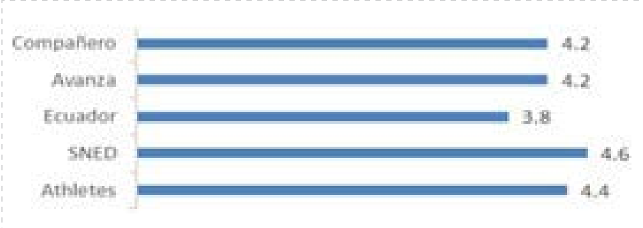

FIGURE 11: *Tutors satisfaction with the different tutoring programs.*

Students participating in *Compañeros Program* value very positively this program and consider it as a program very useful to adapt to their new life at university, learn about the life in Campus and other activities, as it can be observed from the results in Figure 10. In addition, freshmen students valued with a 3.7 out of 5, the perception on how this program helped them in their academic results, thus evidencing that the peer- to-peer approach favors both the integration of students and their academic success. The students participating in *Avanza Program*, also value the fact of being in contact with a peer that has passed the subjects in which they failed. The main criticism in this program is the possibility of having a fellow- student from a different degree than their own. However, basic subjects such as Physics have common programs in many degrees so this is not usually a problem, though there may be slight variations. Students consider that the program moderately helps them to do a better approach to pass the subjects they failed.

In 2021-22, students participating in E*cuador program* evaluated the program with a 3.3 out of 5. The orientation given to face a critical situation in their studies is crucial, but the success depends on several factors. In 2021-22, approximately 33% of the students passed the critical subjects and about 31% passed some of them. These results indicate that it is a good strategy to help students in critical situations. The high-performance athletes consider the academic support a very positive way to cope with the sports career and their studies at university. The satisfaction of students in the program of SEND is difficult to assess as it can vary enormously depending on the context of each student as well as their specific educational needs.

IV. SUMMARY, CONCLUSIONS AND FUTURE ACTIONS

Orientation programs serve as support for academic success in the studies at university. However, when preparing the orientation projects, each university should consider the characteristics of the students. Some universities like Purdue offer summer orientation days for freshmen as a good option for orientation. According to C. Davidson [12]

Outdoor Orientation Programs (OOPs), such as welcome days in Campus help incoming students assimilate into university life and handle the stress of the new social and academic environment. In UC3M, open doors for students interested in accessing UC3M, and welcome days, for new students, offer a good opportunity learn about life on campus, social events, and other activities such as gym, theater or cultural trips.

In Figure 12, a scheme illustrating the tutoring programs offered at UC3M during their four years of the bachelor's degree studies. For first-year students, the 'peer-to-peer' programs are a very good option because they offer an opportunity to get academic support based on the closeness of a peer, thus providing a unique environment that helps them to relieve anxieties and get ready for the academic year. Students at risk of leaving their studies also have the possibility of guidance and personalized orientation with a tutor in Ecuador program. In every program a team of professionals, including psychologist is in close contact with the responsible of the programs at the university (i.e., the orientation commission). Additionally, in year 2022-2023, a new program for students with high capacities will be offered as a new strategy to deal with diversity in our classrooms. Other actions carried out at UC3M include mentoring programs and the promotion of STEM education.

FIGURE 12: *Schematic overview of the tutoring programs offered at UC3M.*

In general, orientation actions offered at the UC3M are a valuable tool and provide the appropriate framework to help students in their academic success. Orientation plays a key role in new students helping them to face the new life at university. The UC3M orientation programs go beyond enrolment, offering several options during their studies, from the first year until the completion of their university studies.

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REFERENCES

[1] K. Strydom, C. J. S. Fourie. "The perceived influence of diversity factors on effective strategy implementation in a higher education institution". Heliyon vol.4 (4), No. e00604, 2018.

[2] Diversity in Education. Learning in a world of differences. Ed: Prof. D. Joshi, Dr. S. Chabra, Dr. I. Dutta. Bookman, 2020. ISBN: 978-93- 90154-33-3.

[3] D. Rock, H. Grant. Why diverse teams are smarter. Harvard Business Review, 4(4), pp. 2-5, 2016.

[4] M. Asim et al. The Evidence for Tutoring to Accelerate Learning and Address Educational Inequities During Canada's Pandemic Recovery. The Diversity Institute of Toronto Metropolitan University, 2022.

[5] S. Oda, A. K. Yamazaki, and M. Inoue, "A comparative study on perceptions of cultural diversity in engineering students," 10th annual International Conference on Education and New Learning Technologies (EduLearn), IATED, Palma de Mallorca, July 2-4, 2018.

[6] Princeton University Peer tutoring Programs (Available Online, 2022).

[7] European Agency for Special Needs and Inclusive Education. https://www.european-agency.org/country-information/spain/systems-of-support-and-specialist-provision

[8] https://www.uc3m.es/about-uc3m/uc3m-rankings-acreditacions

[9] UC3M Financial and Management Report for 2020, approved by the Governing Council and Social Council on 11 June 2021. https://www.uc3m.es/about-uc3m/our-students.

[10] K. Evensen. "Benefits and Level of Satisfaction a First-Year Orientation Program Delivers for Freshmen in College" Master of Arts in Higher Education. Thesis, 2017 (https://pillars.taylor.edu/mahe/92).

[11] https://www.uc3m.es/sport//competitions/high-level_athlete

[12] C. Davidson, A. Ewert. "College Student Commitment and Outdoor Orientation Programming". J. Exp. Educ, vol.43 (3), pp 299-316, 2020.

Technical papers

Investigating the dynamics of women admission to information technology degrees in Russian universities

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***Abstract* — Women remain strikingly under underrepresented in jobs related to engineering and technology; besides, in the US and Europe during several past years the shares of women in technology degrees have generally been showing either decline, or stagnation, or negligible growth. The reluctance of women to pursue engineering and technology degrees finds a variety of explanations, from the lack of interest to the unwillingness to study in a male-dominated culture. Some countries set specific measures to attain women to pursue degrees in engineering and technology and monitor women's admission to Information and Communication Technologies (ICT) degrees at the universities. Others, like Russia, focus mostly on the overall student population admitted to ICT degrees but do not monitor student population gender-wise. The aim of this research effort was to collect and analyze the data on women's admission in undergraduate ICT programs in Russia. The contribution of this study is that no data on women's enrollment to ICT degrees in Russia has been publicly available before. Nine universities in Russia provided these data on women's enrollment in ICT degree programs for several past years, mostly from 2011 to 2021. In 2021, cumulative intake in ICT degree programs of these universities was about 10k students, which constitutes about 1/3 of the total student body in such programs in Russia. Based on the analysis and comparison of the data for Russia with similar data for other countries in Europe, USA and Asia, the overall trend of women admission to ICT majors in Russia is currently aligned with the US and Europe trends. We have observed some fluctuations depending on the geographical location of the universities.**

Keywords — gender diversity in STEM, women enrollment in Information and Communication Technologies programs

I. INTRODUCTION

Global Gender Gap Report 2021 [1] identifies Economic Participation and Opportunity gap as the second largest of the four gaps under study. The speed of closing this gap, i.e., involving more women in the economy, showed positive, albeit reduced, dynamics, and still remains the critical metrics of the index – according to the Report, it will take 267.6 years to close this gap. Clearly, this process needs to be accelerated. Having fully achieved gender parity in terms of access to education and healthcare, Russia now ranks 25th among the 156 countries represented in the latest index in women's participation in the economy.

IT industry is considered one domain where increased women engagement could both contribute to establishing gender parity in economic participation and help overcome understaffing the said industry is experiencing. Global tendency, however, is that women remain underrepresented in jobs related to engineering and technology; besides, during several past years the shares of women in technology degrees have generally been showing either decline, or stagnation, or negligible growth [2]-[6]. In view of the generally recognized underepresentation of women in STEM, the means to further reduce gender asymmetry is to attract more women to relevant educational programs and to subsequently retain women in STEM jobs.

To attract more students to pursue careers related to Information and Communication Technologies (ICT), a number of measures have been taken in Russia, but the growth has either slowed down or has been replaced by decline [7, p.123]. The reluctance of women to pursue engineering and technology degrees and jobs finds a variety of explanations, the lack of interest, prevailing gender stereotypes, unwillingness to study or work in a male-dominated culture among them [8]-[10]. Though the question is open on whether extra effort should be put in attracting women to study ICT or should existing numbers and shares of women in the said programs be perceived as natural and kept as they are [11], some countries set specific targets to attain women to pursue degrees in engineering and technology and monitor enrollment of women to ICT university degrees. Russia traditionally focuses on the overall student population admitted to ICT degrees but does not monitor student population in terms of gender parity. To the best of our knowledge, to date no studies or data on the enrolment of women in undergraduate ICT degree programs in Russia is publicly available; hence the primary aim of this study was to collect such data and compare them with the global trends. Another target was to find out whether universities collect such data and whether they will be willing to share such data for research purposes. In this study we aimed to answer three research questions:

RQ1: What is the share of women in ICT undergraduate degree programs in Russia?

RQ2: What is the dynamics of the share and of the number of women in ICT undergraduate degree programs in Russia?

RQ3. How do the universities under study compare to each other in terms of gender diversity in ICT undergraduate degree programs?

The rest of the paper takes a form of three chapters: Methods, where we describe data collection process; Findings, where we present the collected data and its analysis; and Discussion and conclusion, where we discuss the implications of the study results as well as its limitations, and propose the focus of further research.

II. METHODS

This study is an exploratory research effort. To collect the data, we identified fifteen universities in Russia that meet the following criteria:

- they run ICT degree programs
- they are located in different federal districts of Russia
- they represent both new and established organizations
- they are likely to provide the requested data as they are contacts of the research team

The requested data were the number of women enrolled in ICT undergraduate degree programs, by year, and the total number of students enrolled in the said programs, by year. Nine of the 15 universities have provided the requested data within the study period (Table 1). These universities belong to five of the eight federal districts of Russia. The data were collected between December 2021 and February 2022 by direct requests.

For the calculations of the average annual growth rates of the shares and the number of women enrolled in undergraduate ICT degrees, we used formula:

$$((End\ Value/Start\ Value)^\wedge(1/Periods)\ -1 \qquad (1)$$

TABLE 1: *The list of the universities that provided data for the study*

Full university name	Short University name	Year founded	Federal District of Russia
Innopolis University	Innopolis	2012	Volga
Far Eastern Federal University	FEFU	1899	Far Eastern
Kazan National Research Technical University named after A. N. Tupolev - KAI	KAI	1932	Volga
Moscow Institute of Physics and Technology	MIPT	1946	Central
Northern (Arctic) Federal University	NARFU	2010	Northwestern
Peter the Great St. Petersburg Polytechnic University	Polytech	1899	Northwestern
Saint Petersburg State University of Aerospace Instrumentation		1941	Northwestern
Southern Federal University	SFEDU	1915	Southern
The University of Management "TISBI"	TISBI	1992	Volga

III. FINDINGS

A. Data collection method

The data were requested from 15 universities, where the research team are affiliated or with whom the research team had been collaborating. The assumption was that partners will be more willing to share the data. Nine of the 15 universities (60%) that were requested the data provided them within the required period. The data that we have collected in this research represent around 1/3 of the total student body in ICT programs in Russia. The evaluation of this outcome, as well as the reasons for it should be further studied.

Clearly, however, to collect more data, the strategy will be to target more educational institutions and to specifically focus on the representation of all the Federal districts. Besides, the range of data can be extended, e.g., reasons for the intake numbers and the shares fluctuations, dropout rates and their reasons, conversion rates from intake to graduation, degree change rates for female and male. Further research will also investigate if the universities monitor their graduates' career paths to find out 'career dropout rates' in ICT jobs in Russia; this interest is inspired by Athena factor project [10]

B. Results

The shares of women enrolled in undergraduate ICT degrees in the universities under study (Table 2) mostly remain in the range of 15% to 30% (Figure 1), *mode*=26, *median*=23. This persistence, along with the growth of vacancies in IT companies and the general absence of the admission targets at the universities and state level for women in the said degrees, can indicate a well-established view of educational and general community on women in IT. Another observation is that universities with higher total enrolment seem to demonstrate more stable average annual growth rates of the shares of enrolled women (Table 3); this effect might be due to particular ICT degrees where female students will be more willing to enroll; the matter, however, requires further investigation.

Further, we observed a somewhat positive correlation of the growth of the number of women enrolled in undergraduate ICT programs with the growth of the total number of applicants in the said programs (Figure 2).

In general, the number of women enrolled in ICT degrees was increasing from 2009 to 2021 (Table 4). A significant increase in the numbers after 2011 is associated with an increase of the available data from statistics on universities. The drop in 2021 is due to the lack of the data for this year from one of the biggest contributors, MIPT.

TABLE 2: *The shares of women enrolled in ICT undergraduate degree programs by university, by year, %*

Uni/year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Innopolis					19	21	17	23	15	15	19
								20	25	30	23
KAI				21	23	19	27	17	15	19	17
MIPT	21	26	25	23	24	26	28	26	25	26	
NARFU		22	27	22	18	26	26	26	25	28	17
Polytech		25	25	25	26	29	30	30	29	29	29
				17	4	22	25	24	25	26	26
SFEDU					30	24	23	22	21	24	21
TISBI		16	18	19	14	22	27	13	8	16	22

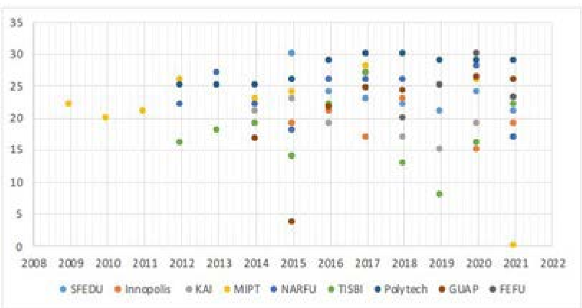

FIGURE 1: *The dynamics of the shares of women enrollments in ICT undergraduate degree programs.*

TABLE 3: *Average annual growth of the shares of women enrolled in ICT undergraduate degree programs by university, by year, %*

University	Average annual growth rate of the share of women in ICT degrees in the last four years (2018 - 2021)	Average annual growth rate of the share of women enrolled in ICT degrees within 2011-2021	Total number of students enrolled in ICT degrees in 2020
Polytech	-1%	2%	3926
GUAP	3%	6%	3251
MIPT		2%	1376
SFEDU	-2%	-6%	809
KAI	0%	-3%	553
FEFU	5%	5%	369
NARFU	-13%	-3%	242
TISBI	19%	4%	191
Innopolis	-6%	0%	180

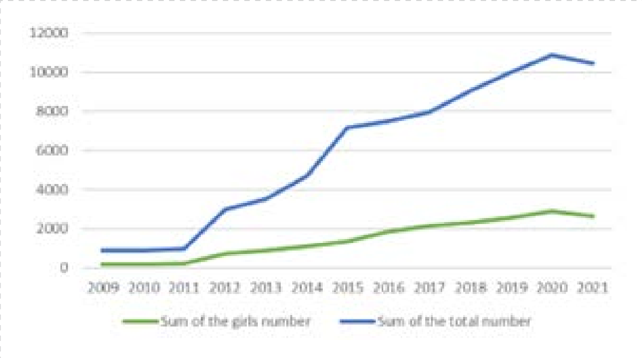

FIGURE 2: The dynamics of the total number of enrolled students and the number of enrolled women in ICT undergraduate degree programs. Y axis represents the number of students.

The largest increase in the number of women (Figure 3) is observed in 2016 in two universities in the northwestern federal district of the country: Polytechnic University and GUAP. This may be due to a change in the training policy in the said district or in specific universities (for example, an increase in the number of state-funded seats; at the same time, no new areas of training were opened in these universities during this period). The case of GUAP is particularly interesting: in 2016, the number of women increased by 6.6 times compared to the previous year. At the same time, the total number of students enrolled in ICT degrees increased only by 1.13 times during the same period. However, a significant increase in the total number of the enrolments was a year earlier: in 2015 it increased by almost 4 times compared to 2014. At the same time, the number of girls decreased.

Most of the universities under study demonstrate the increase of the average annual growth rate of women enrolled in ICT degrees (Table 5). The outlier metric for FEFU might be due to the limited number of years analyzed (four). Polytech and GUAP, which enrol the highest number of women in ICT degrees, also show the highest average annual growth rate (Figure 4).

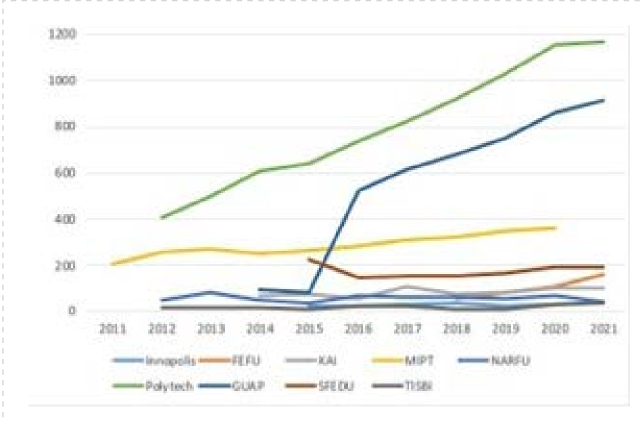

FIGURE 3: The dynamics of the number of enrollments of women in ICT udergradute degree programs. Y axis represents the number of students.

TABLE 4: The number of women enrolled in ICT degree programs by university, by year

Uni / year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Innopolis					23	26	32	34	26	27	43
FEFU								54	79	111	163
KAI				66	73	59	109	74	84	100	104
MIPT	206	260	273	252	266	285	312	320	346	362	
NARFU		49	79	50	35	69	65	62	55	67	44
Polytech		404	500	609	637	735	820	918	1030	1151	1166
				94	79	521	613	680	750	859	915
SFEDU					223	150	153	156	169	194	193
TISBI		16	15	19	11	21	22	13	8	30	37
Total	**206**	**729**	**867**	**1090**	**1347**	**1866**	**2126**	**2311**	**2547**	**2901**	**2665**

TABLE 5: The average annual growth of the number of women enrolled in ICT degrees, 2011-2021

University	Average annual growth rate of the number of women in ICT degrees, within 2011-2021	Number of women enrolled in ICT degrees in 2020
Polytech	12%	1151
GUAP	12%	859
MIPT	6%	362
SFEDU	-2%	194
FEFU	45%	111
KAI	7%	100
NARFU	-1%	67
TISBI	10%	30
Innopolis	11%	27

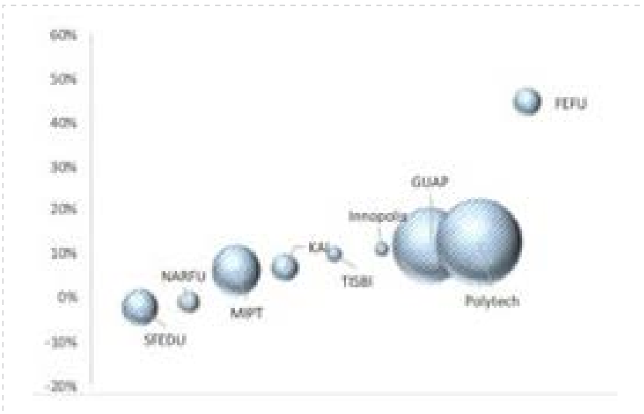

FIGURE 4: Average annual growth rate of the number of enrolled women, 2011- 2021. The size of the data points represents the number of the women enrolled in ICT undergradute degree progrm of a particular university in 2020. The vertical axis represents the growth rate, %.

NARFU and SFEDU showed the decrease of both the average annual rates for the share and for the number of women enrolled in ICT degrees. Two universities in the Northwest federal district, Polytech and GUAP, the most significant contributors to the metric of the number of women enrolled in ICT undergraduate degrees among the universities under study, show the increase of both of annual average growth rate of the share of women and the number of women.

Hence, though the ultimate target of the universities is to increase the number of ICT graduates, the increase of the share of women might also be a relevant task for this goal.

IV. DISCUSSION AND CONCLUSION

The major findings are related to (1) data collection procedure; and (2) gender diversity in ICT undergraduate degree programs.

In terms of data collection, the procedure proved that universities have gender-wise data of their students, and substantial shares of universities are willing to share such data. For further step of the research the procedure should be elaborated in order to engage more universities located in all the eight federal districts in Russia and to collect other relevant data, i.e., women dropouts in ICT degrees and career paths, relevant events that could impact the increases and decreases of the metrics, e.g., opening a new program, merging with another university, getting funding for women enrolment specifically. Such data will allow to plan for admission campaigns, to introduce curricular that will in turn allow universities to attract more women in ICT programs while wisely allocating funds. Career paths analysis is essential as graduating increased numbers of women in the economy might not meet the goals of the market; for example, Athena Factor project showed that around 41% of women in high tech tend to leave their jobs in corporations, and half of them abandon altogether occupations they were trained for further in their career [10].

Regarding gender diversity in ICT programs in Russia, the collected data indicate that women are under-represented in ICT undergraduate degree programs – the highest share of women in the said degrees is 30% in Polytech, and these metrics have mostly fluctuated between 15% and 30% in the universities that are young or established, big or small, of narrow or broad specialization, for about 10 consecutive years. These values coincide with similar metrics for the US (e.g., reports from 2011-2012 to 2019-2020 in [5] show that the total numbers of awarded bachelor's degrees in Computer Science, Computer Engineering, and Information increased from 13% to 21.5%) and Europe (e.g., in [4] for 2016 the shares of women in ICT degree programs ranged from 8% in Belgium to about 31% in Romania). Such under-representation of women in ICT degree programs in Russia can be explained by the lack of deliberate efforts of the universities to attract more women to the said programs, and the reluctance of the state to enforce such a policy, which is not necessarily counter-productive. Russia government has recently announced a national project for promotion of engineering education – Advanced Engineering Schools, one of the major target domains is ICT[1]. This initiative clearly signifies the urgent need of qualified engineers in general and CS engineers in particular, in the economy of the country. The increase of the number of qualified engineers can be achieved by addressing more intensively a "new" audience – women. It should be noted, though, that Russia ICT degree programs can hardly be the only source of female staff for IT companies. Online non-degree programs as well as life-long non-degree programs provided by the universities or other educational organizations can contribute to meeting the market need.

The limitations of this study are mostly related to the nature of exploratory research, the main one is that some results of such research efforts are usually hard to generalize. We find the results related to data collection process sufficient and useful for determining the design of our further broader research. However, though the collected data represent as much as 1/3 of the population of the students pursuing ICT degrees [7], the number of the universities that provided the data on the enrolment was lower than we expected, and several federal districts are either absent or under-represented, which makes these data not generalizable. However, we consider the mere fact of the publication of the data of the shares and numbers, as well as the dynamics of those metrics, on the women enrolment in ICT undergraduate degree programs in Russia to be the main contribution of this work.

For our further broader research, we will target universities and other educational institutions which are more or less established contacts of the research team or their universities – either through research or through educational collaborations. Future research can go in several directions, namely, the ways to attract and retain women in ICT degree programs, the comparison of the enrolment and retention rates of the students of degree vs non-degree ICT programs, online vs remote vs offline ICT programs, their contributions to the labor market, and the ways to retain women in ICT jobs.

REFERENCES

[1] World Economic Forum. 2022. Global Gender Gap Report 2021. [online] Available at: <https://www.weforum.org/reports/global- gender-gap-report-2021/> [Accessed 30 July 2022].

[2] Unesdoc.unesco.org. 2022. [online] Available at: <https://unesdoc.unesco.org/ark:/48223/pf0000377433/PDF/377433e ng.pdf.multi.page=129> [Accessed 30 July 2022].

[3] "Statistics explained," Statistics Explained. [Online]. Available: https://ec.europa.eu/eurostat/statistics- explained/index.php?title=ICT_specialists_in_employment#ICT_specia lists_by_sex. [Accessed: 30-Jul-2022].

[4] R. Colomo-Palacios, C. Casado-Lumbreras. "National cultures and gender balance in ICT: A preliminary study." Proceedings of the 13th European Conference on Software Architecture-Volume 2. 2019.

[5] S. Zweben, B. Bizot, "The CRA Taulbee Survey," Computing Research Association [Online]. Available: https://cra.org/resources/taulbee-survey [Accessed: 16-Oct-2022].

[6] Un.escap, “ICT for Development Education for digital inclusion in Asia and the Pacific,” Repository Home, 07-Apr-2020. [Online]. Available: https://repository.unescap.org/handle/20.500.12870/606. [Accessed: 30-Jul-2022].

[7] “ТРУД И ЗАНЯТОСТЬ В РОССИИ (“Jobs and employment in Russia”) -Gov.ru,” Росстат (Rosstat). [Online]. Available: https://rosstat.gov.ru/storage/mediabank/Trud_2021.pdf. [Accessed: 30-Jul-2022].

[8] T. Stanko, O. Zhirosh, and D. Krasnikhin, 2014, December. Why girls with an interest in IT in high-school do not choose an IT career. In 2014 International Conference on Interactive Collaborative Learning (ICL) (pp. 131-137). IEEE.

[9] T. Stanko, and O. Zhirosh, 2017, November. Young women who choose IT: what role do their families play?. In 2017 7th World Engineering Education Forum (WEEF) (pp. 88-93). IEEE.

[10] Hewlett, S.A., Luce, C.B., Servon, L.J., Sherbin, L., Shiller, P., Sosnovich, E. and Sumberg, K., 2008. The Athena factor: Reversing the brain drain in science, engineering, and technology. Harvard Business Review Research Report, 10094, pp.1-100.

[11] V.A., Lagesen, I., Pettersen, and L., Berg, 2022. Inclusion of women to ICT engineering–lessons learned. European Journal of Engineering Education, 47(3), pp.467-482.

Technical papers

African diaspora engineering education student experiences in the US: A collaborative autoethnographic study

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***Abstract* — The number of students of African origin traveling abroad for postgraduate engineering education has increased over the last 30 years. Studying abroad provides unique experiences and benefits for African students and the host country. These experiences place international scholars in an ideal position to reflect on the different experiences between the practices, attitudes, social diversity, and competency development they find in their new study destinations and hence can make suggestions for improvement in their home and host countries. This paper explores the experience, reflections, and adaptation of African scholars to their international educational context during the COVID pandemic, using a collaborative autoethnography methodology. Elements of the theoretical frameworks of acculturation theory and adaptability theory were used in the collection, analysis, and discussion of the paper to address the following research questions: 1) What are the experiences and perspectives of African Diaspora graduate scholars in undertaking engineering education studies in the US? 2) What improvements are suggested for the study environments in their home countries and in the US? The findings raise provocative thoughts about the culture of and the philosophies behind the present nature of instruction, assessment, student supervision, experiences, and workload in the US and African countries. We argue for a need to disrupt several realities that have become a norm for African diaspora students and suggest how this can be done drawing from our own experiences within these unique environments.**

Keywords — diversity, inclusion, African diaspora, engineering education, studying abroad

I. INTRODUCTION

Studying abroad provides unique learning experiences for students. Consequently, for the past thirty years, there has been an increase in the number of students from Europe, Asia, and Africa studying abroad, the United States (US) being a major destination [1], [2]. International students' decision to study outside the shores of their home countries has been found to be informed by social, human, and cultural capitals [3]. While African students tend to gravitate toward international environments for postgraduate study, reports show that they seek to uphold their identities, arguably because they are aware of deep colonial histories between their nations and the host nations [4]–[6].

Study abroad is not only beneficial to the students but is also a key contributor to the economies of the host nations. Studies conducted in 2018 showed that the US alone generated a revenue of over $40 billion through international students [7] although this figure dipped during the global Covid-19 pandemic [8]–[10]. Aside from economic benefits, the arrival of international students to the US has also been linked to the development of the sociocultural awareness of American students [11]–[14]. Interculturally competent graduates are highly sought after by US employers [15]– [17]. Conversely, the migration of students to the West has also been criticized for reducing the talent pool of developing nations [7] begging the question that these countries are responsible for an unending case of "brain drain" [18], [19]. We draw the attention of the reader to these underlying issues because international students are constantly grappling with them in their respective programs.

The literature surrounding the acculturation and adaptation of international students is extensive [13], [20]–[22] but the use of the umbrella term "international students" has been skewed towards students from Asia, Europe, and the

Americas [23]–[25], with significant focus on the experiences of undergraduate students. Our review of the literature revealed that an ubiquitous term like "international" subsumes many people groups. The few studies that talk about the experiences of African students studying abroad describe the stress, struggles, and racial discriminations they face while adapting to their study environments [26]–[29]. Unsurprisingly, there is still a large gap in the scholarship of the considerations, thoughts, anxieties, and experiences of African diaspora scholars, much more so in engineering education. This provides a unique opportunity to engage in a group inquiry on the experiences of African graduate scholars studying in the US, involved in engineering education research.

The aim of this study is to explore our varied experiences as African students and scholars studying in the US through a collaborative autoethnographic study. Our study is guided by the following research questions: 1) What are the experiences and perspectives of African Diaspora graduate scholars in undertaking engineering education studies in the US? 2) What improvements are suggested for the study environments in their home countries and in the US?

II. THEORETICAL FRAMEWORK

Our study unpacks the experiences of African international graduate students and scholars using a conceptual understanding that borrows from acculturation theory [30], and an adaptability framework [31]. These theories have been developed and extensively used in the literature surrounding cross-cultural mobility and integration [32]. Consequently, they were useful to help us conceptualize the processes by which international students navigate their cultural and social identities in diaspora. We used the four definitions of assimilation, integration, separation, and marginalization suggested from acculturation theory to develop reflection prompts for ourselves. Our two core research questions were developed from these reflection prompts.

Leveraging Martin and colleagues' work [31], we modified the tripartite dimensions of adaptability namely, cognitive, behavioral, and affective in analyzing the data. The cognition dimension was conceived as philosophical (thinking), behavioral as social and cultural, and affective as emotional. As we reflected on our individual and collective responses to the reflection prompts, we went back to the foundational theories to help make sense of what we were seeing in the data and this led us to include the material/physical dimension.

III. POSITIONALITY STATEMENT

The authors who are also the participants of this study are nine African scholars (eight doctoral students and one short-term research scholar) who are currently studying at six universities across the US. We consist of six males and three females, representing our home countries of Liberia, Nigeria, South Africa, and Uganda (hereafter collectively referred to as "home"). We all have undergraduate engineering qualifications and collectively have diverse experience across industry and academia with various portfolios ranging from early career researchers, specialists, management, and thought leaders in engineering education. Whilst we have varying epistemological and ontological paradigms, we have agreed to take a collaborative constructivist approach in this study. We recognize that our constitutions as Africans studying internationally are laced with our own views and perspectives tied to our backgrounds and individual experiences. These factors are never fixed, are constantly evolving, and ever present in research [33]. Thus, we do not deny that these inherent biases shape our methodology and how we report our findings in this study. Most importantly, we do not claim that these findings are representative of the experiences of all international African students' studying engineering education abroad.

IV. METHODS

The study takes a collaborative autoethnographic approach, a qualitative research method conducted by two or more researchers dialoguing to analyze and interpret the collection of autobiographic data [34]. Collaborative autoethnography enables the articulation of insider knowledge of a cultural experience from one's own position and experience [35], [36]. It allows multiple researchers to contribute to data generation, analysis, and writing and hence provides multidimensional perspectives to the research [34]. Also, collaborative efforts in engineering education are important to foster student identity formation [37], [38].

Our collaborative autoethnographic study was developed through a series of online discussions, using Zoom. This related to our experiences as nine African students with experiences in the United States and at home. These discussions were led and facilitated by the lead author with rules of engagement and confidentiality requirements clearly articulated and agreed amongst all participants. The data were collected through a combination of a survey and three open- ended collaborative discussions. We initially generated a series of discussion prompts and an online survey-style living document based on the theoretical framework which was used as a roadmap for the discussions. We responded to the discussion prompts in our spare time offline, and the online meetings were used to facilitate collective reflections and narratives. During the meetings, our discussions fostered revisions and updates based on the follow-up questions we had for each other. Throughout, we sought to understand and clarify each participants' thoughts and experiences.

With the data from the written survey and follow-up open discussions, meetings were scheduled to collaboratively analyze the data. The theoretical framework was used to initially synthesize the results, and the results underwent a member checking process for the authors to validate and verify whether their information and views had been captured accurately and described coherently.

V. RESULTS & DISCUSSION

The analysis identified 12 thematic areas, of which we only extensively discuss instruction, assessment, and workload in this paper, as these most closely align with the conference theme. In addition, our analysis revealed extensive data for these 3 areas. The four dimensions identified from the theoretical framework: social/cultural, philosophical, physical/material, and emotional were integrated into each of the thematic areas to improve readability. Our discussions and reflections cover the breadth of our adaptations to the education systems in the US, which include disruptions experienced due to the COVID pandemic. We also offer our perspectives on why differences exist between our home and host contexts and suggest improvements. All claims and reported results in these sections are solely based on the analysis of the experiences of the 9 participants.

TABLE 1: *Number in consensus*

Grouping	None	Few	Some	Most	All
Number of people	0	2-3	4-5	6-8	9

In the discussion section, when we refer to "few", we infer that the response was agreed by "2-3 people"; "some, 4-5"; and "most, 6-8". Where appropriate, we specify when one, none, or all participants agreed with the assertions (See Table 1).

A. Instruction

The first theme illustrates how we experienced the varying modes and means of instruction in the US and at home.

1) Mode of Instructional Delivery - Active, Blended, Collaborative (ABC) Learning

The culture of instructional delivery in higher education is differentiated along the lines of student-centered teaching and the traditional style of lecturing [39]–[41]. In our reflections, we realized that several classes we took as graduate students in the US required active participation as opposed to the traditional style of teaching at home. One participant reflected:

"I think that some of the lecturers here (US) have really embraced new educational methods…where lecturers are mostly facilitators. Back at home I faced the sage-on-the-stage type of instruction in many cases."

This comment reveals our preference for student-centered classes because we believe that students are both intellectual and social beings. Hence, we argue that engaging interactions should be a key component of instructional design. We discovered increased learning gains when the classroom culture is actively engaging rather than passive. Ironically, despite the associated benefits of active learning, a few of us reported peculiar cases where it was overdone in some classes in the US, limiting the time for deeper reflections:

"… [active learning activities] can be mentally exhausting sometimes. In some activities, we just zoned out".

We also shared differing views on our adaptation to the 'unusual' learning environment created by COVID. While most of us felt we adapted well to the remote style of instructional delivery in the US, a few of us could not mask our struggles with this mode of teaching. An excerpt from the camp of those who adapted well to the change is presented:

"I started my PhD program in an online environment, and I am really happy [it] exists since I needed to be at home during the initial stages of the COVID pandemic. I adapted quite easily…remote classes can actually be useful since you can have access to your computer while you work."

It is important to problematize the fact that this statement assumes that students already have resources that make online learning possible i.e., computers, internet, and electricity [42]. Conversely, those among us who struggled with online learning, despite having these resources complained about what exactly it cost us. In the words of one participant:

"Remote classes are not my [preferred] method of learning, I prefer in-person classes and group study. I was robbed of my preferred means of learning during the Covid- 19 outbreak."

Upon reflection, for those of us who struggled with remote learning, we believe our struggle stemmed from the fact that it deprived us of an especially vital component that we culturally enjoy i.e., in-person interactions. On the other hand, the yearning to experience 'newness' could be the underlying factor responsible for those of us who adapted easily to remote learning.

2) Means of Instructional Delivery - Different Strokes for Different Folks

Cultural differences have a strong impact on the learning experiences of international students [43]. Perhaps nowhere is this more prominent than in the ways we adapted to new accents, sports metaphors, or pop culture references. This expectedly introduced some learning difficulty for us within the first few months of our arrival in the US, especially understanding some illustrations or even jokes made by instructors, to which everyone laughed except for the international students. In the words of two of the authors,

"I had to become more and more comfortable with telling instructors - "Please, can you repeat what you just said? What was that? I am not familiar with that reference." Teachers sometimes speak so fast that [even] my relatively well- developed 'listening skills' struggle."

"Other times, they [instructors] make references to American shows or movies that may be so popular to the rest of the class, but I have no idea what they are saying. It was embarrassing at first. But as I practiced asking for clarifications, I realized I learned more, I even gave students like me who struggled the permission to ask about and understand things better."

Clearly, these references are grounded in the cultural orientations of people in the US. However, we observed that pushing through the discomfort of asking for clarifications not only helped us, but also gave other international students who were hesitant to pause the flow of class a sense of belonging and the boldness to ask for clarifications themselves.

B. Assessments

The second theme concerns our experience with the different forms of assessments at home and in the US. We discussed the designs of assessments and the differences in the philosophies behind the designs. We also discussed the intention: whether it was to pass students or weed them out, to create an elitist system or an inclusive one?

We all reported the abundance of both formative and summative assessments at home; summative assessment being the final examination and formative referring to assessments prior to the final examinations [44]. At home, formative assessments are not weighted highly, and are generally low-stakes assessments, therefore students do not necessarily focus on them [45]. Furthermore, we observed that students' performances on these formative assessments have little bearing on their successes in the course. Consider one of the author's frustrations over this:

"It makes it very difficult for you to do projects, because the question you ask yourself is - all these projects I'm doing, for just 30 marks?"

Conversely, our experience in the US shows that all assessments prior to the final assessment are weighted much higher than at home and are based on assessing your learning progressively. Hence, they are taken more seriously by students. Furthermore, it is rare in the US that a concept will be tested more than once. Unlike at home, understanding of concepts in the US will either be tested in the formative assessments or final examinations, but rarely in both.

Assessments in the US are based on clearly communicated outcomes, and students know what is expected of them, unlike many of the assessments experienced back home. This difference took some time for us to adapt to, which caused some level of anxiety. We were mostly used to expecting some trick questions or questions that were ordinarily not covered in the lecture or suggested material content. To address trick questions at home requires different learning strategies. Students often practice different types of problems, and in some cases, consult textbooks and other material that were not suggested by the lecturer. One respondent commented:

"If you're doing an undergraduate engineering qualification and you just superficially go through the content, you're not going to make it. You would have to either get thorough conceptual understanding or attempts several examples just to understand how those concepts work"

Initially, some of us decided that we should use the same strategy in the US. We learned over time by observing how students in the US approached assessments; that it was better to focus mainly on the outcomes illustrated in the course. Many of us adjusted accordingly, especially during periods of high workload. Another respondent contributed to the discussion thus:

"They (students in the US) can just submit against those outcomes in like maybe a couple of hours, and I'll probably spend 2 days trying to understand more than what those outcomes require...It was perhaps because I was not used to the outcome-based system that they know. I didn't learn like that. I learned to understand the depth of a concept rather than focusing on the outcomes"

A possible consequence of this outcome-based assessment design is that students in the US can become very mechanical, master the art of ticking the boxes without necessarily digging deep for understanding [46]. This could make them less prepared for real-world problems which are known to be ill- structured and rarely ever designed like exam questions.

As we dug deeper into the reasons behind these differences in the design of assessments in our home and host countries, we began to see a pattern. At home, there appears to be an elitist system of creating engineers [47]. The facilitation of learning and assessments are designed not for people to achieve outcomes, but to separate people based on their approach to learning, and their intellectual prowess [48]. Few participants explained that at home, the profession of engineering was historically restricted to certain race groups for a long time. Other categories of engineering professionals were created like technologists and technicians. Although this seemed to be politically justifiable, it still served to create an elitist system within the engineering profession. Other participants reported a similar form of elitism. All of us seemed to agree that our patriarchal systems had historically marginalized women from the field. We have seen similar situations in the US although they are not as prominent.

Finally, some of us believe that in our home countries, even if the undergraduates graduate with top class degrees, they lack relevant technical skills for the workplace. This can be inferred from the following excerpt:

"I studied software engineering; [yet], I couldn't code after 4 years of learning programming. I couldn't program but I passed all the exams"

This was not a consensus finding across all our home countries and respective programs in Africa. Some programs had assessment systems not being aligned to skills required by industry, which meant that intensive learning programs were required to bring undergraduates up to speed within industry:

"They [graduates] either have to do another course, or they have to learn everything from scratch in the workplace environment"

Despite the assessment methods at home, we saw our undergraduate education context giving us a strong foundation for the workplace, even though the required technical skills were not aligned to industry. Our ability to get through an educational system with the type of assessments experienced, combined with limited defined outcomes and minimal resources and support from our home educational system, required us to be resourceful in attaining what we needed to succeed. This we believe gave us an opportunity to develop learning skills, engage more in peer support, and made us more adaptable and innovative in our approach to learning and engineering.

C. Workload

When discussing workload in the US, we included coursework, research, assistantship or fellowship responsibilities, and leadership activities. We compared workload in our home countries and the US, and how we adapted to them during the COVID pandemic.

1) Comparing Workload in the US to our Home Countries

The most prevalent theme that we discussed was the high workload in the US. The reason for this is due to the combination of different tasks that students and faculty are expected to do. For example, a graduate student can work on research projects, coursework, their dissertation, or leadership roles in the university or community [3]. One of the largest elements which contributed to the high workload was coursework:

"The workload was high given my learning approach, but also there are assignments due almost every week. Added to my dissertation, supervision, and paid work, it sure got to over 80- and 90- hour weeks"

The common notion is that 40-hour weeks (20 hours for assistantship work and 20 hours for coursework) is the norm for international students during the study semester. However, in this excerpt, the student reports that the amount of combined time is twice what is expected. The coursework has detracted them from their assistantship and dissertation work. Another student discussed how the workload can also sometimes be self-inflicted due to personal goals they have set:

"My workload is quite heavy here in the US. I am trying to complete my PhD quite quickly and I am taking many courses. I have fewer family and friends here in the US, so I am able to focus more on myself and my work."

There were also several comparisons drawn between the workload in the US and the workload at home. This student is commenting on how much more time or energy taking a course in the US is when compared to a course in their home country:

"Workload in the US is super dense compared to my home country. I jocularly tell my friends that taking two courses in the US equals taking 8 in my home country."

However, one participant commented: *"Changing fields, the work was the same, but the nature and timing of the work was different"* to which most of us agreed. We thus perceived that the workload was not necessarily higher, but the transition from engineering to engineering education caused the workload to appear higher.

2) Adjusting to the Workload

When discussing the workload, many of us spoke about the factors that influenced how we adjusted to life in the US as it related to our graduate studies. Being in a different country where the social and cultural norms are different to that of most African countries, makes adjusting to the workload challenging [1]. One of us compared the traditional US student who has been living in the US their whole life to an African international student:

"I think that we are also not used to how to manage the workload here, because we are not cultured in this system, unlike people in the US."

The educational system is also quite different and some of us found that the workload can be overwhelming to transition into because of that [2]. However, some university departments in the US do build in time for students to transition during their first year of studies. This works to some extent. To cope, most of us also learned that we needed to prioritize our choices when invited on to new projects that grab our attention as described by a participant:

"The best word that a grad student will ever learn to say is NO. I can stand by that. It took years but I later learned to say NO to requests to meet, invitations to be a part of this paper or that. Only if it falls perfectly within the purview of my future work will I say yes. There are so many shiny interests in grad school in the US. Not everything that glitters deserves your attention."

This excerpt presents the idea that a student will have to prioritize their workload choices at times to either focus on their coursework, dissertation, assistantship work, or student experience. This poses a challenge without adequate guidance, support and mentorship.

D. Other Considerations

Other thematic areas of our discussion included graduate student supervision, cultural inclusion, leadership roles, system trustworthiness, approach and barriers to change, resources and financial stressors, ethics, and overall experience. All of us agreed that the choice of a graduate supervisor is an important life decision, and that power differential in the student-supervisor relationship is more observable at home. In the US, this is less obvious. Another consensus we reached is that research supervisors in the US are more easily approachable than at home where ageism is more prevalent. We also discussed the approach and barriers to change for faculty in the educational systems at home and in the US. At home, we think stakeholders' reluctance to adapt to change stems from the bureaucratic systems, the philosophy of respecting tradition, and the fear of becoming redundant in the face of change. Also, we identified limited teaching and research funding in engineering education as a significant issue at home. This could be responsible for the prevalent traditional lecture-mode of teaching we find at home.

We discussed several financial stressors that we experience in the US and at home. Lack of access to scholarships and grants is a big issue at home for students and faculty. International students also have less access to funding in the US compared to nationalized US students. In the US, other financial stressors include cost of medical care, accomodation, food, parking, and credit. Leadership roles for students appear less respected and supported in the US compared to home. The US provides better educational resources, that are easier to access compared to what we find at home. The understanding, respect, and execution of policies is a big concern in most of our home countries which is very different compared to our observations in the US.

VI. RECOMMENDATIONS

To address our second research question, we categorized our recommendations under instruction and course design, assessment, inclusion, transition, and support.

A. Instruction and Course Design

Efforts should be made at home to encourage intrinsic motivation to learn, and the environment needs to be made to feel more like a learning system instead of a "weeding out" system for students. There should be an increase in student- centered learning in our home countries that incorporate more active learning activities. The US, although implementing active learning better in classrooms, should carefully consider the amount of active learning in some classes to allow adequate time for deep engagement. Courses at home should be better structured and adopt a more outcomes-based system, with instructors indicating clear expectations. Courses at home should be scaffolded in such a way that students are set for success. There should be more focused work than "busy work" allocated in courses both in the US and at home, as one of our participants suggested, "the workload should be reduced as 'throwing' a lot of content at students may not necessarily mean they are learning." There should be an increase in the use of blended learning to incorporate both the in-class and online experience rather than reverting to fully in- class only in both the US and our home countries.

B. Assessment

We suggest including higher weighting on formative assessments prior to the final summative assessments. This can improve student motivation for continuous study. There should be a limitation on trick questions. More attention should be given to assessments that test deep conceptual understanding. Both the US and home contexts should improve reflection facilitation techniques after assessments, so that students can have a deeper understanding of their misconceptions. The assessment system in the US should give some priority to an input and process-based system which can encourage students to dive deeper into the content rather than them learning how to tick the right boxes only. There should be more alignment between success in studies and preparedness for industry.

C. Inclusion

Both the US and home countries should incorporate a variety of international and local contexts within their instruction and assessments. We would recommend that lecturers in the US attend intercultural awareness development workshops. We also recommend a program for international students to become more interculturally aware of the idiosyncrasies of the local context in the US. Classification of different categories of engineering practitioners at home should be evaluated to promote improved access and inclusion into the engineer category.

D. Transition and Support

There should be a deeper analysis on workload, which clearly articulates the time spent by international students studying, working, researching, and engaging with other important aspects of student experience. The reasonableness and expectations of the hours should be further debated. Allowance for transitional aspects illustrated in this paper should also be considered and systematically built into the programs. One participant suggested: *"There must be room for student experience beyond research and courses."*

Students who are studying engineering education should be oriented to the expected changes in social science, and the differences regarding assessments in engineering. The early introduction of an ontological and epistemological course illustrating the differences in engineering and social sciences could aid students to adjust to changes they experience in the new discipline. Orientation programs should include explaining the assessment systems in the US, and how they compare to other international systems. This could help alleviate anxiety of students and assist them to adapt their learning strategies. Systems of support (peer, emotional, psychological) should be facilitated for international students, rather than left to individuals to discover on their own. This should include adjustment to social and cultural norms.

VII. CONCLUSION / FUTURE WORK

In this paper, we aim to fill a gap in the literature surrounding the diverse experiences and perspectives of African students studying abroad. We report the experiences and perspectives of 9 African graduate scholars with research and educational experience in 4 African countries and the US. We also suggest recommendations for changes in the education systems both in the US and in our home countries. The discussions are limited mainly to the themes of instruction, assessments, and workload experiences. All reported results and recommendations in this paper are solely based on collaborative analysis, and reflection on experiences of the 9 participants. Although there may be similarities illustrated by other studies, this remains to be explored for the purposes of transferability.

Whilst there are strengths in this paper, based on the diverse and extensive backgrounds of the participants combined with the depth of reflections illustrated in the collaborative methods, there are some limitations. The participants are only from four countries out of the over 50 countries that make up the African continent. Even the experiences of the participants of these four represented countries are not generalizable across the four countries. Further work will need to incorporate the views of other countries, an objective that this group is motivated to explore. Furthermore, countries can have different educational systems both in the public and private space, hence these diversities need to be incorporated in the future work. In addition, the experiences of the participants in the US are more recent, however their experience of the study environment in the home countries has been during the time of their undergraduate and/or master's programs. It is therefore likely that the comparison with their home educational environments may not be up to date, together with comparisons made based on experiences between different levels of programs. Hence further studies will have to be conducted to assess the assertions of the participants.

REFERENCES

[1] K. Sarkodie-Mensah, "International Students in the U.S.: Trends, Cultural Adjustments, and Solutions for a Better Experience," J. Educ. Libr. Inf. Sci., vol. 39, no. 3, pp. 214–222, 1998, doi: 10.2307/40324159.

[2] Institute of International Education, "Open Doors 2021 Report on International Educational Exchange," Washington, D.C., 2021. Accessed: Nov. 19, 2021. [Online]. Available: https://www.iie.org:443/en/Why-IIE/Announcements/2021/11/US-Institutions-Top-Choice-for-Intl-Students

[3] M. H. Salisbury, P. D. Umbach, M. B. Paulsen, and E. T. Pascarella, "Going Global: Understanding the Choice Process of the Intent to Study Abroad," Res. High. Educ., vol. 50, no. 2, pp. 119–143, Mar. 2009, doi: 10.1007/s11162-008-9111-x.

[4] J. Beoku-Betts, "African Women Pursuing Graduate Studies in the Sciences: Racism, Gender Bias, and Third World Marginality," NWSA J., vol. 16, no. 1, pp. 116–135, 2004.

[5] F. Maringe and S. Carter, "International students' motivations for studying in UK HE," Int. J. Educ. Manag., vol. 21, no. 6, pp. 459– 475, Jan. 2007, doi: 10.1108/09513540710780000.

[6] H. K. Adriansen and L. M. Madsen, "Capacity-building projects in African higher education: Issues of coloniality in international academic collaboration.," Learn. Teach. 1755-2273, vol. 12, no. 2, pp. 1–23, 2019.

[7] E. Redden, "Study Abroad Numbers Grow," Inside Higher Ed, Nov. 13, 2018. https://www.insidehighered.com/news/2018/11/13/study- abroad-numbers-continue-grow-driven-continued-growth-short- term-programs (accessed Aug. 06, 2022).

[8] M. Whatley and S. Castiello-Gutiérrez, "Balancing finances, politics, and public health: international student enrollment and reopening plans at US higher education institutions amid the COVID-19 pandemic," High. Educ., vol. 84, no. 2, pp. 299–320, Aug. 2022, doi: 10.1007/s10734-021-00768-7.

[9] NAFSA, "Fall 2020 Survey: Financial Impact of COVID-19 on International Education," NAFSA, 2020. https://www.nafsa.org/policy-and-advocacy/policy-resources/fall- 2020-survey-financial-impact-covid-19-international-education (accessed Aug. 06, 2022).

[10] E. Buckner, Y. Zhang, and G. L. Blanco, "The impact of COVID-19 on international student enrolments in North America: Comparing Canada and the United States," High. Educ. Q., vol. 76, no. 2, pp. 328–342, 2022, doi: 10.1111/hequ.12365.

[11] B. Bollag, "Get Out of the Country, Please," Chron. High. Educ., vol. 51, no. 3, p. 42, Nov. 2004.

[12] D. Geary, "How Do We Get People to Interact? International Students and the American Experience.," J. Int. Stud., vol. 6, pp. 527–541, 2016.

[13] H. Wu, E. Garza, and N. Guzman, "International Student's Challenge and Adjustment to College," Educ. Res. Int., vol. 2015, p. e202753, Feb. 2015, doi: 10.1155/2015/202753.

[14] B. Bollag, "Report Urges Federal Effort to Triple Number of Students Studying Abroad," Chron. High. Educ., vol. 50, no. 13, pp. 33–34, Nov. 2003.

[15] T. K. Bikson, G. F. Treverton, J. S. Moini, and G. Lindstrom, "New Challenges for International Leadership: Lessons from Organizations with Global Missions," RAND Corporation, Jan. 2003. Accessed: Aug. 06, 2022. [Online]. Available: https://www.rand.org/pubs/monograph_reports/MR1670.html

[16] L. Brajkovic and R. M. Helms, "Mapping Internationalization on US Campuses," Int. High. Educ., no. 92, Art. no. 92, Jan. 2018, doi: 10.6017/ihe.2018.92.10277.

[17] G. C. Wolniak and M. E. Engberg, "Do 'High-Impact' College Experiences Affect Early Career Outcomes?," Rev. High. Educ., vol. 42, no. 3, pp. 825–858, 2019, doi: 10.1353/rhe.2019.0021.

[18] A. J. Kaba, "The Black World and the Dual Brain Drain: A Focus on African Americans," J. Afr. Am. Stud., vol. 11, no. 1, pp. 16–23, Jun. 2007, doi: 10.1007/s12111-007-9008-3.

[19] J. Mittelmeier, A. Gunter, P. Raghuram, and B. Rienties, "Migration intentions of international distance education students studying from a South African institution: unpacking potential brain drain," Glob. Soc. Educ., vol. 20, no. 4, pp. 523–541, Aug. 2022, doi: 10.1080/14767724.2021.1947202.

[20] E. F. Caldwell and D. Hyams-Ssekasi, "Leaving Home: The Challenges of Black-African International Students Prior to Studying Overseas," J. Int. Stud., vol. 6, no. 2, pp. 588–613, Apr. 2016, doi: 10.32674/jis.v6i2.372.

[21] D. Hyams-Ssekasi, C. P. Mushibwe, and E. F. Caldwell, "International Education in the United Kingdom: The Challenges of the Golden Opportunity for Black-African Students," SAGE Open, vol. 4, no. 4, p. 2158244014562386, Oct. 2014, doi: 10.1177/2158244014562386.

[22] R. A. Smith and N. G. Khawaja, "A review of the acculturation experiences of international students," Int. J. Intercult. Relat., vol. 35, no. 6, pp. 699–713, 2011, doi: 10.1016/j.ijintrel.2011.08.004.

[23] E. Dufflin, "International students in the U.S., by country of origin 2020/21," Statista, Nov. 17, 2021. https://www.statista.com/statistics/233880/international-students- in-the-us-by-country-of-origin/ (accessed Nov. 19, 2021).

[24] G. Gereffi, B. Rissing, and R. Ong, "Getting the Numbers Right: International Engineering Education in the United States, China, and India," J. Eng. Educ., 2008.

[25] World Bank, "International Comparative Study : Engineering Education in India," World Bank, Washington, DC, Apr. 2013. Accessed: Nov. 19, 2021. [Online]. Available: https://openknowledge.worldbank.org/handle/10986/16562

[26] S. Boafo-Arthur, "Acculturative Experiences of Black-African International Students," Int. J. Adv. Couns., vol. 36, no. 2, pp. 115– 124, Jun. 2014, doi: 10.1007/s10447-013-9194-8.

[27] S. Hanassab, "Diversity, International Students, and Perceived Discrimination: Implications for Educators and Counselors," J. Stud. Int. Educ., vol. 10, no. 2, pp. 157–172, Jun. 2006, doi: 10.1177/1028315305283051.

[28] J. Lee and T. Opio, "Coming to America: challenges and difficulties faced by African student athletes," Sport Educ. Soc., vol. 16, no. 5, pp. 629–644, Oct. 2011, doi: 10.1080/13573322.2011.601144.

[29] I. H. Hashim and Y. Zhiliang, "Cultural and gender differences in perceiving stressors: A cross-cultural investigation of African and Western students in Chinese colleges," Stress Health J. Int. Soc. Investig. Stress, vol. 19, no. 4, pp. 217–225, 2003, doi: 10.1002/smi.978.

[30] F. W. Rudmin, "Critical History of the Acculturation Psychology of Assimilation, Separation, Integration, and Marginalization," Rev. Gen. Psychol., vol. 7, no. 1, pp. 3–37, Mar. 2003, doi: 10.1037/1089-2680.7.1.3.

[31] A. J. Martin, H. G. Nejad, S. Colmar, and G. A. D. Liem, "Adaptability: How students' responses to uncertainty and novelty predict their academic and non-academic outcomes.," J. Educ. Psychol., vol. 105, no. 3, pp. 728–746, Aug. 2013, doi: 10.1037/a0032794.

[32] W. Liu and A. Rathbone, "The Complexity of International Student Identity," J. Belong. Identity Lang. Divers., vol. 5, no. 2, Jul. 2021, Accessed: Apr. 13, 2022. [Online]. Available: https://bild- lida.ca/journal/volume-5_2-2021/j-bild_5-2_liu_rathbone/

[33] W. E. Rowe, "The SAGE Encyclopedia of Action Research," 2 vols., Thousand Oaks,: SAGE Publications Ltd, 2022. doi: 10.4135/9781446294406.

[34] J. C. Lapadat, "Ethics in Autoethnography and Collaborative Autoethnography," Qual. Inq., vol. 23, no. 8, pp. 589–603, Oct. 2017, doi: 10.1177/1077800417704462.

[35] H. Chang, F. Ngunjiri, and K.-A. C. Hernandez, Collaborative Autoethnography, 1st edition. Walnut Creek, Calif: Routledge, 2012.

[36] T. E. Adams, S. L. Holman Jones, and C. Ellis, Autoethnography. Oxford ; New York: Oxford University Press, 2015.

[37] E. Crede and M. Borrego, "The Effect Of International Diversity On Graduate Engineering Education: A Literature Review," in 2010 Annual Conference & Exposition Proceedings, Louisville, Kentucky, Jun. 2010, p. 15.1224.1-15.1224.12. doi: 10.18260/1-2-- 15975.

[38] A. Strong, R. Louis, J. London, I. Ngambeki, and B. Sattler, "Exploring the Reasons for Collaboration and Cooperation Among Graduate Student Researchers," in 2012 ASEE Annual Conference & Exposition Proceedings, San Antonio, Texas, Jun. 2012, p. 25.621.1-25.621.17. doi: 10.18260/1-2 21378.

[39] S. Freeman et al., "Active learning increases student performance in science, engineering, and mathematics," Proc. Natl. Acad. Sci., vol. 111, no. 23, pp. 8410–8415, Jun. 2014, doi: 10.1073/pnas.1319030111.

[40] J. L. Faust and D. R. Paulson, "Active Learning in the College Classroom," J. Excell. Coll. Teach., vol. 9, no. 2, pp. 3–24, 1998.

[41] A. A. Rahman, B. Aris, H. Mohamed, and N. M. Zaid, "The influences of Flipped Classroom: A meta analysis," in 2014 IEEE 6th Conference on Engineering Education (ICEED), Kuala Lumpur, Malaysia, Dec. 2014, pp. 24–28. doi: 10.1109/ICEED.2014.7194682.

[42] M. Olayemi, "'Give me electricity first. I'll worry about all this fancy technology later,'" Medium, Sep. 11, 2020. https://medium.com/@moyemson/give-me-electricity-first-ill- worry-about-all-this-fancy-technology-later-a1df84fdb593 (accessed Mar. 08, 2022).

[43] H. Forbes-Mewett and C. Nyland, "Cultural Diversity, Relocation, and the Security of International Students at an Internationalised University," J. Stud. Int. Educ., vol. 12, no. 2, pp. 181–203, Jun. 2008, doi: 10.1177/1028315307308136.

[44] W. Harlen and M. James, "Assessment and Learning: differences and relationships between formative and summative assessment," Assess. Educ. Princ. Policy Pract., vol. 4, no. 3, pp. 365–379, Nov. 1997, doi: 10.1080/0969594970040304.

[45] Y. Sayed and A. Kanjee, "Assessment in Sub-Saharan Africa: challenges and prospects," Assess. Educ. Princ. Policy Pract., vol. 20, no. 4, pp. 373–384, Nov. 2013, doi: 10.1080/0969594X.2013.849056.

[46] M. D. Svinicki, Learning and Motivation in the Postsecondary Classroom. Bolton, MA: Anker Publishing Company, 2004.

[47] B. Kloot and S. Rouvrais, "The South African Engineering Education Model with a European Perspective: History, Analogies, Transformations and Challenges," Eur. J. Eng. Educ., vol. 24, no. 2, pp. 188–202, Mar. 2017, doi: 10.1080/03043797.2016.1263278.

[48] A. V. Bengesai and J. Pocock, "Patterns of persistence among engineering students at a South African university: A decision tree analysis," South Afr. J. Sci., vol. 117, no. 3/4, Art. no. 3/4, Mar. 2021, doi: 10.17159/sajs.2021/7712.

Technical papers

Problem-solving in an open-ended, peer assessed learning activity

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***Abstract* — Students need to be comfortable applying their (theoretical) knowledge contextually, to an array of open-ended problems, particularly once they transition to the world of work. However, they often battle with this – rather wanting to focus on 'exam-type' calculations (without complicating contexts). One route to encourage them to explore open-ended problems is through giving them the choice of topic or problem to solve or analyse. Further, peer learning activities can enhance student engagement and provide a wide array of problems or scenarios for the students to be exposed to. In this work, students were asked to describe the application of fluid mechanics principles in self-selected contextual scenarios. Presentations on their findings were presented to, and assessed by, peers. The students' approaches to the assignment were mapped onto Legitimation Code Theory's epistemic plane, and thereafter compared to problem-solving skills of established engineers. Students who comfortably engaged with knowledge from all four codes in a non-linear fashion, as is typical for engineers with good problem-solving skills, were more likely to have good academic performance. In general, the students found the assignment to be enjoyable – since they were able to pursue their own curiosity (albeit in the context of fluid mechanics!). Further, the peer assessment allowed for both exposure to others' work, but also facilitated a self-reflection on their own performance. The two key ideas presented here (curiosity-driven contextual problem solving, and peer assessment) show significant promise in enhancing students' abilities to face open-ended problems, and may have application in many courses.**

Keywords — peer assessment, problem-solving, epistemic plane, LCT, sociocultural theories of learning

I. INTRODUCTION

Significant empirical research in the field of engineering problem-solving suggests that effective problem-solving requires the problem solver to shift between "Principles, Procedures, Possibilities, People and Places" (the 5 Ps)[1] in a non-linear fashion. In effect, this implies that to stimulate problem solving in students, one should encourage them to not only consider 'exam-type' calculations [2], but also look at practical, real-world, open-ended, or poorly defined problems. To which the students can bring their theoretical knowledge to bear, to generate solutions (of which there may be several). Allowing each student to select a unique problem and subsequently share its solution with peers reduces the burden on educators. Since the students also actively contribute to the classroom activities by sharing from their own perspective, a more inclusive environment is generated [3], [4].

Research and anecdotal feedback also provide evidence that engineering graduates are intimidated by open-ended problems, but this is a crucial ability required by industry [5] given the dynamic and increasingly complex sociotechnical contexts in which our graduates are required to function.

Clearly, it is important that these skills are developed in our engineering graduates before they transition to the world of work.

A key educational instrument that has helped educators to understand how problems are solved and how to improve problem-solving teaching is the Legitimation Code Theory (LCT) dimension of the epistemic plane. The epistemic plane is a Cartesian plane which represents the relationship between the 'what' and 'how' of problem solving. It may be used to visually represent the relationship between fundamental concepts and methodologies as they relate to the problem- solving exercise, and thus trace the trajectory of the problem solver [6].

In this work, we discuss an assignment in Fluid Mechanics that saw students identify and describe the application of fluid mechanics concepts in the world around them. Each student was allowed to choose their own appropriate topic to investigate. Students presented their work to peers in a video presentation, and each student thereafter assessed the presentations using a predefined marking rubric. In particular the focus was on exposing each student to a number of contextually varied cases of fluid mechanic applications, and through peer assessment allow them to reflect on others' and their own work. Since the assignment was carried out during the COVID-19 pandemic, a collaborative online learning tool, Moodle's Workshop, was used to coordinate all activities amongst the students.

The use of peer assessment in undergraduate courses is commonplace, particularly in large class settings. While there is concern about the use of peer assessment in consideration of the differential between peer allocated marks and educator allocations [7]. Nonetheless, it is a useful tool for generating engagement [8], and allows for students to experience a range of contexts (presented by their peers). Peer assessment allows for introspection and reflection as a by-product of examining others' work [9], [10]. Further, the use of peer assessment may end up being motivating for students [11].

Drawing on a translation device used to analyse professional engineering problem solving [5], the students' description of the contextual application of fluid mechanics principles in the submitted videos, and the approach to preparing the presentation as described in survey responses, were analysed. Results from the analysis were mapped onto the epistemic plane to determine 1) what each student's preferred quadrant (or code) was, and 2) how much each student could shift between the different quadrants (codes) of the plane during the task and thereby engage with codes that are preferred and those that are not.

The project hopes to highlight how by giving students agency [12], and then examining through peer assessment, one might traverse the 5Ps, while maintaining motivation of the students. This will allow educators to become cognisant of those who struggle with shifting between the 5 Ps, with problem solving, and contextualization, to allow for better teaching to the needs of the students.

The purpose of this study is then to examine so called 'code shifting', within the framework of LCT, to visualize students' approaches to problem solving, with the overarching intention of developing approaches and methods to stimulate good problem-solving in engineering students.

II. CONTEXT

This study was conducted within the second year of a four- year chemical engineering degree program at a research- intensive university in South Africa. The program is International Engineering Alliance (IEA)-aligned and accredited by the Engineering Council of South Africa, a signatory of the Washington Accord. As such, while there are context and societally specific aspects within this program, research conducted with these cohorts is likely to be broadly applicable to other global institutions and engineering programs. The study was conducted between 2020 and 2021, looking at the cohort of students in the Fluid Mechanics module in 2020. The number of registered students was 70. Each of the four years of study in the chemical engineering program has a major theme introduced in the modules taught:

- Year 1 - Natural and Mathematical Sciences
- Year 2 - Engineering Science
- Year 3 & 4 - Design and Synthesis

The Fluid Mechanics module is taught in the second semester of Year 2. At this stage, students are expected to start being more comfortable with applying fundamental principles and methods to small but open-ended scenarios. These scenarios are often in the form of practical laboratory experiments or small investigative assignments. The second semester of Year 4 is solely focused on Design and Synthesis, with students being tasked with completing a research project and a capstone design project. The capstone design project specifically expects students to draw on fundamental principles and methods taught in previous years to conceptualise and design a working chemical processing facility.

III. THEORY

Types of insight or knowledge that an engineering student engages with in a problem-solving exercise can be classified by how ambiguous or well-known the underpinning phenomena is (ontic relations, OR), and also by how open-ended or structured the approach to solving is (discursive relations, DR). These two criteria, ontic and discursive relations, can be weakly (-) or strongly (+) bounded and hence form the axes of the LCT epistemic plane. Four quadrants or "codes" are formed depending on the strength of each relation, corresponding to a type of insight [4]:

- Situational (OR+, DR-) - related to various Possibilities; this insight helps the student answer "what"
- Purist (OR+, DR+) - related to Principles and fundamental theory; this insight helps the student answer "why"
- Doctrinal (OR-, DR+) - related to Procedures and fixed methodology; this insight helps the student answer "how"
- Knower/no (OR-, DR-) - related to People and Places; this insight helps the student answer "who" and "where"

A student who can comfortably incorporate insights by traversing all four knowledge codes is more likely to produce a robust solution. Research also shows that successful practising engineers regularly engage with the four codes in problem-solving exercises [13]–[15]. This "shifting" between the codes in a non-linear fashion can be plotted on the epistemic plane by identifying the type of knowledge an individual is engaged in through the course of looking for a solution.

Although each individual student may have a preference to one or two of the codes, a typical engineering class will likely have all four codes represented. Thus, students who work together in problem solving exercises may be able to observe other ways of approaching the same problem and thereby broaden their problem-solving skills. This would be similar to how diverse engineers in a team are able to draw on each other's strengths in practice [5]. The benefits of students working together on a task, or even giving each other feedback on tasks performed individually, include a less intimidating environment and having things be explained by a peer who is more "on the same level" compared to a lecturer, i.e. within the same zone of proximal development [16]. The effectiveness of learning that can be achieved was evaluated indirectly, by asking students if the task did indeed help them learn fluid mechanics concepts better.

IV. METHODOLOGY

In each year that the study was run, students were asked to choose a topic or application of fluid mechanics principles in the world around them. The suggested topics were then screened to make sure there were no duplicate topics (i.e. each student was to work alone!). Students were divided into groups of 4 - 5, making sure that each small group did not have more than one topic of a particular theme. Examples of themes included: water and hydrodynamics; aerodynamics; machinery; and animal movement patterns. After screening, students were instructed to work on the approved topics and create a 5 minute video presentation of their findings, as individuals. Students were asked to specifically describe the application or topic chosen, the relevant fluid mechanics principles, and how these principles were at work in the chosen application. Any preferred software could be used to create the video. The videos were submitted to a collaborative online learning tool on the Moodle platform called Workshop. The Workshop activity allowed submission of videos from students, and could also be used by the students to view and give feedback on their peers' submissions. A predefined rubric was used to assess the video submissions. The rubric featured 3 criteria with 3 levels each, and descriptive statements were supplied to help each student judge which level best fit each criterion.

Once the task was complete, students were asked to vote for the best presentation that they assessed and voluntarily fill in a feedback survey describing their experience. The survey questions asked were:

1. Describe how you approached this task and at each stage why you did it like that. [Open-ended, essay type question]
2. Has the task enabled you to better understand Fluid Mechanics principles? [Yes/Maybe/No]
3. In one word, describe your experience of this task.
4. Do you think the task should be given to students again in future? [Yes/Maybe/No]

A key investigation of this work was to determine how students interacted with different types of insight from the epistemic plane in a problem-solving exercise. In order to better understand the practices of students while working on the assignment, the submitted presentations as well as the answers to the first survey question were analysed. For the analysis, a translation device was used to interpret the students responses, and to code and assign content to one or more of the epistemic plane codes. Table I shows this translation device, which allows analysis of students' responses to give insight into their approach and insights with regards LCT's dimensions. For the submitted presentations, the content being described at any time would determine which code it was assigned, e.g. defining density was assigned the "purist" code, while discussing the first derivative of an equation was assigned "doctrinal". For the survey responses, a student's mention of previous experience swimming as inspiration for their topic was assigned "knower", while a student who mentioned looking at numerous videos on YouTube to understand their topic better was assigned "situational". The results of the epistemic plane analyses were compared to the marks the students received in the module at the end of the semester (hereafter referred to as "FM"). At the time of analysis, most of the students had completed all modules from the first 3 years of the academic program. Therefore, an average mark for all modules in the 3 years (hereafter referred to as "3yA") could be calculated and also compared to the epistemic plane analysis.

TABLE 1: *Translation device used to code content in video presentations and survey responses*

	Presentation (video)	**Approach to task (survey)**
Purist	Theoretical concept discussed	Very detailed responses with e.g. numbered list of steps taken
Doctrinal	Method, procedure, steps, equation	Uses sequential-type words (first, then, afterwards, etc.), consults "approved" sources for instruction such as textbook, task instructions, etc.
Situational	Specific context or topic discussed	Looks for sources of information or instructions outside of "approved" sources (e.g. social media)
Knower	People or places of interest	Talks to other people, describes what the topic means to them, etc.

V. FINDINGS

A. Analysis of submitted videos

A sample of the videos submitted by students were analysed using the translation device described previously. A total of 18 videos were chosen, taking care to choose those that had also responded to the voluntary feedback survey. The students in the sample achieved a final mark for the module (FM) that spans the range 50 - 85%, and had average marks for all modules presented in the first 3 years of the program (3yA) also in the range 50 - 85%. From the epistemic plane analysis, a number of students showed appreciable code shifting, and could explain their chosen topic by incorporating theory, procedures and various stakeholders. An example of the code shifting displayed by a Student #1 is shown in Figure 1a. The content covered by this student in their video moved non-linearly between the codes in the order as numbered in the various quadrants of the plane.

An example of a student (#2) who did not successfully code shift is shown in Figure 1b. This Student #2 does not show the non-linear trajectory between the four codes that Student #1 did. Therefore this student would be expected to demonstrate poorer problem-solving skills. However, this turned out to not be the case at all. If academic performance was used as an indication of problem-solving skills (an assumption yet to be tested – perhaps future work will examine this), the student with potentially poorer problem-solving skills had a better academic performance. Student #1 achieved FM = 50 - 60%* and 3yA = 60 - 70%, while Student #2 achieved 70 - 80% for both FM and 3yA. Furthermore, the results when the rest of the sample was considered was that the code shifting demonstrated during the presentation seemed to show no obvious relationship to either FM or 3yA.

*Wherever possible, marks for individual students are given as a range spanning ±5%, while an average for multiple students is given as the calculated value.

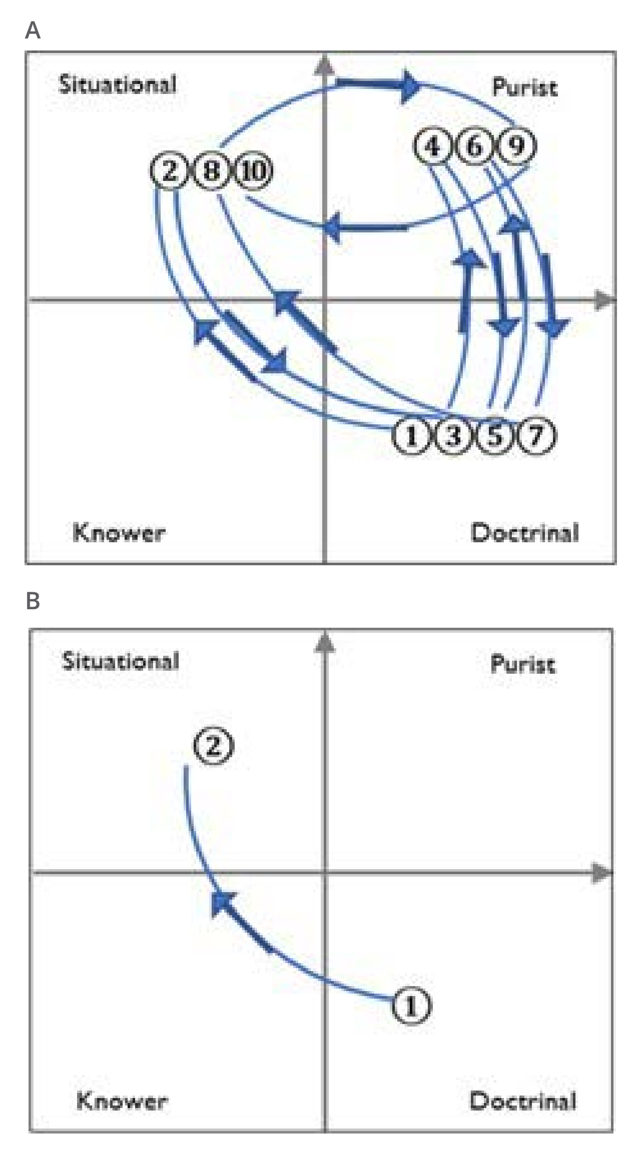

FIGURE 1: Code shifting displayed during presentation: a) Student #1) and b) Student #2

Instead of code shifting demonstrated in the presentation being seen to bear a correlation to academic performance, code shifting in the presentation was rather related to how well liked a specific presentation was by peers. The sample of videos analysed included 7 videos that were chosen as best in their respective groups: 4 of these videos showed significant code shifting such as Student #1 in Figure 1a; 2 videos showed some code shifting while 1 showed very little code shifting. Therefore, code shifting during the presentations may lead to presentations that are more interesting and appealing to students, perhaps in the same way that an engineering lecture may be more interesting to students if the lecture content varies between theory, procedure and application. One consideration, which should be explored in further work, is the (often studied [7]) bias within peer assessment, and how that relates to these transitions and code shifting demonstrations.

It may be worth noting that Student #2 was one of only a few that were noted to create semantic waves in their presentations [17]. Semantics is a different LCT dimension which classifies the degree of complexity or abstraction, and is often used in teaching the link between theory and practice. Although Student #2 presented knowledge from the epistemic plane codes in a linear manner, they made a point to draw parallels to concrete examples that may be more familiar to students. Considering the overall code shifting demonstrated by the class did not have a significant relationship to academic performance, analysis of the presentation content may indeed be better suited to the semantic plane rather than the epistemic plane. Students' understanding of the fundamental principles and their application to various contexts would then be judged based on the technicality of the language used (semantic density) as well as the ambiguity or concreteness of examples used in their explanations (semantic gravity). This analysis of presentation content would likely have a stronger correlation to academic performance, and is intended for follow-up research.

B. Analysis of approach to task

Contrary to results from the analysis of video presentations, the analysis of students' approach to the task did have a correlation to academic performance. The most apparent correlation was between a student's preferred code and marks achieved. The analysis of two students' answers are shown as examples in Figure 2. Student #3 (Figure 2a) achieved 55 - 65% for both FM and 3yA and seems to have engaged with primarily Situational and Doctrinal-orientated insight. Student #4 (Figure 2b) achieved higher marks than Student #3 (75 - 85% for both FM and 3yA) and seems to have engaged with insight from all four codes. Student #3 was noted to have a preference for the Situational code, with perhaps a secondary preference to Doctrinal, while Student #4's first preference appeared to be Doctrinal with a more balanced appreciation of the other three codes. Preferences for each quadrant were judged based on the number of words in the survey response that fit each code and also how many times each student tended to return to a particular knowledge code.

The results from Students #3 and #4 can be extended to the rest of the group sampled: those that had a first or second preference for a code with strong discursive relations (Purist or Doctrinal) and/or could code shift with ease were more likely to achieve higher marks. A summary of the marks achieved per code identified is given in Table 2, while the relationship between ease of code shift and marks is in Table 3. Table 2 also gives the number of students assigned to each code as well as the standard deviation for each average mark calculated. Although there was equal representation of students with preference for either strong or weak discursive relations, the calculated averages for codes with strong discursive relations (Doctrinal or Purist) such as Student #4 tended to be higher than for codes with weak discursive relations (Situational or Knower) such as Student #3. Marks in general increased in the order: Situational; Knower; Doctrinal; Purist.

The results in Table 22 are not surprising. Since the first 3 years of the chemical engineering program do engage in strong discursive relations-oriented content more [18] students with a preference for weak discursive relations likely experienced more code clashes when engaging with content in various modules. Thus, they were not able to perform as well as their peers who had preferences for codes with stronger discursive relations. One area which may prove fruitful to examine in further work is how to explicitly guide students through apparent code-clashes, particularly as they progress through epistemic transitions and require more contextual thinking.

It was possible to identify code clashes, discomfort that students had when engaging with insight other than their preferred, in students' survey responses if students expressed a frustration with any stage of completing the task. Some students appeared to have rather comfortably engaged with insight from all four codes and therefore indicate what seems like no code clashes at all. For a number of students, it was not clear whether they experienced the code clashes. All three categories of students (code clash present (Y); no code clash (N); code clash unclear (U)) have average marks as given in Table II. The data in the table indicate that students that experienced code clashes were more likely to have relatively poorer academic performance.

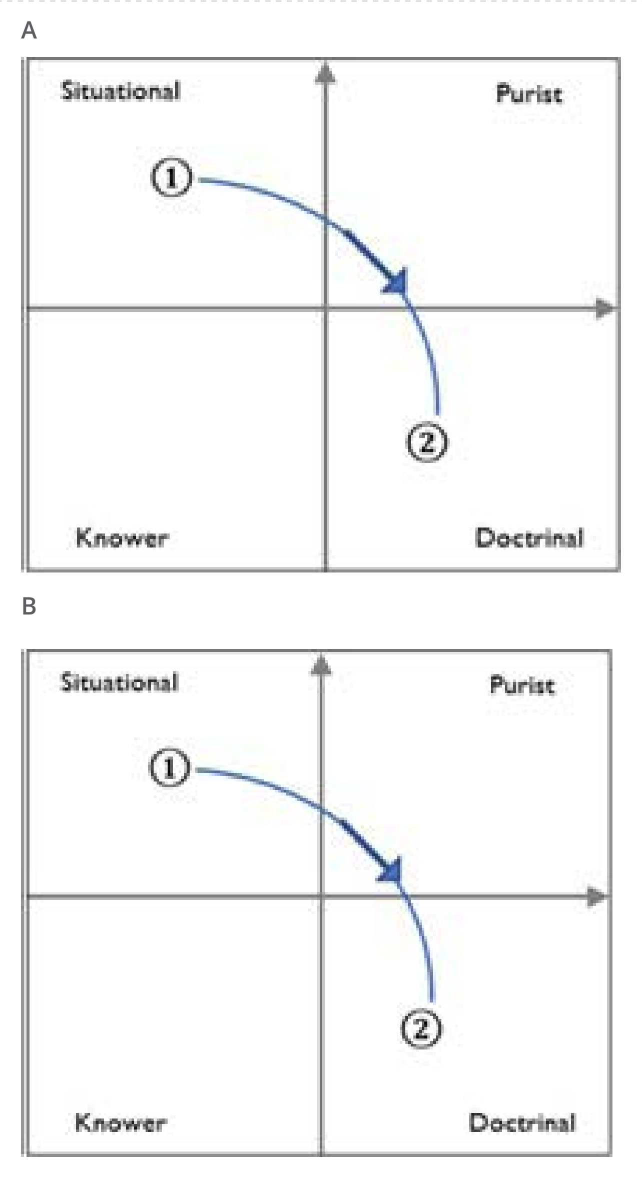

FIGURE 2: *Code shifting displayed in survey answers to approach to task: a) Student #3 and b) Student #4*

Of the students that were identified as having experienced code clashes, 4 showed a first preference for codes with weak discursive relations (2 Situational, 2 Knower) while only 1 had a first preference for a strong discursive relations code (Doctrinal). One of these students (Situational) has not been able to complete all modules offered in the first three years of the academic program at the time of the analysis. The other four students' codes when listed in increasing order of marks (3yA) are: Situational, Knower, Knower, Doctrinal. The student with a Doctrinal preference was the only student in the group to achieve 3yA greater than 70% while the other three had marks between 55 - 70%. This order of the marks corresponds to the results in Table I, where students with a preference for Doctrinal or Purist were more likely to achieve a higher mark. A similar range of marks were obtained for FM, with the codes in increasing order of marks being: Knower, Situational, Situational, Doctrinal, Knower. Thus it may seem that students who experience a code clash are more likely to be those with a preference for weak discursive relations, and thus more likely to struggle engaging with the more purist and doctrinal-orientated module content presented.

TABLE 2: *Averages of module and 3-year average for each quadrant*

		Final mark in module (FM)		Average mark for all modules in first 3 years (3yA)	
Code	**Preference**	**No. of students**	**Average [%] (±StdDev)**	**No. of students**	**Average [%] (±StdDev)**
Purist	First	2	70.1 (±13.3)	2	76.3 (±7.5)
	First or second	3	68.9 (±11.0)	3	75.2 (±6.3)
Doctrinal	First	7	66.7 (±9.5)	6*	70 (±4.2)
	First or second	13	66.1 (±9.4)	12*	69.8 (±6.2)
Knower	First	4	66.1 (±4.4)	4	68 (±2.7)
	First or second	7	64.3 (±5.1)	7	65.7 (±4.6)
Situational	First	5	60.8 (±4.5)	4*	63.5 (±7.0)
	First or second	6	62.1 (±5.0)	5*	64.3 (±6.5)
Total		**18**	**65.3 (±8.6)**	**16***	**68.6 (±6.5)**

*1 student assigned Doctrinal and 1 student assigned Situational had not complete all modules offered in the first 3 years at the time of the analysis

TABLE 3: *Averages of module and 3-year average compared to apparent code clashes*

	Final mark in module (FM)		Average mark for all modules in first 3 years (3yA)	
Averages based on criteria:	**No. of students**	**Average [%] (±StdDev)**	**No. of students**	**Average [%] (±StdDev)**
Code clash (Y)	5	63.6 (±3.8)	4*	66.0 (±5.3)
Unclear code clash (U)	7	64.5 (±9.7)	6*	68.4 (±8.4)
No code clash (N)	6	67.7 (±9.5)	6	70.6 (±3.9)
Total	18	65.3 (±8.6)	16*	68.6 (±6.5)

*1 student assigned Doctrinal and 1 student assigned Situational had not complete all modules offered in the first 3 years at the time of the analysis

Of the students that experienced either no or unclear apparent code clash, there was no obvious relationship between their first preferred code and academic performance. However, all students that had no code clash had Doctrinal as either first or second preferred code, showing they were likely able to easily engage with the strong discursive relations- nature of the module content presented in the first three years of study.

The results from this analysis indicate that a number of interventions may be beneficial if introduced during the first three years of the program. For these first 3 years, code clashes for students with a preference for codes with weak discursive relations seem more prevalent. These potential code clashes affect not only the morale of the students who experience frustration when engaging with module content, but it also seems to influence their academic performance. Therefore, potential academic interventions would be intended to help students with a preference for weak discursive relations engage with the strong discursive relations present in the academic material more meaningfully.

It should be noted that students with a preference for weak discursive relations are not the only group having to navigate significant code clashes. The fourth year of the academic program features two large, open-ended projects that are well suited to a weak discursive relations orientation [14]. These projects may be well received by students who enjoy creative problem-solving in an unstructured environment. Therefore academic interventions introduced from the third year onwards should be in order to guide students with a preference for strong discursive relations to navigate any potential code clashes when engaging with situational and knower codes in the fourth year of the program. Students from the 2020 Fluid Mechanics class are currently completing their fourth year of study. When available, their academic performance from the capstone projects will be compared to the preferred orientations identified in the survey responses. This comparison will be in order to see if the results obtained when comparing preferred orientations and 3yA still hold. If they do indeed hold, it may mean that the intended weak discursive relations nature of the fourth year does perhaps still contain a large degree of strong discursive relations-orientated material.

C. Overall experience of task

The other questions asked of students in the feedback survey indicated that the students enjoyed the assignment. By assessing each other's work, the students could self-judge how well they explained the fluid mechanics concept (Principles), its related equation or calculation methodology (Procedures), its application to the particular context chosen (Possibilities) and who/what the application may relate to (People and Places). The range of contextual applications brought by students extended beyond typical industry-related examples that they may see in textbooks. Thus, in seeing "new" ways of applying familiar (in the context of the course) fundamental concepts, their ability to solve more complex and open-ended problems in their senior years may be enhanced. In providing students with the wide range of applications, their understanding of the fluid mechanics concepts was improved and epistemological access was enabled [9].

VI. CONCLUSIONS

Multiple learning goals can be achieved by fostering student-centred learning environments. In this work, peer learning and assessment were used to improve students' understanding of fluid mechanics concepts and also to expose the students to various ways of problem-solving. The increased exposure may serve as a basis for developing good problem-solving skills to be applied in more senior courses. Tools from the Legitimation Code Theory framework provide ways of analysing how learning occurs in the student-centred learning environments. Examining the data from this work showed a split between students who approach the work from a more Situational perspective, versus those who remain within the Doctrinal. However, for good learning, code shifting between approaches gives rise to better, contextual understanding. The epistemic plane can be used as a basis to design appropriate academic interventions to assist students in dealing with code clashes between their tendencies and the requirements of their courses, and to help them improve their ability to code shift for improved problem solving.

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REFERENCES

[1] K. Wolff, "Insights into conceptual and contextual engineering problem-solving practices in the 21st century: some implications for curriculum redesign," in Proceedings of the 3rd Biennial Conference of the South African Society for Engineering Education, 2015, no. July, pp. 189–198, Accessed: Apr. 16, 2020.

[2] R. W. M. Pott and S. Nortjé, "The use of student question-posing in reactor design to encourage an open- ended approach to learning," Eur. J. Eng. Educ.

[3] S. Winberg and C. Winberg, "Using a social justice approach to decolonize an engineering curriculum," in 2017 IEEE Global Engineering Education Conference (EDUCON), 2017, pp. 248–254.

[4] K. S. Collett, B. von der Heyden, R. W. M. Pott, and J. Stander, "A collaborative auto-ethnographic exploration of socially just practices by new academics in two South African higher education institutions," South African J. High. Educ., vol. 32, no. 6, pp. 582–603, Dec. 2018,

[5] M. Group, "Talent Shortage Survey," 2018. [Online].

[6] K. Maton, Karl Maton: Knowledge and knowers: towards a realist sociology of education. Routledge, 2014.

[7] H. Li et al., "Peer assessment in the digital age: a meta- analysis comparing peer and teacher ratings," vol. 41, no. 2, pp. 245–264, Feb. 2015

[8] H. Idrus, H. Mulyono, R. M. Ramli, E. Bhattacharyya, and S. Zulaiha, "Implementation Of Peer Review Assessment To Engineering Students," SHS Web Conf., vol. 124, p. 01001, 2021,

[9] D. Reinholz, "The assessment cycle: a model for learning through peer assessment," vol. 41, no. 2, pp. 301– 315, Feb. 2015,

[10] K. J. Topping, Using Peer Assessment to Inspire Reflection and Learning. New York: Routledge, 2018.

[11] A. Planas Lladó et al., "Student perceptions of peer assessment: an interdisciplinary study," vol. 39, no. 5, pp. 592–610, Jul. 2014,

[12] P.-Y. Oudeyer, J. Gottlieb, and M. Lopes, "Chapter 11 - Intrinsic motivation, curiosity, and learning: Theory and applications in educational technologies," in Motivation, vol. 229, B. Studer and S. B. T.-P. in B. R. Knecht, Eds. Elsevier, 2016, pp. 257–284.

[13] R. W. M. Pott and K. Wolff, "Using legitimation code theory to conceptualize learning opportunities in fluid mechanics," Fluids, vol. 4, no. 4, 2019,

[14] K. Wolff, C. Dorfling, and G. Akdogan, "Shifting disciplinary perspectives and perceptions of chemical engineering work in the 21st century," Educ. Chem. Eng., vol. 24, Jun. 2018,

[15] M. Tadie, R. Pott, N. Goosen, P. Van Wyk, and K. E. Wolff, "Expanding 1st year problem-solving skills through unit conversions and estimations," in IEEE Global Engineering Education Conference, EDUCON, 2018, vol. 2018-April, pp. 1035–1043,

[16] A. Kozulin, "The concept of activity in Soviet psychology: Vygotsky, his disciples and critics," in An introduction to Vygotsky, Routledge, 2002, pp. 111–134.

[17] K. Maton, "Making semantic waves: A key to cumulative knowledge-building," Linguist. Educ., vol. 24, no. 1, pp. 8–22, Apr. 2013,

[18] K. Wolff, "A language for the analysis of disciplinary boundary crossing: Insights from engineering problem-solving practice," Teach. High. Educ., vol. 23, no. 1, pp. 104–119, 2018,

Technical papers

The effect of online assessments and feedback practices on civil engineering students' learning

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Abstract — **The move to online teaching and learning at higher institutions because of the Covid-19 pandemic in the year 2020 challenged engineering programs to change how they have been conducting their assessments. Before Covid, this process was done to check whether module outcomes are achieved and provide a grade for the student. Nowadays continuous assessments are used instead of summative assessments and civil engineering schools must now re-think the whole purpose of the assessment process. This paper reports on a study which was designed to find out if assessments given to engineering students are improving and enhancing their understanding and promote better learning. Our important goal as engineering lecturers is to prepare students for a professional life through assessment, teaching and learning.**

The study focused on the small number of students who study civil engineering technology at the University of Johannesburg. Assessment within the engineering discipline is ordinarily orientated towards illustrating competence in particular assignments utilizing only conventional or traditional assessment methods such as tests and exams. This work aimed to assist students to increase their learning potential from assessments and lecturers to provide constructive assessment feedback. The main research question was to find out the extent that students learn from assessment and feedback in the Theory of Structures module under civil engineering technology.

The vehicles that were used to collect data includes lecture observations, questionnaires, and interviews. The research data collection was conducted over few weeks of the second semester with first year students doing Theory of Structures. Three types of data were collected from this study. The first was a semester test results and feedback. After the test, focus group interviews were conducted to students' feedback on the test process and they also gave details about how they found questions and solutions. The third instrument of data collection was the use of questionnaires in the form of online surveys. The analysis of data started by documenting the results obtained from the interviews, and online questionnaires. The audio recordings from interviews were transcribed using Otter software. The transcribed text was then merged with findings from questionnaires and analyzed using open coding by Quirkos software.

The study showed that more work still needs to be done to educate students about the importance of assessment as the findings showed that there are students who still focus on grades during assessment and not real learning. Nowadays feedback is even more important since most students are using blended or online learning which requires support and guidance from the lecturer. Although the focus was on small size of sample or few participants compared to the faculty of engineering student population, the study still managed to provide findings that will be applied to improve assessment and feedback practices.

Keywords — student assessment, feedback, engineering education.

I. INTRODUCTION

The important goal of engineering lecturers is to prepare students for a professional life through integration of assessment, teaching and learning. This is a study designed to find out if assessments given to engineering students are improving and enhancing their understanding and promote better learning. The study focused on the small number of students who study civil engineering technology at the University of Johannesburg in South Africa. Assessment within the engineering discipline is ordinarily orientated towards illustrating competence in particular assignments utilizing only conventional assessment methods which includes tests and exams. As a lecturer, the author, conducted a research study to assist students to learn from assessments and fellow colleagues to provide constructive assessment feedback.

The adequacy of educational programs is dependent on how well lecturers understand the part of evaluation in student learning and how well they are prepared to alter their techniques in such a way that they utilize evaluation as a tool for the enhancement of student learning. If evaluation is considered as a fundamentally part of learning, students tend to receive a profound learning approach that is characterized by making connections and effectively looking for the meaning and an understanding of a given assignment [7].

I have seen in the department of civil engineering technology that after each assessment, students are given their marks, and marking guidelines or memorandum. As lecturers in the department, we do not determine whether there was learning in the assessment process but assume that students know what to do to improve. Engineering faculties normally receive criticism from their students and external stakeholders for not paying attention to effective assessment methods that must be implemented in the programs. Engineering academic staff members do not get trained to deliver good teaching, learning and assessment, which results in some of them not able to incorporate a good assessment practice in their course. This research was conducted to provide solutions and ideas on how to use assessment feedback to enhance learning of engineering students.

The proper approach to evaluation practices is to provide constructive feedback to student activities. The purpose of providing feedback to students is to assist students to master the topics and it is meant to guide them on the areas of improvement. Nowadays feedback is even more important since most students although they have gone back to higher institutions, they still learn using contact teaching, online teaching or a combination of face to face and online (blended learning) and most students are tested using continuous assessment. Effective assessment strategies not only have a potential to improve student learning, but they are also responsible for quality assurance of the academic programs. This research aims at improving students' online learning through using effective assessment strategies.

Online and continuous learning has now become more essential due to the transformation of systems in higher education since the introduction of different levels of lockdowns introduced by the covid-19 pandemic. Reference [1] mention that online education has been a popular means to cultivate, develop and aspire students through distance learning. This study is to examine whether the introduction of online learning and continuous assessment in Theory of Structures module under the civil engineering department has positive effect and helps to improve students' performance and understanding.

II. LITERATURE REVIEW

Lecturers and educational leaders have persistently talked about student assessment in higher education [6]. Academics communicated concerns that the strategies utilized to evaluate students are not connected to student learning [3]. Continuous discussions centered on such points as whether a student's success in examinations relates to high standards, what evaluation assignments are best for learning, whether evaluation practices advance long lasting learning, and how feedback may help progress student advance [3]. Examiners recognized that lecturers do not continuously connect assessment with quality. Instead, they see assessment as a practice that implies assessment and the formation of grades.

The move to online teaching and learning at higher institutions because of the Covid-19 in 2020 pandemic challenged engineering programs to change how they have been conducting their assessments. Before Covid, this process was done to check whether module outcomes are achieved and provide a grade for the student. Nowadays continuous assessments are used instead of summative assessments and civil engineering schools now must re-think the whole purpose of the assessment process.

This action research study reiterate that assessment and feedback practices assume a critical part in accomplishing the aims and objectives and consequently guaranteeing quality engineering education. Assessment practices evolve occasionally, concerning advancements in the course curriculum and informative plan of Engineering programs. To manage the steadily changing situation of engineering education set-up, lectures need to learn and adopt effective assessment practices and kinds of feedback that urge and motivate students to achieve learning outcomes of the module.

Engineering faculty members need not to go through staff development and training programs or obtain education qualifications to teach engineering students. This may bring about making troubles for them to develop assessment strategies module outcomes. It is stated that adopting a wrong or inappropriate assessment practice misguides students for learning improvements and provides wrong information to them about where they stand in a module [12]. Inappropriate or wrong assessment practices thus hurdle in achieving the engineering education objectives in higher education.

Reference [2] mentioned that coordination suitable assessment evaluation practices into academic programs must be a major objective of each engineering educational institution. To actualize a suitable evaluation practice on a module in engineering education, academic staff members' culture is required to be corrected, so that they will comprehend the significance of evaluating students' exhibitions and their connection with students' learning goals. Reference [13] states that conventional shapes of evaluation found in higher education (such as composing examinations) may not be sound representations of engineering practices. He points out that indeed although conventional evaluation forms are simple to manage, it is way better to go for more true assessment practices like a project-based assessment to reflect real-world engineering practices.

III. RESEARCH QUESTIONS

Assessment makes a difference to an individual university lecturer to get valuable feedback on what, how much, and how well their students are learning. Lecturers can then utilize this data to refocus their teaching to assist students to make their learning to be more productive and more compelling.

The main research question was:

"To what extent do students learn from assessment and feedback in the civil engineering technology programme?"

and the sub-question was:

"Is assessment and feedback part of the learning process for the Theory of structures module?

IV. METHODOLOGY

The vehicles that were used to collect data consisted of questionnaires and interviews. The research data collection was conducted over a 4-week period with first year students doing Theory of Structures year module during their second semester (July – November period).

All the students taking part in the research were referred to as participants. Each participant authorized their participation through written consent that outlined both participants and researcher's rights and responsibilities in alignment with the confidentiality and university's private policies. If a participant was not happy with a question during an interview, they were allowed to refrain answering the questions and if at any point they felt uncomfortable participating they were allowed to leave the online room. Same applies on the questionnaires, no one was forced to complete it. The class had a total of 60 students where only 29 students voluntarily participated in the questionnaire and 15 students were selected to conduct the focus group interviews.

The action of the research started by teaching online the topic in the module Theory of Structures called 'second moment of area' and observed how the students responded to the teaching and recorded the findings on the online journal. The online semester test was then given to students on the work taught on second moment of area. Marking of the Online Test was done, and the results and feedback were released to students. Everyone was given a chance to reflect on their feedback and query their marks. Care was taken throughout the entire research process to respect the privacy and needs of the participants. Even if they did consent, they knew that they can still withdraw from the research anytime without affecting their academic performance in the module. Hence, there was a need for the lecturer to have a clear solid line between module curriculum and part of the experiment. Students were not going to be affected in anyway with poor grades should they decide not to participate in the research.

Two main types of data were collected from this study. The first type was collected by conducting and recording focus group interviews with the students using blackboard collaborate ultra from the university's learning management system. The focus of the interviews was on their experience in the online teaching, assessment, and feedback of the second moment of area section under the Theory of Structures module. Students were invited to volunteer to participate in the interviews and a total of 15 students were selected. Participants were divided into three groups using the marks of the online test and two other tests written in the first semester (January – June Period). Group 1 consisted of five high performing students based on the average mark of the three tests, Group 2 had five middle performing students and Group 3 had the last five low performing students. Each group was interviewed in a different time slot. Prior to starting each session of the interviews, few concepts of student assessment were clarified for common understanding by all participants, requested participant consent for the recording of the discourse and guaranteed confidentiality. The interview schedules included a minimum of five general questions to facilitate discussions. The five questions were: What is the purpose of assessment in your own view? Did assessment tasks support your learning? Did feedback support your learning? Any suggestions for effective feedback practices? And Which type of assessment do you prefer and why? Formative or summative or continuous. The focus group interviews were conducted to get their feedback on the test process, and they also gave details about how they found questions and solutions. The interviews were not too formal to make students feel at ease when answering the questions.

The second instrument of data collection was the use of questionnaires in the form of online surveys. The online questionnaire was deployed to all 60 students in the class, and they were all invited to participate and were given a week to complete the survey. The online questionnaire was aimed to answer most of the research questions about student learning through assessments. The questionnaire provided continuity of research and data collected from the interviews. A total of 29 responses were received from the questionnaire. An online journal was used to record any field notes and observations during the study. The field notes were also taken while students were writing the online semester test and during the marking and quality assurance of the marks for students.

V. FINDINGS

The main objective of the study was to investigate the effect of assessment and feedback on learning. The following section is the analysis of results obtained from questionnaires and interviews. As already stated in previous sections that a total of 29 students participated in the questionnaires and a total of 15 students participated in focus group interviews. The groups were divided into three, where, Group 1 consisted of five top performing students, Group 2 had five middle performing students and Group 3 had five low performing students.

The analysis of data started by documenting the results obtained from the interviews, and online questionnaires. The audio recordings from interviews were transcribed using Otter software. The transcribed text was then merged with findings from questionnaires and analyzed using open coding by Quirkos software. The latter is a qualitative data software that uses bubbles to organize data into codes and themes by dragging the text into an appropriate theme for analysis. The codes were summarizing key words and were written next to the transcribed text based on unit of meaning. Lastly, the codes were gathered in ranking order to identify the main categories which were also based on areas identified in the literature review. Four main categories emerged: (1) purpose of assessment; (2) assessment feedback; (3) suggestions for effective assessment and feedback practices and (4) formative and summative assessment. The questionnaire results were organized into tables and graphs according to the patterns identified. The results were also compared with the findings that were discovered from the literature review. Microsoft excel' s descriptive tool was used to collate and analyze data obtained from interviews and surveys.

There are different purposes of assessment in the higher education space. One purpose of assessment is to gather relevant information about student performance or progress, or to determine student interests to make judgments about their learning process. After receiving this information, lecturers can reflect on each student's level of achievement, as well as on specific inclinations of the group, to customize their teaching plans. The first goal of the investigation was to get perceptions of students about the purpose of assessment. There was a noticeable trend between Group 1 and Group 2 responses to the question. Both understood that assessment is a tool that is used to check if the module outcomes are achieved by students. A single participant from Group 1 mentioned that "assessment is to test our level of understanding the work and to check whether we are left behind". This was supported by a fellow group member who stated that "we need assessment in order to keep track of the work that lecturers are giving us so that we make sure that we're on par". Group 2 participant stated that "The assessment is a way for a lecturer to see if the students understand the work". This response showed that students understand that lecturers also benefit from the assessment process, and they can be able to adjust their teaching for the benefits of most people involved. Group 3 supported this view through one of their members starting that "assessment is for you to check our understanding whether we understand what you taught us".

According to [14] assessment must be considered as an integral part of learning so that students can adopt a deep learning approach which is characterized by making connections and actively searching for the meaning and an understanding of a given task. Assessment should not be seen as a separate component of learning but must be integrated to the entire learning process. The responses from Group 1 displayed that the assessments conducted in the module supported their learning process. Testimonies to this is the following statements from different participants during interviews: "Sir assessment does support our learning because it encouraged me to push and to study because if there was no assessment, I was going to be lazy and not want to study", "Learning for me, it's the most important thing than obtaining marks", "It does support our learning because we're able to see where we made mistakes and where we were wrong so we can learn and to do better". The above extracts from interviews are an indication that students in this group moved beyond obtaining marks for the assessment but they focused on learning. Contrary to Group 1, the views were different in the third group, for example one participant stated that "for me personally I select chapters to learn from, there are certain chapters that I just want to pass and forget". The third group which consisted of low performing students was more concerned about the marks than the learning journey. A similar question was also asked in the questionnaire about learning during assessment and the results show that most students do gain knowledge during assessment. The graph in

Figure 1 shows that more than 95% of the students did learn through assessment.

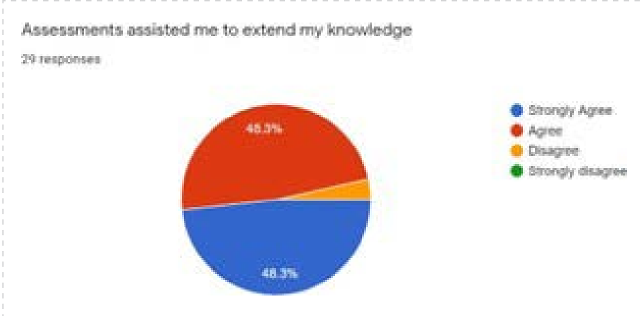

FIGURE 1: *Assessment with knowledge*

Feedback is an integral response of a lecturer to student's work after an assessment activity. It should not be treated separately but should form part of learning and should be able to help students to enhance their learning. In the module Theory of Structures feedback was given as a dialogue in class after assessment results were released. A collaborative learning approach was adopted to deliver feedback to students and most of them liked the method used and they recommended that it is implemented to their other modules. One participant from Group 1 stressed out the importance of feedback by starting that, "I think delivery of feedback is very important. We can get feedback, and then we see where we got wrong, and then we can get the marking memorandum, but I think we need to bridge that gap between getting the feedback and then the marking memorandum."

The questionnaire results as shown in Figure 2 indicated that most students received feedback in a timely manner, except for a few who disagreed. One participant from interviews suggested a proper time for sending feedback by stating that, "...feedback must at least be provided in two weeks' time." The questionnaire results in Figure 3 also showed that there is almost a quarter of a class that does not learn from feedback for different reasons. This should be addressed by applying more effective feedback practices in class.

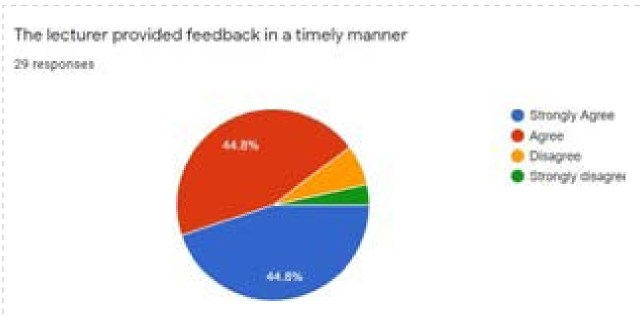

FIGURE 2: *Feedback in timely manner*

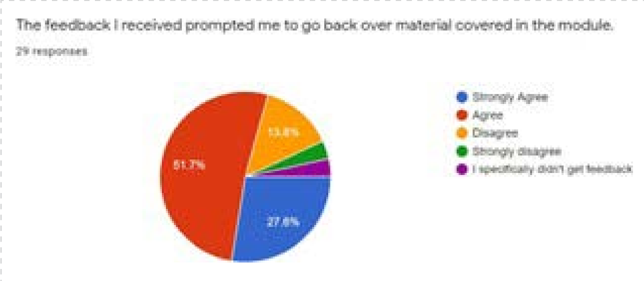

FIGURE 3: *Feedback and studying*

VI. CONCLUSION

The study demonstrated that assessment influences the learning process of students, which agrees with the findings by [10] who concluded that assessment is a means of assisting students to learn. He showed that formative assessment can improve learning when planned to supply students with feedback around qualities of their work and paths they can take to progress. Nowadays feedback is even more important since most students are using online learning or blended learning which requires support and guidance from the lecturer. Although only small size of sample or few participants compared to the faculty of engineering student population, the study still managed to provide findings that will be applied to improve assessment and feedback practices. More work still needs to be done to educate students about the importance of assessment as the findings showed that there are students who still focus on grades during assessment and not real learning. It was interesting to note that there was no student who preferred the lecturer to provide marking memorandums as part of feedback. This showed that students preferred the method of discussing the assessment rather than sending them the marking memorandum.

REFERENCES

[1] E. Stacey and L. Visser, "The history of distance education in Australia," 3rd ed., vol.6, Quarterly Review of Distance Education, 2005, pp. 253-259.

[2] J. Mcgourty, "Four strategies to integrate assessment into the Engineering Education environment," 4th ed., vol.88, Journal of Engineering Education, 1999, pp. 391-395.

[3] J.R. Fraenkel and N.E. Wallen, "How to design and evaluate research in education," Fifth ed. New York: McGraw-Hill, 2003.

[4] K.K. Bhagat and J.M. Spector, "Formative Assessment in complex problem-solving domains: The emerging role of assessment technologies," vol 20, Educational technology and society, 2017 pp. 312-317.

[5] K. Mumm, M. Karm and M. Remmik, "Assessment for learning: Why assessment does not always support student teachers' learning," 6th ed., vol.40, Journal of Further and Higher Education, 2016, pp. 780- 803.

[6] L. McDowell, K. Sambell, C. Montgomery, "Assessemnt for learning in higher education,"1st ed., 2012, London.

[7] N.L. Subheesh and S.S. Sethy, "Learning through assessment and feedback practices: A critical review of engineering education settings," 3rd ed., vol.16, EURASIA Journal of Mathematics, Science and Technology Education, 2019.

[8] P.A. Johnson, "A short guide to action research," Pearson Education Inc, 2008.

[9] R. O'Brien, "An Overview of the Methodological Approach of Action Research," Faculty of Information Studies, University of Toronto, 1998.

[10] S. Jimaa, "The impact of assessment on students learning," vol 28, Social and behavioral sciences, 2011, pp. 718-721.

[11] S. Newstead, "The purposes of assessment," 2nd ed., vol.3, Psychology learning and teaching, 2003, pp. 97-101.

[12] S. Oyinloye and S.N. Imenda, "The impact of assessment for learning on learner performance in Life Science," 11th ed., vol.15, EURASIA Journal of Mathematics, Science and Technology Education, 2019.

[13] S. Palmer, "Authenticity in assessment: reflecting undergraduate study and professional practice,"2nd ed., vol.29, Eur. J. Eng. Educ., 2004, pp. 193-202.

[14] Y.E. Woyessa, S.P. Van Tonder and D. Van Jaarsveldt, "Alternative student assessment in engineering education: Lecturers' perceptions and practices," The 2nd International Multi-Conference on Engineering and Technological Innovation IMETI, 2009, Orlando, Florida, pp. 224-229.

Technical papers

Comparing different modes of teaching and learning: Extended degree modules vs. mainstream modules online

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***Abstract* — This study investigates student perceptions of their preferred mode of teaching (online, hybrid or face-to-face), as well as their preferred mode of online teaching (live online classes, pre-recorded online presentations, or a combination of both) within a mathematics-based curriculum. Extended engineering degree programme, offered to students who have not achieved the minimum requirements for mainstream study or have chosen to enhance their mathematics and science foundations, students in their first and second year of study completed a questionnaire based on their experiences of the online teaching approaches in their mainstream and augmenting modules. The results were captured and analysed in SPSS and indicated the following: 1) students prefer some in- person interaction between themselves and the lecturers in the modules, as opposed to a complete online approach; 2) students value a mix of different online approaches to teaching and learning. For example, providing the students with pre- recordings of content and also scheduling a session that students can attend for live demonstrations or lectures; and 3) students found the approach to online teaching and learning by the extended engineering degree programme more beneficial to that taken by modules in the mainstream curriculum. The reasons for this are varied and relate strongly to the smaller group sizes offered by an extended degree and the emphasis placed on teaching by lecturers within the programme, as well as the interaction and platform for questions offered during live class sessions. The implication of these findings is that lecturers can enhance student learning by offering different modes of instruction online, and that the need for in-person interaction between lecturers and students remains. Moreover, small group sizes serve as opportunities to enhance student foundations.**

Keywords — Online, hybrid model, face-to-face, augmenting, mainstream

I. INTRODUCTION

At the onset of the Covid-19 pandemic, traditional contact universities in South Africa made the shift from in-person contact classes to remote online teaching and learning. This transition had to be made in a limited timeframe and required lecturers and students to use the Learning Management System (LMS) at their disposal, to be available to complete course content remotely, and to have the resources to complete course content online. Lecturers sought to find the balance between utilizing various online modes of teaching and learning while taking into consideration ongoing electricity supply issues and students' unequal access to resources.

Online instruction remained the primary mode of teaching and learning at the University of Pretoria for the duration of 2020 and 2021, and the first semester of 2022 via a portal known as clickUP. In this time, lecturers and students were encouraged to adjust to this new domain and to explore ways in which to engage most effectively with the teaching and learning cycle.

The Engineering, Built Environment, and Information Technology (EBIT) Faculty's ENGAGE Programme is the extended engineering degree programme offered to qualifying students at the University of Pretoria. Students in this programme have typically not achieved the minimum requirements for entry into the mainstream four-year degree programme, but have shown promise in Mathematics and Physical Science in Grade 12. This programme is augmentative to the mainstream degree scheme, offering support modules parallel to mainstream counterparts in years one and two of the programme (year one for the mainstream students), as well as an additional module titled 'Professional Orientation' which focuses on soft (durable) skills development. The student cohort is capped at 270 to allow for smaller groups and academic support, compared to the mainstream cohort of up to 1 500 students. This structure allows students to make the shift from high school to university while their foundations are strengthened and requires continuous assessment and supportive tutorial-based and discussion class learning [1][2].

When the shift to online teaching and learning took place in 2020, the ENGAGE programme lecturers had to consider ways in which to offer students their foundational academic support from afar, mainstream lecturers had to learn to manage large class sizes and technical instruction remotely, and both had to contend with the access issues stated previously. This led to different teaching and learning approaches being used within the ENGAGE programme and across the mainstream modules.

The study at hand explores the results of first- and second-year ENGAGE student questionnaires on the effectiveness (or ineffectiveness) of the teaching approaches taken in the ENGAGE programme and in the mainstream counterparts, and compares student experiences with the goal of establishing how best to deliver mathematics-based content remotely for student success. Although the mainstream and extended degree programmes differ in size and emphasize different aspects of student development, it is useful to consider whether or not lecturers can aid each other in creating supportive learning environments remotely. Additionally, education is advancing into the hybrid space and importance is increasingly placed on teaching and learning for student success in this context [3].

II. RATIONALE

For years there have been concerns about student throughput and retention rates in extended and mainstream engineering degree programmes in South Africa with the Engineering Council of South Africa (ECSA) reporting that only 35% to 60% of engineering students complete their degrees at different educational institutes [4]. Of this number, only 10% obtain their professional registration [5]. There are various contextual factors that influence these retention rates. Some of these include school-level factors, career counselling, high school grades, high school rank, financial aid, and academic support [6]. While the responsibility of the lecturers and/or facilitators is outside of the scope of many of these, academic support is something that is influenced by the mode and manner of teaching and learning.

This understanding, along with the growing demand for scarce skills such as those promoted in engineering studies [7], has led to an upsurge of research in Engineering Education, where several groups have formed to address engineering education internationally and in Africa to shift perspective from *what* is taught to *how* it is taught. When classes were forced to move online, this came to the fore even more so as it was a largely unexplored and underdeveloped space in traditional contact universities.

Historically, lecturers and/or facilitators in extended degree programmes tend to place emphasis on teaching and student support, given that this role relates directly to academic support. For this reason, class attendance is compulsory, lecture groups are small, continuous assessment is practiced, and frequent feedback is provided [8]. However, in the mainstream programme, large class sizes often do not allow for class attendance to be monitored, or for small lecture groups, continuous assessment, and regular feedback to be offered. Subsequently, this minimizes the opportunity for lecturers to offer academic support.

However, when it comes to online teaching and learning, the need for academic support becomes even greater and instructors are required to more closely monitor student participation and cooperation, encourage active learning, offer prompt feedback, emphasize time on task, communicate expectations, and encourage different ways of learning [9]. This is because students are often isolated from their peers and cannot engage directly with the instructor. Thus, both augmenting module and mainstream module lecturers have to offer an academically supportive environment to students so that student retention numbers do not reduce further.

Many lecturers and/or facilitators approached this challenge differently and chose different modes of content delivery. For example, some modules made use of virtual classes, others made use of PowerPoint presentations and videos, while others made use of class notes. Some mainstream modules began the practice of offering continuous assessment and feedback as additional academic support and others offered a large project as the mode of assessment. All of these approaches were experimental. Therefore, these practices need to be evaluated to establish which serves best to complement the teaching and learning objective. Consequently, this study looks at how the students experienced these different approaches so that lecturers can share best practices and harness a supportive academic environment across the engineering curriculum.

III. APPROACHES TO TEACHING AND LEARNING

Teaching and learning can be categorised according to three primary approaches: face-to-face, online, and hybrid [10]. A face-to-face approach dictates that all classes take place in person on campus; an online approach dictates that classes and related activities are conducted virtually, using online resources and the LMS; and a hybrid approach combines elements of both.

Historically, a face-to-face approach was the primary mode of teaching and learning by the University. However, with the onset of the Covid-19 pandemic, classes shifted to a full online medium. As staff and students adapted to the environment and protocols were lifted, a hybrid approach was introduced. When the study was conducted in 2021, the lecturers were still required to conduct classes online remotely due to social distancing protocols, with some practicals and tutorials taking place in-person on campus with limitations on student attendance.

Extended engineering degree programme lecturers offered live virtual classes that were compulsory for students. The support staff (assistant lecturers and tutors) within these modules would monitor attendance and offer additional online consultations. Lecturers also made use of breakout sessions and teamwork to help students generate relationships with their peers and to assist them in gaining confidence in this setting. In line with this shift, the ENGAGE lecturers continued to offer continuous assessment as it is a basic principle of the programme.

Conversely, due to comparatively large classes, many mainstream modules (specifically those who have an ENGAGE counterpart) were unable to provide live virtual classes to students on the LMS. Support was provided through different remote-style tutorial classes, whereby students liaised primarily with tutors. Due to the setting, interaction between lecturers and students was often limited. However, in an attempt to mitigate this, some lecturers implemented more class-based assessments; thus, mirroring the continuous assessment model applied in the ENGAGE modules. In addition, many of the mainstream counterparts offered pre-recorded videos or narrated PowerPoints as a substitute for face-to-face lectures — this was largely due to the logistics around comparatively high student numbers.

The online approach led lecturers to experiment with the use of narrated PowerPoint presentations, live video conferences, and class recordings, depending on the module requirements and associated logistics. The merits and drawbacks of these different approaches are well documented [11][12], but this study explores student preferences related to these mediums.

IV. EXPERIMENTAL METHODOLOGY

An online questionnaire was distributed to all first- and second-year ENGAGE engineering students at the University of Pretoria. Out of the 315 registered students across the two years, 80 responded to the questionnaire. The questionnaire was distributed at the end of 2021 to target the cohort of students that as a result of the Covid-19 pandemic, had never been exposed to face-to-face teaching, or had limited exposure thereof. ENGAGE students were selected because they had experienced two different online teaching approaches across their ENGAGE and mainstream modules. These students granted their consent for the researchers to use the results of the questionnaire anonymously by completing a form at the start of the year. Additionally, ethical clearance for academic research purposes was provided to staff at the institution in 2021 if they conducted research in teaching and learning. An online questionnaire was used due to the virtual teaching and learning environment of the institution at the time.

The data collection process, which commenced one month before the end of the second semester of 2021, spanned a period of two weeks. The results were evaluated by using a mixed-methods approach to data analysis (quantitative and qualitative techniques) [13]. The students were tasked with rating their level of agreement to twenty (a combination of open-ended and closed-ended) questions. These questions were categorized according to four main sections, namely: background information on the student, comparison of the mainstream and ENGAGE modules, additional perceived benefits of the ENGAGE degree over the mainstream degree, and the preferred online teaching approach for students. However, the results were analysed in line with the aims and objectives of the research.

Once the data had been captured, it was processed in IBM SPSS for the purposes of statistical analysis. This software provides both descriptive statistics and correlation analysis, which allowed the researchers to determine the relationships between different independent and dependent variables.

V. RESULTS AND DISCUSSION

This section consists of three sub-sections related to the themes identified in the data analysis. These are:

A) the overarching teaching approaches that were applied in the online environment offered by the University of Pretoria at the time;
B) the students' experience of the transition made by ENGAGE modules and their mainstream counterparts to online teaching and learning; and
C) a correlation analysis between the preferred online teaching approach and the main takeaways from the questionnaire.

A. Analysing responses to overarching teaching and learning approaches

The first question relates to the preferred method of teaching and learning. Each respondent had to select their preference between face-to-face, a hybrid model, or pure online teaching and learning.

Based on the statistical analysis, 49.37% of the respondents prefer a hybrid model. Amongst the comments that were made, students prefer this approach because it aids in their time management. Furthermore, it gives them the opportunity to watch recordings after class has been conducted, enabling them to revisit lectures. However, by being on campus, students have the option to schedule consultations with lecturers which they believe benefits the learning process. Additionally, it enables the students to grow a peer community that encourages learning to take place.

Furthermore, 45.57% of the respondents prefer a face-to-face only teaching approach. Although they had minimal exposure to such an approach at the time, they believe that the online environment (irrespective of how it is integrated) makes it difficult for them to learn new content. Some students also believe that an online approach promotes plagiarism, which might devalue their degree. It is also worth noting that most of the students expected to experience a face-to-face environment, which was relinquished as a result of the Covid- 19 pandemic and associated lockdown restrictions.

Finally, only 5.06% of the respondents prefer pure online teaching and learning. The reason why the students selected this option is because they feel that the online environment promotes remote learning and flexibility within their schedules.

The second question relates to the preferred approach to online teaching and learning. Each respondent was asked to choose between pre-recorded narrated presentations, live interactive sessions, or a combination of both live sessions and a recording while classes take place virtually. 62.03% of the students prefer an online approach where both live interactive sessions and recorded sessions are available. The feedback from the students indicates that the benefits of such an approach are threefold: firstly, by accessing recordings of a presentation, students can access a lecture and re-watch it when convenient; secondly, the addition of a live session gives students the option of asking the lecturer questions on material covered; finally, recordings of live sessions allow students to increase playback speeds and reduce the time it takes for examples to be completed. Live interactive sessions (without an associated recording) as the sole teaching approach is preferred by 26.85% of the respondents, while pre-recorded narrated presentations are preferred by the remaining 11.39% of respondents.

B. Student experience of online teaching and learning in mainstream and ENGAGE modules

The next question relates to the transition from face-to- face to online teaching and learning. The two departments applied different approaches (as stated in Section III), meaning that a comparable result could be obtained. It is important to note that these results are not a reflection on each department or module, but rather on the process they followed in adapting to the environment, irrespective of the reason for such an approach. The students were asked to rate their experience of how the mainstream and ENGAGE modules made the transition to online teaching and learning. Students had to rate their experience on a scale of 0 (zero) to 10 (ten), with 0 being very poor and 10 being excellent.

The mean score of the corresponding mainstream modules was 5.26, while the mean score for the ENGAGE modules was 7.69. This is likely due to the emphasis placed on academic support by the ENGAGE programme.

C. Correlation between online teaching and learning approaches and student learning experience

The method of online teaching and learning differed from module to module. All of the modules presented in the ENGAGE programme opted to apply a live interactive approach whereby classes took place on the LMS. However, due to class sizes and schedules, many mainstream lecturers opted to present class via a pre-recorded narrated presentation medium. In essence, recordings of the theory were available for download, while some tutorial sessions allowed for student-tutor or student-lecturer interaction. To determine the effectiveness of the approaches taken by the different modules, a correlation test was performed whereby a relationship between the teaching approach and the identifying themes was determined. Figure 1 depicts the results obtained by denoting the preferred teaching and learning approach as an independent variable, while the average feedback scores are denoted as a dependent variable for each of the themes determined by the questions.

The first question that students were asked relates to the implementation of a 'flipped classroom' approach. A flipped classroom approach is a method where students implement self-study before the class is conducted [14]. The results from the research indicate that, in general, students do not rate the value of this approach very high. Students who prefer live online sessions rate their perceived value as 5.14 out of 10. The average value then increases to 5.89 for students who prefer a pre-recorded online approach. Finally, students who prefer a combination of both rate the benefit of such an approach at 5.82. The reason why a maximum average for this metric was found for students who preferred a pre- recorded or recorded online session is because class preparation compliments this preferred study approach. Conversely, live online sessions alone provide an opportunity for students to ask the lecturer questions related to the content of the lecture period, thus increasing time in class and decreasing time for self-study.

The second question worth noting relates to the use of continuous assessments as learning opportunities. Students were asked how continuous assessments benefit their learning — a major distinguishing factor between the ENGAGE degree and mainstream degree is that ENGAGE provides more continuous assessment opportunities. In general, students' rate this as the greatest benefit to them learning new content. Students who prefer live online sessions rate the effectiveness of continuous assessments at 8.79. The average effectiveness then progressively decreases to 8.25 and 8.14 for students who prefer pre-recorded presentations and those who prefer a combination of both, respectively. Student responses indicate that they prefer this method because it highlights areas for improvement and gaps in understanding before a semester test is written. Additionally, continuous assessments ensure that students do not fall behind on their study expectations.

The ENGAGE programme includes additional skills- and practices-based modules (JPO 110 and JPO 120) that mainstream students are not exposed to. Questions three and six required students to rate the perceived benefits of the unique skills they obtained from the additional modules offered by the ENGAGE programme. In general, students who prefer a live online approach rate the benefit of these extra skills very high at 8.30 for both questions three and six. This then decreases to 6.78 and 6.00 for students who prefer only pre-recorded online sessions for questions three and six respectively. The average value then increases to 7.69 and 7.51 (for questions three and six) for students who prefer a mix of both approaches. The reason why such a deviation occurs relates to the preferred online teaching and learning method. Because the extra modules are reliant on direct interaction with the students, students who are not invested in these interactions will not experience a considerable benefit. Student involvement is key for the development of skills and practices and those who prefer pre-recorded sessions or a combination of both will not be directly involved in the learning experience and may perceive their time as wasted. Conversely, students who prefer to a live online session will apply the skills and practices offered by the additional modules and are more likely to gain the benefits thereof.

The last set of questions relates to how the ENGAGE modules assist the students in preparing for the equivalent mainstream counterparts and the completion thereof. In general, students who prefer a live online approach rate the aforementioned questions high with an average score of 8.30 in terms of preparing for mainstream module counterparts, and 8.10 in terms of the completion of mainstream module counterparts. The ratings then decrease to 6.78 for the completion of mainstream counterparts for students who prefer only pre-recorded lecture presentations while the average score for the preparation of mainstream counterparts decreased to 7.00 for those who prefer pre-recorded lecture sessions. However, the mean scores then increase to 7.59 and 7.51 for those students who prefer a combination of live online sessions and recordings. In general, the lack of discrepancy in these results indicates that the ENGAGE modules serve their primary purpose by providing students with the necessary foundations and academic support to complete the mainstream counterparts.

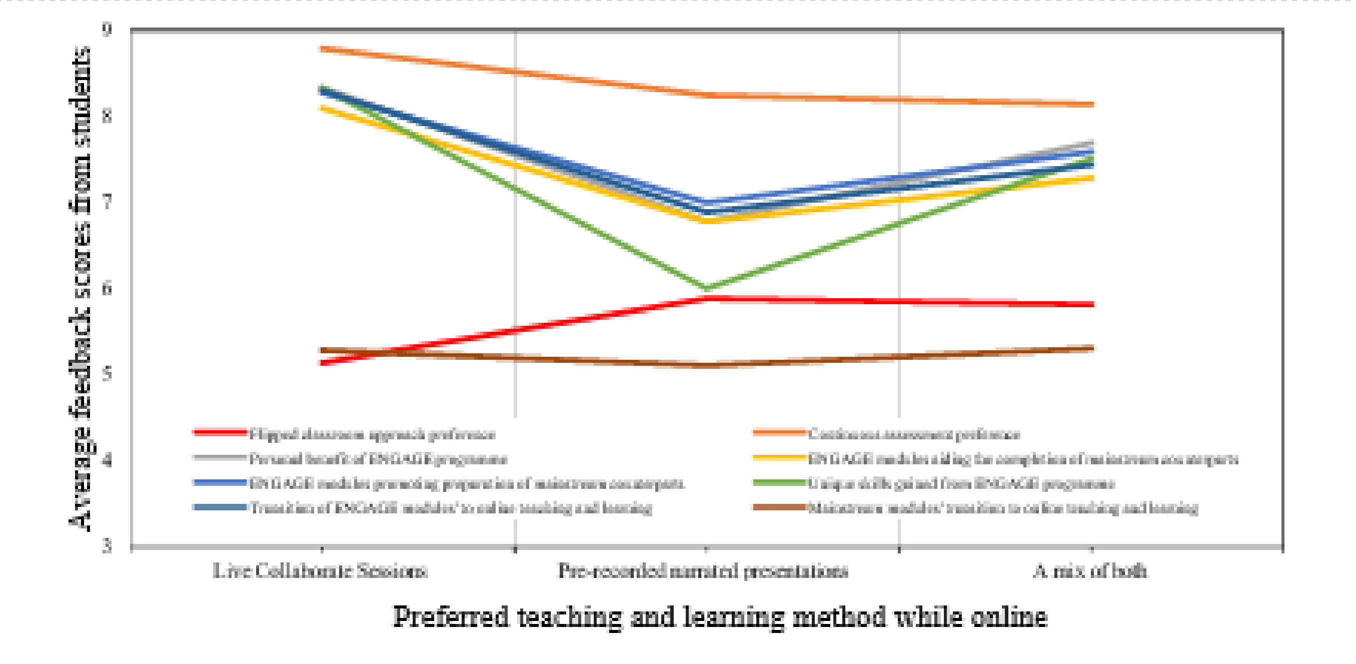

FIGURE 1: Preferred online teaching and learning method as function of feedback scores for each question

VI. CONCLUSION

The purpose of this research was to evaluate the results of first- and second-year student questionnaires on the effectiveness of the approaches taken in the ENGAGE programme and in the mainstream counterparts offered at the University of Pretoria during the transition to the online teaching and learning environment.

The first notable conclusion is the overwhelming preference for some face-to-face interaction (face-to-face or hybrid) between lecturers and students. The results suggest that a hybrid model with face-to-face interaction is an approach that can be considered for future teaching and learning practices. However, a pure online approach is not preferred by the students as it limits their contact with lecturers and opportunities for support.

The second conclusion that can be made relates to the different online approaches that can be implemented. The results indicate that students prefer live online sessions, or a combination of these and recorded sessions. Students did not favor a pre-recorded lecture style approach, likely due to the limited opportunities for interaction and an inability to ask questions.

Finally, the results indicate that the benefits of comparatively small groups (as found in the ENGAGE programme) result in a higher degree of participation for all of those involved. As such, the aim must be to reduce group sizes so as to optimize the benefits for the student and allow for lecturer-student engagement.

VII. LIMITATIONS AND RECOMMENDATIONS

The questionnaire link was distributed to students via both the live online lectures and the recordings. However, it is predicted that the majority of the respondents were active students who were present online during distribution as opposed to those accessing recordings afterwards. Student participants were only ENGAGE students who were more likely to require the additional assistance offered by the programme. As such, student feedback may be influenced accordingly.

It is recommended in future studies that participation increase to a more representative student sample (increasing participation to 60% of the student cohort as opposed to 20%).

Additionally, it is assumed that the student-participants had limited exposure to face-to-face learning. Future research includes repeating the same experiment with students who have had exposure to face-to-face, online, and hybrid teaching approaches. This will enhance student feedback because they will have had exposure to the positive and negative aspects of both.

REFERENCES

[1] E. Müller, Student Guide: ENGAGE, Pretoria: University of Pretoria, 2022.

[2] Council on Higher Education, "Extended Programmes with an Integrated Foundation Phase: Theoretical considerations for curriculum design," Council on Higher Education, Pretoria, 2020.

[3] A. Jamison, A. Kolmos and J. Holgaard, "Hybrid Learning: An Integrative Approach to Engineering Education," Journal of Engineering Education, vol. 103, no. 2, pp. 253-273, 2014.

[4] G. Fisher, "Improving throughput in the engineering bachelor's degree," 28 October 2011. [Online]. Available: https://www.ecsa.co.za/about/pdfs/091211_ECSA_Through put_Report.pdf. [Accessed 4 August 2022].

[5] Engineering Council of South Africa, "Engineering Skills Pipeline," ECSA, Johannesburg, 2022.

[6] A. Bengesai and J. Pocock, "Patterns of persistence among engineering students at a South African university: A decision tree analysis," South African Journal of Science, vol. 117, no. 3/4, pp. 1-9, 2021.

[7] I. Scott, N. Yeld and J. Hendry, "Higher Education Monitor: A case for improving teaching and learning in South African higher education," October, 2007.

[8] E. Müller, "Progress report on ENGAGE programme: cohort 2010 to cohort 2022," University of Pretoria, Pretoria, 2022.

[9] M. Sadiku, P. Adebo and S. Musa, "Online teaching and learning," International Journals of Advanced Research in Computer Science and Software Engineering, vol. 8, no. 2, pp. 73-75, 2018.

[10] H. Kurthen, "Hybrid, Online, Face-to-Face Teaching: When is it an efficient learning tool?" The International Journal of Learning, vol. 12, no. 5, pp. 237-245, 2006.

[11] L. Lapitan, C. Tiangco, D. Sumalinog, N. Sabarillo and J. Diaz, "An effective blended online teaching and learning strategy during the Covid-19 pandemic," Education for Chemical Engineers, vol. 35, pp. 116-131, 2021.

[12] L. Goodson and L. Nilson, Online Teaching at Its Best: Merging Instructional Design with Teaching and Learning Research, Hoboken (NJ): John Wiley & Sons, 2017.

[13] M. D. Gall, J. P. Gall and W. B. Borg, Educational Research, 7th ed., Boston (MA): Allyn and Bacon, 2003.

[14] I. T. Awidi and M. Paynter, "The impact of a flipped classroom approach on student learning experience," Computers & Education, vol. 128, pp. 269-283, 2019.

Technical papers

Learning styles of first-year undergraduate engineering majors at an Indian technological university

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Abstract — **Education has been considered as the ladder for the socio-economic development of individuals and society. Thus, there exists a demand for educational institutions that provide quality education. Such an endeavor requires institutions to be adaptive, considering and incorporating appropriate teaching and learning techniques to address changing needs. While there exists considerable research on understanding and applying different approaches to enhance learning through teaching techniques, there is a relative lacuna in our understanding of the learning styles that students use to process information. This lacuna can limit the effectiveness of pedagogical approaches in improving student learning outcomes.**

Research has shown that students process information through varied means, for example, while some prefer theories/concepts others prefer facts/data or while some prefer visual media others prefer text or audio. Over the years researchers have proposed different theories and developed multiple models to study learning styles used by students. In this study, we attempt to identify the preferred learning styles used by students in the first year of an undergraduate engineering program using the Felder-Solomon ILS (Index of Learning Style) scale. A quantitative research approach was used to identify the learning dimensions preferred by this cohort of students. Based on the analysis visual, reflective, sequential, and sensing were the preferred learning styles for the population studied. The results of this study can be used by faculty to suitably adapt their pedagogical practices.

Keywords — learning styles, quantitative, statistical analysis, dimensions

I. INTRODUCTION

Education is the pathway that can lead every individual towards success enabling socioeconomic development of the society. Thus, there is an imperative demand for quality education and considerable resources are being allocated in support of achieving these goals. But, individuals learn and acquire knowledge in different ways and these individual differences in the effective modes of instruction or study are collectively referred to as learning styles [1], [2]. While the idea of learning styles has long been recognized [1], [3]–[5], during the early days the term "cognitive style" was more widely used [1], [5], [6]. Over the last 40 years the term "learning styles" has been used to represent a broader construct of cognitive style that considered needs of individual students in considering pedagogical approaches [2], [7].

Learning styles, defined as differences in preferred learning processes between individuals, traces its origins to work on *cognitive styles* [3], defined as an individual's preferred means of acquiring and processing knowledge, i.e., cognitive functioning [8], [9]. Over the last 50 years the philosophical underpinnings of cognitive styles has been applied to domains such as decision making styles [10], [11], personality styles [12], and learning styles [2], [13], [14], with the highest interest observed in application to education, specifically learning styles, [3].

Some of the earliest work on application of cognitive styles to education was performed in the 1970s, with models by Gregorc [15], [16] and Kolb [17], [18]. While Gregorc built models of learning based on phenomenological approach using the dimensions of perception (information grasping) and ordering (arrangement and use of information), Kolby proposed models based on the experiential learning theories of John Dewey, Kurt Lewin, and Jean Piaget. While there have been other models proposed, the works of Gregorc and Kolb have been the most influential forming the basis for the development of other models and psychological instruments. For example Felder-Silverman developed their learning style model based on the works of Kolb and Jung [13] which formed the basis of the Index of Learning Styles questionnaire developed by Felder-Solomon [19]. For a more detailed review of theories, models, and instruments for measuring learning styles see [4].

Due to the growing interest among researchers and educators in understanding the various learning styles multidisciplinary research is being conducted [1], [3], [5], [20]. Furthermore, researchers have also attempted to understand the learning styles in the context of individual fields e.g., English language teaching [21], [22], health sciences [20], [23]–[26] and engineering [13], [27].

It has been known for long that there is a great variation among students inregards to their preferred learning style, e.g. audio, visual, and logical reasoning [20]. And student learning outcomes might suffer when there is a mismatch between their preferred learning style and the teaching style adopted [13]. Consequently, this makes the work of educators challenging: can teaching styles be personalized to individual students? And if yes, how? Before this can be answered successfully, educators need to determine the learning styles of their students. Over time scholars have proposed various theories/models to determing the differences among the students. Myers-Briggs type indicator (MBTI) [12], [28], VARK [29], [30], Kolb learning styles [14], [31], and Felder-Silverman learning style model (FSLSM) [32] are some of the major models that have been proposed and extensively validated.

Technological advancements in ICT and its potential to improving student learning outcomes has made ICT an integral part of education [33]–[36], changing both parental [37] and student expectations of pedagogy [38]. Furthermore, the disruptions to education caused by the COVID-19 pandamic and the resulting widespread use of ICT in education [39], [40] has provided the students and teachers with first-hand experience and made use of ICT more acceptable [41], [42]. The infrastructure built to address the forced migration towards online only education can now be used to provide innovative solutions to improve student learning outcomes.

One area of research that is gaining interest among scholars is the intersection of learning styles and ICT depedant pedagogical approaches like blended learning [43], [44]. And the current acceptance of ICT for learning among various stakeholders, combined with facilities created for online education during COVID disruptions, makes this an interesting and excellent time to study learning styles among the new generation of students. The results of these studies can help both provide insights into the learning styles of the students and open new avenues of research, combining ICT, AI/ML, and pedagogy that can potentially lead to personalized education.

The aim of this study was to understand the learning styles of the incoming cohort of undergraduate students (i.e., first- year UG students) at a private technological university in India and determine if there were differences amongst the students based on their gender. The Felder-Solomon ILS (Index of Learning Styles) [19] questionnaire was used to collected information on student learning styles. The paper is arranged as follows. The Methodology and Results are discussed in Sections II and III. Finally, in Section IV a discussion of the results and conclusions are presented

II. METHODOLOGY

Improving students understanding of the concept is a challenge and different pedagogical strategies have been implemented by educators to help students learn better. For decades educators have been developing and implementing different teaching strategies to improve students learning. As previously stated, one size doesn't fit all similarly one learning style does not fit all. A study is conducted to identify and assess preferred learning styles (Active, Reflective, Sensing, Intuitive, Sequential, Global) of first-year engineering students. And also observe the relationship between the variables.

The study was conducted using a quantitative research approach. An autonomous technological University was selected for the research study, and first-year engineering students were selected as the participants. The first-year engineering students were identified as participants for the reason that they were new to the engineering field and had been through online and offline teaching modes; we felt that they can serve best. A set of instruments/ questionnaires were borrowed from the Felder-Solomon Index of Learning Style(ILS) [19]. These items were built to assess students learning preferences based on four learning style dimensions. ILS is used to classify individual learning style preferences by the students.

A. Data collection

For this study, a survey containing items from ILS was developed and distributed to the participants using a google form link. A convenient sampling strategy was used for data collection. Before taking the survey, participants were asked to provide online consent and were permitted to opt-out of the survey anytime.

B. Data Analysis

The data collected was thoroughly screened for missing values and outliers, and the identified missing values and outliers were discarded. The data size of n = 182 was obtained for analysis. A software tool IBM SPSS v27 was used for analysis. Initially, descriptive statistical analysis was conducted to examine the characteristics and distribution of the sample using mean, standard deviation, and skewness. An Analysis of Variance (ANOVA) was done to observe if there is any difference in the preference of learning style dimensions between male and female students in the cohort studied. The instruments used in this study were tested and validated in earlier studies and hence were acceptable to use. The internal consistency of the questionnaire was tested using Cronbach's Alpha and a Cronbach's Alpha of .836 was obtained indicating good consistency and high reliability. Once the reliability was obtained further analyses were conducted

III. RESULTS

To examine the first-year engineering students preferred learning style a descriptive statistical analysis was done. As shown in Table 1. The data indicated that the mean for visual (M = 4.11, SD = .578) was larger than the mean for verbal. Whereas Active (M = 3.70, SD = .715) had larger mean than Reflective (M = 3.56, SD = .689), Sensing (M = 4.11, SD =.553), had larger mean than Intuitive (M = 4.09, SD = .575), and Sequential (M = 4.02, SD = .508), had larger mean compared to Global(M = 3.82, SD = .532). Based on the mean values, it can be inferred that the first-year engineering student's preferred learning styles were Visual, Active, Sensing, and Sequential. The data also reported that the standard deviation for Active was the largest indicating a large variation in the data distribution compared to other dimensions.

TABLE 1: *Mean and standard deviation score*

Sl. No	Learning Styles	Mean (M)	Standard Deviation (SD)
1	Visual (Vis)	4.11	.587
2	Verbal (Ver)	3.43	.693
3	Active (Act)	3.70	.715
4	Reflective (Ref)	3.56	.689
5	Sensing (Sens)	4.12	.553
6	Intuitive (Int)	4.09	.575
7	Sequential (Seq)	4.02	.508
8	Global (Glob)	3.82	.532

Further analysis was done to confirm the preferred learning style from the four dimensions. The data indicated that 87.36% of first-year engineering students preferred visual learning style whereas 41.75% of the students preferred verbal. 67.03% of students preferred Global and 79.12% of students preferred Sequential learning style. 74.72% of the students preferred Reflective whereas 67.03% of students preferred Active learning style. 80.76% of students preferred Sensing whereas 69.78% of students preferred Intuitive learning style. Table 2. Provides the percentage of student's preference of learning style for Four dimensions.

TABLE 2: *Percentage of student's preference of learning style*

Sl. No	Learning Styles	%
1	Visual	87.36
2	Verbal	41.75
3	Active	67.03
4	Reflective	74.72
5	Sensing	80.76
6	Intuitive (	69.78
7	Sequential	79.12
8	Global	67.03

Based on the above analysis the preferred learning styles were Visual, Reflective, Sensing, and Sequential.

The data was further analysed to observe the difference in learning style preference between male and female first-year engineering students. An (Analysis of Variance) ANOVA test was conducted to observe the difference in learning style preference between male and female students. The data was initially analysed to see if it satisfies the assumptions for ANOVA. It was observed that all the data was not normally distributed violating the assumption of normality. Since F statistics is robust to violations of normality still ANOVA analysis can be done on this sample [50], [51]. Leven's test indicated that the assumption for homogeneity of variance was statistically significant for Visual, Verbal, Sequential, Global, Active, Reflective, and Sensing, Intuitive with the p- value greater than .05α, indicating that the variance are not significantly different from each other meeting the assumption of homogeneity of variance. Hence we fail to reject the hypothesis that the groups have equal variance.

An ANOVA analysis was conducted. As per the data, Verbal F(1,180) = 2.184, P=.141, Sequential F(1,180) =1.231, P=.269, Global F(1,180) = 1.197, P=.275, Active F(1,180) = .348, P=.556, Reflective F(1,180) = .007, P=.936, Sensing F(1,180) = .313, P=.576, and Intuitive *F*(1,180) =.822, P=.366 dimensions were statistically significant with the p-value >.05α indicating that there was no statistically difference between the male and female students preference for above mentioned learning styles. Whereas Visual *F*(1,180) = 5.314, *P*<.05 showed that the p-value was smaller than .05 alpha indicating that there was a statistically significant difference between male and female students for Visual learning style.

The data was further analysed to observe the relationship between the four dimensions of learning style. A Pearson correlation coefficient was calculated to evaluate linear relationship between the variables. As per the data visual learning style had the statistically significant largest positive correlation (*r=.469, p < 00.1*) with Sequential. Verbal had largest positive correlation with (r = .424, *p < 00.1*) with Sequential learning style. Active had statistically significant largest positive correlation with (r = .463, *p < 00.1*) with Global. Reflective had statistically significant largest positive correlation with (r = .478, *p < 00.1*) with Sequential. Sensing had statistically significant largest positive correlation with (r = .609, *p < 00.1*) with Global. Intuitive had statistically significant largest positive correlation with (r = .575, *p < 00.*1) with Sequential. Sequential had statistically significant largest positive correlation with (r = .478, *p < 00.1*) with Reflective. Global had statistically significant largest positive correlation with (r = .463, *p < 00.1*) with Active learning style.

TABLE 3: *ANOVA*

	F	sig
Visual	5.314	. 022*
Verbal	2.184	.141
Global	1.197	.275
Sequential	1.231	.269
Active	.348	.556
Reflective	.007	.936
Intuitive	.822	.366
Sensing	.313	.576

Note: **p<.001

As per Pearson correlation, the sequential and sensing reported the strongest and positive statistically significant correlation between all the variables. Whereas Visual and reflective reported a weak positive statistically significant Pearson correlation coefficient. Table III shows the results.

IV. DISCUSSION AND CONCLUSION

The idea of cognitive styles is being widely applied in the field of education, specifically in understanding the differences in learning styles of students [3]. And while there are a multitude of studies applying various models/constructs to study these individual differences, researches have, questioning their utility, called learning styles a myth [52], [53].[53] highlight that there is a dearth of support, in the form of controlled studies, for the claims of learning styles because content influences the style of teaching, and consequently learning styles cannot be separated from the context. But, because learning generally involves information delivered via multiple forms [52], while an matching between individual learning styles and course materials might not be possible, it might be possible to adapt teaching to meet the needs of the majority of the students.

The results indicated that the students at the study site preferred visual, reflective, sensing and sequential as their learning styles. Based on the learning styles that they have preferred, we can state that students prefer visual view of the content to understand the concept and being sensing learners, before jumping to the conclusion they will prefer to learn facts and then solve problems using standard approaches. As a reflective learner they tend to work alone. Being a sequential learner students will learn the content in the incremental steps to find solutions. This data will provide faculties a proper direction in developing relevant content and pedagogy suitable to students learning styles. The data can be further analysed to observe the difference in learning style preferences between genders. In this study, the ratio of male to female students was significantly different and all were undergraduate students majoring in engineering. Hence, in a future study we would like to include students from diverse domains and with a more even distribution between male and female students. Since in this study we have studied students those who have faced both offline and online course, now we would like to even study post covid student preferences and do a comparison

REFERENCES

[1] H. Pashler, M. McDaniel, D. Rohrer, and R. Bjork, "Learning styles concepts and evidence," Psychol. Sci. Public Interes. Suppl., vol. 9, no. 3, pp. 105–119, Dec. 2008, doi: 10.1111/J.1539-6053.2009.01038.X/ASSET/IMAGES/LARGE/10.1111_J.1539-6053.2009.01038.X-FIG2.JPEG.

[2] P. Kirby, "Cognitive Style, Learning Style, and Transfer Skill Acquisition. Information Series No. 195.," Information Series, no. 195. National Center Publications, The National Center for Research in Vocational Education, The Ohio State University, 1960 Kenny Rd., Columbus, OH 43210 ($7.25), 1979.

[3] M. Kozhevnikov, "Cognitive Styles in the Context of Modern Psychology: Toward an Integrated Framework of Cognitive Style," Psychol. Bull., vol. 133, no. 3, pp. 464–481, 2007, doi: 10.1037/0033-2909.133.3.464.

[4] S. Cassidy, "Learning Styles: An overview of theories, models, and measures," Educ. Psychol., vol. 24, no. 4, pp. 419–444, Aug. 2004, doi: 10.1080/0144341042000228834.

[5] L. J. Swanson, "Learning Styles: A Review of the Literature.," Educational Research Information Centre. Jul. 1995.

[6] F. Romanelli, E. Bird, and M. Ryan, "Learning Styles: A Review of Theory, Application, and Best Practices," Am. J. Pharm. Educ., vol. 73, no. 1, Feb. 2009, doi: 10.5688/AJ730109.

[7] C. S. Claxton and Y. Ralston, "Learning Styles: Their Impact on Teaching and Administration. AAHE-ERIC/Higher Education Research Report No. 10, 1978." Publications Department, American Association for Higher Education, One Dupont Circle, Suite 780, Washington, DC 20036 ($4.00), 1978.

[8] G. S. Klein and H. J. Schlesinger, "Perceptual attitudes toward instability: I. Prediction of apparent movement experiences from Rorschach responses," J. Pers., vol. 19, no. 3, pp. 289–302, 1951, doi: 10.1111/J.1467- 6494.1951.TB01103.X.

[9] G. S. Klein, "The personal world through perception.," in Perception: An approach to personality., R. R. Blake and G. V Ramsey, Eds. Ronald Press Company, 1951, pp. 328–355.

[10] M. Kirton, "Adaptors and innovators: A description and measure," J. Appl. Psychol., vol. 61, no. 5, pp. 622–629, Oct. 1976, doi: 10.1037/0021-9010.61.5.622.

[11] A. J. Rowe and R. O. Mason, Managing with style: A guide to understanding, assessing, and improving decision making. San Francisco: Jossey-Bass, 1987.

[12] R. Harrington and D. A. Loffredo, "MBTI personality type and other factors that relate to preference for online versus face-to-face instruction," Internet High. Educ., vol. 13, no. 1–2, pp. 89–95, Jan. 2010, doi: 10.1016/J.IHEDUC.2009.11.006.

[13] R. M. Felder and L. K. Silverman, "Learning and Teaching Styles in Engineering Education," Eng. Educ., vol. 78, no. 7, pp. 674–681, 1988.

[14] S. J. Cavanagh, K. Hogan, and T. Ramgopal, "The assessment ofstudent nurse learning styles using the Kolb Learning Styles Inventory," Nurse Educ. Today, vol. 15, no. 3, pp. 177–183, Jun. 1995, doi: 10.1016/S0260-6917(95)80103-0.

[15] A. F. Gregorc, "Learning-teaching styles-potent forces behind them," Educational leadership, vol. 36, no. 4. ASSOC SUPERVISION CURRICULUM DEVELOPMENT 1250 N PITT STREET, ALEXANDRIA, VA~..., pp. 234–236, 1979.

[16] A. F. Gregorc, "Style as a symptom: A phenomenological perspective," Theory Pract., vol. 23, no. 1, pp. 51–55, Jan. 1984, doi: 10.1080/00405848409543089.

[17] D. A. Kolb, "Management and the Learning Process," Calif. Manage. Rev., vol. 18, no. 3, pp. 21–31, Apr. 1976, doi: 10.2307/41164649/ASSET/41164649.FP.PNG_V03.

[18] D. A. Kolb, Experiential learning: Experience as the source of learning and development, 2nd ed. Upper Saddle River, New Jersey, USA: Pearson Education, 2014.

[19] "Index of Learning Styles | Resources for Teaching and Learning STEM." https://educationdesignsinc.com/index-of-learning-styles/ (accessed Sep. 25, 2022).

[20] L. Curry, "Cognitive and learning styles in medical education," Acad. Med., vol. 74, no. 4, pp. 409–413, 1999.

[21] J. Hu, Y. Peng, X. Chen, and H. Yu, "Differentiating the learning styles of college students in different disciplines in a college English blended learning setting," PLoS One, vol. 16, no. 5, p. e0251545, May 2021, doi: 10.1371/JOURNAL.PONE.0251545.

[22] C. Lethaby and R. Mayne, "A critical examination of perceptual learning styles in English language teaching," IRAL - Int. Rev. Appl. Linguist. Lang. Teach., vol. 58, no. 2, pp. 221–237, Jun. 2020, doi: 10.1515/IRAL-2017-0067/MACHINEREADABLECITATION/RIS.

[23] D. Rohrer and H. Pashler, "Learning Styles: Where's the Evidence?.," Med. Educ., vol. 46, no. 7, pp. 634–635, Jun. 2012.

[24] N. Ilçin, M. Tomruk, S. S. Yeşilyaprak, D. Karadibak, and S. Savcl, "The relationship between learning styles and academic performance in TURKISH physiotherapy students 13 Education 1303 Specialist Studies in Education," BMC Med. Educ., vol. 18, no. 1, pp. 1–8, Dec. 2018, doi: 10.1186/S12909-018-1400-2/TABLES/7.

[25] S. Shorey, V. Chan, P. Rajendran, and E. Ang, "Learning styles, preferences and needs of generation Z healthcare students: Scoping review," Nurse Educ. Pract., vol. 57, p. 103247, Nov. 2021, doi: 10.1016/J.NEPR.2021.103247.

[26] J. Stander, K. Grimmer, and Y. Brink, "Learning styles of physiotherapists: A systematic scoping review," BMC Med. Educ., vol. 19, no. 1, pp. 1–9, Jan. 2019, doi: 10.1186/S12909-018-1434-5/TABLES/2.

[27] M. Heenaye, A. Gobin, N. Ali, and M. Khan, "Analysis of Felder-Solomon Index of Learning Styles of Students from Management and Engineering at the University of Mauritius," J. Educ. Vocat. Res., vol. 3, no. 8, pp. 244–249, 2012, [Online]. Available: www.learningfromexperience.com.

[28] S. E. Cooper and J. A. Miller, "Mbti Learning Style-Teaching Style Discongruencies," Educ. Psychol. Meas., vol. 51, no. 3, pp. 699–706, Sep. 2016, doi: 10.1177/0013164491513021.

[29] H. R. Mozaffari, M. Janatolmakan, R. Sharifi, F. Ghandinejad, B. Andayeshgar, and A. Khatony, "The Relationship Between the VARK Learning Styles and Academic Achievement in Dental Students," Adv. Med. Educ. Pract., vol. 11, p. 15, 2020, doi: 10.2147/AMEP.S235002.

[30] W. L. Leite, M. Svinicki, and Y. Shi, "Attempted Validation of the Scores of the VARK: Learning Styles Inventory With Multitrait–Multimethod Confirmatory Factor Analysis Models," Educ. Psychol. Meas., vol. 70, no. 2, pp. 323–339, Aug. 2009, doi: 10.1177/0013164409344507.

[31] Hong Lu, Lei Jia, Shu-hong Gong, and Bruce Clark, "The Relationship of Kolb Learning Styles, Online Learning Behaviors and Learning Outcomes," Educ. Technol. Soc. , vol. 10, no. 4, pp. 187–196, Sep. 2007, Accessed: Sep. 25, 2022. [Online]. Available: https://www.jstor.org/stable/jeductechsoci.10.4.187.

[32] S. Graf, S. R. Viola, T. Leo, and Kinshuk, "In-Depth Analysis of the Felder-Silverman Learning Style Dimensions," J. Res. Technol. Educ., vol. 40, no. 1, pp. 79–93, 2014, doi: 10.1080/15391523.2007.10782498.

[33] N. Tvengea and K. Martinsen, "Integration of digital learning in industry 4.0," Procedia Manuf., vol. 23, pp. 261–266, 2018, doi: 10.1016/J.PROMFG.2018.04.027.

[34] M. Webb and M. Cox, "A review of pedagogy related to information and communications technology," Technol. Pedagog. Educ., vol. 13, no. 3, pp. 235–286, 2004, doi: 10.1080/14759390400200183.

[35] B. Piper, E. Jepkemei, D. Kwayumba, and K. Kibukho, "Kenya' s ICT Policy in Practice: The Effectiveness of Tablets and E-readers in Improving Student Outcomes," FIRE Forum Int. Res. Educ., vol. 2, no. 1, pp. 3–18, 2015, Accessed: May 12, 2022. [Online]. Available: http://preserve.lehigh.edu/firehttp://preserve.lehigh.edu/fire/vol2/iss1/2.

[36] M. Fernandez-Gutierrez, G. Gimenez, and J. Calero, "Is the use of ICT in education leading to higher student outcomes? Analysis from the Spanish Autonomous Communities," Comput. Educ., vol. 157, p. 103969, 2020, doi: 10.1016/j.compedu.2020.103969.

[37] S. C. Kong, "Parents' perceptions of e-learning in school education: implications for the partnership between schools and parents," Technol. Pedagog. Educ., vol. 27, no. 1, pp. 15–31, Jan. 2017, doi: 10.1080/1475939X.2017.1317659.

[38] M. J. Jackson, M. M. Helms, W. T. Jackson, and J. R. Gum, "Student Expectations of Technology-Enhanced Pedagogy: A Ten-Year Comparison," J. Educ. Bus., vol. 86, no. 5, pp. 294–301, Jun. 2011, doi: 10.1080/08832323.2010.518648.

[39] H. d'Orville, "COVID-19 causes unprecedented educational disruption: Is there a road towards a new normal?," Prospect. 2020 491, vol. 49, no. 1, pp. 11–15, Jun. 2020, doi: 10.1007/S11125-020-09475-0.

[40] X. Zhu and J. Liu, "Education in and After Covid-19: Immediate Responses and Long-Term Visions," Postdigital Sci. Educ. 2020 23, vol. 2, no. 3, pp. 695–699, Apr. 2020, doi: 10.1007/S42438-020-00126-3.

[41] A. Patricia Aguilera-Hermida, "College students' use and acceptance of emergency online learning due to COVID-19," Int. J. Educ. Res. Open, vol. 1, p. 100011, Jan. 2020, doi: 10.1016/J.IJEDRO.2020.100011.

[42] I. van der Spoel, O. Noroozi, E. Schuurink, and S. van Ginkel, "Teachers' online teaching expectations and experiences during the Covid19-pandemic in the Netherlands," Eur. J. Teach. Educ., vol. 43, no. 4, pp. 623–638, Aug. 2020, doi: 10.1080/02619768.2020.1821185.

[43] N. ' Shamsuddin and J. Kaur, "Students' Learning Style and Its Effect on Blended Learning, Does It Matter?.," Int. J. Eval. Res. Educ., vol. 9, no. 1, pp. 195–202, Mar. 2020, doi: 10.11591/ijere.v9i1.20422.

[44] M. F. Mpwanya and S. Dockrat, "Assessing learning styles of undergraduate logistics students using Kolb's learning style inventory: A cross-sectional survey," South African J. High. Educ., vol. 34, no. 3, p. 210, Jul. 2020, doi: 10.20853/34-3-3338.

[45] Y. Akbulut and C. S. Cardak, "Adaptive educational hypermedia accommodating learning styles: A content analysis of publications from 2000 to 2011," Comput. Educ., vol. 58, no. 2, pp. 835–842, Feb. 2012, doi: 10.1016/J.COMPEDU.2011.10.008.

[46] M. M. El-Bishouty et al., "Use of Felder and Silverman learning style model for online course design," Educ. Technol. Res. Dev. 2018 671, vol. 67, no. 1, pp. 161–177, Nov. 2018, doi: 10.1007/S11423-018-9634-6.

[47] Ö. Şimşek, N. Atman, M. M. Inceo-lu, and Y. D. Arikan, "Diagnosis of learning styles based on active/reflective dimension of felder and Silverman's Learning Style Model in a learning management system," Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics), vol. 6017 LNCS, no. PART 2, pp. 544–555, 2010, doi: 10.1007/978-3-642-12165-4_43/COVER.

[48] N. Moussa, "Learning Styles and the Adoption of Modern Technology among Adult Learners," Inst. Learn. Styles J., vol. 1, pp. 11– 21, 2018.

[49] A. H. S. Al-Azawei, "Modelling E-Learning Adoption: The Influence of Learning Style and Universal Learning Theories," University of Reading, 2017.

[50] M. J. Blanca Mena, R. Alarcón Postigo, J. Arnau Gras, R. Bono Cabré, and R. Bendayan, "Non-normal data : is ANOVA still a valid option?," Psicothema, vol. 29, no. 4, pp. 552–557, 2017, doi: 10.7334/psicothema2016.383.

[51] E. Schmider, M. Ziegler, E. Danay, L. Beyer, and M. Bühner, "Is It Really Robust?: Reinvestigating the robustness of ANOVA against violations of the normal distribution assumption," Methodol. Eur. J. Res. Methods Behav. Soc. Sci., vol. 6, no. 4, pp. 147–151, 2010, doi: 10.1027/1614-2241/A000016.

[52] P. M. Newton, "The learning styles myth is thriving in higher education," Front. Psychol., vol. 6, no. DEC, p. 1908, 2015, doi: 10.3389/FPSYG.2015.01908/BIBTEX.

[53] C. Riener and D. Willingham, "The Myth of Learning Styles," Chang. Mag. High. Learn., vol. 42, no. 5, pp. 32–35, Aug. 2010, doi: 10.1080/00091383.2010.503139.

Technical papers

The perspectives of new student enrollees regarding the vacation work program

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***Abstract* — In South Africa, Universities of Technology and some Comprehensive Universities used to offer a three-year diploma, which was two years of theory and a year of Work Integrated Learning. Recently, a three-year degree was introduced that did not have the Work Integrated Learning component. Work Integrated Learning is defined as a form of workplace experience that incorporates both the formal and practical aspects of education within a structured work environment. The absence of Work Integrated Learning in the curriculum for the degree has created a gap because graduates were no more exposed to Industry. The Department of Mechanical and Industrial Engineering Technology facilitated negotiations with industry for students to spend time in the workplace during vacation. Vacation work is a program aimed at equipping students with some industry- relevant practical skills via exposure to the work environment. As a result of the intervention, a group of five students were placed in one of the Mining Companies for vacation work. The aim of this study is to investigate the perspectives of these students regarding the vacation work program. Using qualitative research methods, the participants were asked to share their perspectives. Data shows that vacation work is ideal for the integration of classroom theory with practical work. It can also be concluded that the perspectives of students regarding the vacation work, has an impact on how they adapt to the workplace, and therefore their performance and ability to acquire useful skills during their placement.**

Keywords — Bachelor of Engineering Technology; vacation work; Institutions of Higher Learning, internship.

I. INTRODUCTION

The current era has seen a shift in economic development, environmental and cultural changes, and rapid technological advancement and innovation. Changes in these factors are likely to become more pronounced in the coming decades [1]. The adaptation of Institutes of Higher Learning (IHL) in response to these constantly changing global socioeconomic factors is paramount. This adaptation appears to be eminent if these institutions are to continue to produce graduates ready to provide competitive, efficient and productive human capital in response to these ever-changing global socioeconomic trends [2, 3, 4, 5].

As a result, the vacation work program adopted by the University of Johannesburg (UJ), in the Department of Mechanical and Industrial Engineering Technology, is aimed at preparing the students to enter the workplace as professionals with relevant skills and attributes.

The modern engineer is a multi-disciplinary professional who often works as part of a diverse team. Any engineering leader must combine a wide range of honed professional skills with extensive technical knowledge [6] and the vacation work program seeks to provide this for undergraduate students. There is a consensus among researchers that vacation work or internship programs, when successfully implemented, can act as a bridge between IHL and industry. These programs can equip university students with relevant skills that improve their competence by enabling them to apply their classroom knowledge in a supervised workplace [7, 8, 4, 9, 10]. Internships or vacation work programs are primarily designed to produce graduates who are ready to join an organization as professionals upon completion of their academic studies [11].

A. An overview of internships and vacation work.

To better understand the potential benefits of internships or vacation work, an overview of these critical aspects of education must be provided. An internship is a short-term work engagement that provides undergraduate students with industry-specific experience by exposing them to the real- world work environment during their formal education [12]. Students usually take part in a summer vacation program between November and February for three weeks. Work experience is a fundamental and principal component of these type of programs, as they are primarily designed to prepare graduates to join organizations as professionals upon completion of their academic studies [11].

The vacation work and internship programs are mutually beneficial to all parties involved. The students gain relevant work experience that enables them to gain skills that improve their employability [13]. It prepares them to become an efficient and productive workforce once they have been employed [14]. Research indicates that students who have participated in a vacation work program are more likely to get hired upon completion of their studies, than those who have not [14, 15]. The program provides a symbiotic relationship between industry partners and academic staff. It fosters collaborative relations between the two parties [11]. IHL can better understand the demands and needs of industry, allowing for the revision and adjustment of their curriculum, thus producing graduates with relevant skills to meet industry demands and needs [16]. Industry partners benefit by having extra help with projects at a considerably lower cost than hiring full-time staff to attend to those projects [14]. They also have access to the expertise of academic staff and the advanced facilities of tertiary institutions, because of established collaborations. They also benefit by having new people who bring fresh and innovative ideas and solutions, who are prospective permanent employees [14]. According to [11], the success of internship programs is impacted by the perspectives of all stakeholders (including the intern, faculty, institution and the industrial organization) and the gaps that exist between them. With that in mind, it is important to understand the impact of these perspectives (especially those of the interns) on the intern's ability to gain valuable knowledge and experience during placement.

Learning and socialization were identified by [17] as the two theoretical frameworks closely associated with internship programs. They may be expressed as the acquisition of knowledge through social interactions [18] and they are important in trying to understand how the students' perspectives of the work environment has impacted their learning. The situated cognition theory is also important in trying to better understand how the students' perspectives of the work environment, impacted their acquisition of knowledge. This theory states that learning cannot be regarded as independent of the context in which it takes place. It can be thought of as learning through experience or practice, in which the acquisition of knowledge is achieved through interaction with the natural learning environment [19]. Jawitz, et al., (2005) conducted a study, to investigate the experiences of a group of engineering students at the University of Cape Town (UCT) in their final year of study. They applied Situated cognition theory in the analysis of the gathered data. Their research questions concentrated on the following aspects while analyzing their data [20].

a) Students' interaction and experience with the 'community of practice'.
b) The impact of situated learning experience on the student's identity as a future engineer.
c) The relevance of gained experience in the workplace.
d) Students' response to the community of practice when legitimate peripheral participation was denied.

The objective of this work is to gain an insight into the perspective of new student enrollees regarding the importance of vacation work in the augmentation of the abilities and attributes gained by undergraduate students during their placement. This work seeks to answer the following questions.

a) What were the expectations of the students regarding the vacation work program?
b) How does the students' satisfaction during their placement impact their ability to adapt to the workplace, and learn?
c) What is the impact of the challenges faced by the students on their ability to adapt to the workplace, and learn?
d) Do students believe that classroom learning provides sufficient preparation for the workplace?

These questions will be addressed in this work, with the aim of possible improvement of the vacation work program. This work's contribution to the existing literature in internships and vacation work is the qualitative contribution regarding the perspectives of new enrollee students, regarding the importance of this critical aspect of education in augmenting the abilities and attributes acquired by undergraduate students. Understanding how these perspectives impact the success of internships and vacation work will allow for changes to be made towards the improvement of these programs.

B. Methodology

This study adopted a deductive quantitative design, grounded in situated cognition theory [21, 19]. This design should lead to the understanding of what impact the perspectives of new student enrollees could have on the internship program, allowing for the formulation of relevant conclusion.

This study concentrated on a group of five Bachelor of Engineering Technology (BengTech) undergraduate students from UJ, in the department of mechanical and industrial engineering technology. The students were selected by the Department of Mechanical and Industrial Engineering Technology. This is the first group of BEngTech students to take part in vacation work, hence the limitation in the number of surveyed participants.

The method used to interview the students followed a semi structured interview protocol. The key points related to the students' perspectives regarding the vacation work program. The questions centered around the students' perspectives during the vacation work, and how those perspectives could have impacted their ability to gain useful knowledge. They also covered the students' satisfaction during their placement, and their perspectives regarding the link between classroom education and the work environment. Google forms Questionnaires were provided to the students during their attachment period in a mining company. A subsequent meeting was also arranged between the students, the head of department (HOD), the head of school (HOS), and the student liaison. In the meeting, follow-up questions about the student's experience and perspectives regarding the workplace were presented. Telephonic interviews with the students were also conducted. The questions were aimed at obtaining information regarding the students' perspectives during their attachment period and identifying how those perspectives could have influenced their learning in the workplace. The questions also helped to identify whether they were able to provide useful service to the company to which they were attached while gaining the skills necessary for their progress during their studies. The line of questioning maintained the anonymity of the participants, in line with the South African Protection of Personal Information Act 4 of 2013 (POPIA) which regulates the usage of personal information

II. DATA ANALYSIS

The accuracy of the interview data was verified by the interview recordings and the google forms. Then an a priori coding method was used to classify the data according to the research questions and related literature. The codes were then analyzed following the study by [22, 20].

The data analyzed was obtained mainly from questionnaires administered through google forms, and semi structured interview questions. A meeting was held where additional questions were asked, and the students' responses and suggestions were captured.

C. Research findings

1. What were the students' expectations regarding the vacation work program?

The students' expectations regarding the vacation work were varied. While some had some clearly defined ideas of what they were expecting out of the program, some simply embraced the opportunity that was given to them. Their responses are given below.

Student 1

"I expected that I would learn some skills. The things that we have done at university, like the theory classes, I know that is not the same as being in the work environment."

Student 2

"I thought maybe what we are gonna be doing is like, what miners do. Like the digging, like the hard labor part of mining. That's what I thought we were gonna do. So, um, as time went by, I saw that people there wear um, wear what's this, wear white PPE, and we were given white PPE. We wear told that because we are not mining engineers, we are mechanical engineers so are not even expected to do the hard labor and things like that so, we were just treated like mechanical engineers. Mechanical engineers are people that go there just to look, to observe. That's what we were just doing there, observing and things like that. But I never thought that the mine would be that mechanical."

Student 3

"My expectation was something that's very tough and very hard work, I was expecting to be very cautious when I enter the workplace. I didn't expect something that very light because, based on the rumors that we hear from the outside about the mine safety and, also that mines are not safe, and they are a dangerous place."

Student 4

"It was, basically just industry experience like, learn what mechanical engineers do there, because it's a mine obviously, so we don't have expect mechanical engineers to have that much of a job. Going there was to learn, to learn more basically."

Student 5

"I was actually expecting to do more of the things that we studied on campus. Um, but unfortunately that was not the case. A few things were there but, most of the things we had to learn there, in the mine."

2. How does the students' satisfaction during their placement impact their ability to learn and adapt to the workplace?

The students' responses were quite similar regarding this question. All the students seem to have been satisfied with their experience during their placement, below are the responses they gave.

Student 1

"I am very satisfied because that workspace is very welcoming, and the people there are very kind. The supervisors also were very understanding, so were the foremen. So, in terms of adapting to that environment, I adapted very well, because of how the supervisors were treating and how they were being patient with our work. Um, the environment there is also great, Like I did not have any problems, I was happy to be there, so I did not have so many problems as to not really wanting to go to work or so on and so forth. In general, I am very satisfied and that helped me to be able to my work much more efficiently."

Student 2

"After we started working, after we were done with the part where we had to be registered in the system, and now able to clock in, we felt very welcome. We felt at home. Everyone was very welcoming."

Student 3

"I was extremely satisfied. The environment and the atmosphere were amazing, and the food that they gave us. They provided transport of us to go to work, instead of us having to find our own transport. And the fact that they also doing laundry for us. I had an amazing time there. Honestly speaking it was excellent. So, it affected me positively, because when they continued to these good staff for us, I was also continuing to push myself, so that I don't disappoint the institution of the University of Johannesburg."

Student 4

"I was satisfied, as I have said, we got to interact with one of the most experienced people there. So, what I can say is, we did gain some experience."

Student 5

"I think it was good because um, the way they were treating us, it was equal. Like it was not different from people who are doing BSc or BEng, and we are doing BengTech. We were treated the same, and that made me become more confident and more comfortable than those people. And they were respecting us since we were apparently being called junior engineers."

Vo, et al, (2021), hypothesized that self-confidence is directly proportional to the levels of satisfaction during internship placement. Therefore, how the students were treated could affect their self-confidence and therefore their level of satisfaction. If students are not satisfied, this could hinder their progress during the internship [23]. Since they were the first-ever group to participate in vacation work since the introduction of the BEngTech program. It is important to understand how they were treated as compared to students from other universities, who have been part of the vacation work program for a long time and have an established relationship with the industry. The data presented in Figure 1.1indicates the level of satisfaction among the students. Out of the five students that participated in the vacation work program, three indicated being fully satisfied, while two indicated that though they were satisfied, they wouldn't say they were fully satisfied.

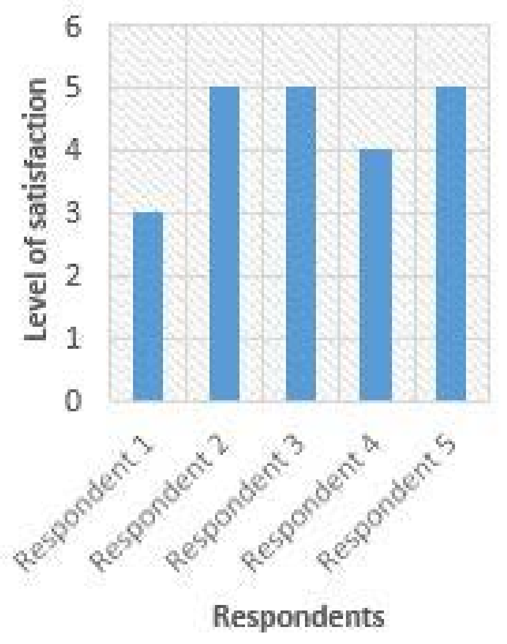

FIGURE1: *Level of satisfaction of the students on a scale of 1 to 5*

Table 1 presents the how the students perceive to have been treated as compared to their counterparts from other IHL.

TABLE 1: *Students perspectives regarding their treatment as compared to their counterparts.*

Respondents	Response
Respondent 1	Experienced equal treatment.
Respondent 2	Experienced equal treatment.
Respondent 3	Did not experience quite the same treatment, however, the treatment was not bad.
Respondent 4	The treatment was different at first, but it eventually become the same.
Respondent 5	The treatment was not the same, however, it was not bad.

The students gave different responses regarding their treatment as compared to students from other universities. This was however in the initial stages of the vacation work program. The students later reported that with time, the treatment they received was no different from that received by students from other universities. This is indicative of the fact previously mentioned, that being the first group of BEngTech students, their capabilities were still unknown to the supervisors. However, with the passage of time, they proved themselves capable. From Figure 1.3. it is observed that 60% of the students reported the treatment as not equal. Only 40% reported equal treatment. The students were later asked in a subsequent meeting what made them believe that the treatment was not the same. The Dominating answer was that the other students were from other leading universities that had an established relationship with industry.

3. *What is the impact of the challenges faced by the students on their ability to learn, and to adapt to the workplkace?*

The students had varied responses regarding this point. It can be deduced from their responses that some had experienced challenges that could have impacted their ability to adapt to the work environment, and therefore therefor their ability to learn. While others experienced challenges that they were able to quickly overcome and therefore adapt to the work environment. The responses of the students are given below.

Student 1

"The challenges that we faced there were mainly the bus schedule. That was one of the challenges, but the biggest challenge we faced was the processes of going through the medicals at Libanon, So, that took a very long time. At the end of the day, we did not have so much time as we initially did, because we wasted time. I wouldn't say wasted, but we spend a lot of time at Libanon, as to maybe we could have finished in less than a week and then it would have been straight to work."

Student 2

"The fact that we were given different PPE was not a problem because at the mine they take the blue PPE very seriously, like blue PPE is for people with high positions, the rest wear the white one. The white ones are for general workers."

Student 3

"The first challenge I experienced was having to get to know new people. And another challenge was trying to start my project. I had no clue where to start, what to begin with, and what to write. And the supervisors were pushing, more pressure, more pressure every week they would come with new information. But as time passed, I managed to overcome the challenge."

Student 4

"Remember sir, we started, I think we started in December. So, during that time, most people were busy during that time, so when we got there, they couldn't like, give us that much time to like, explore and learn all the things that we had to. The excuse they had was, we don't have time, and we can't take you guys there cos we don't have time, its busy at this time of the year."

Student 5

My biggest challenge was to wake up in the morning, because we had to take a four o'clock bus to work. There was only one bus that was going to Driefontein which was our shaft. And also, my supervisor was very strict, and I was finding it very hard to communicate with him. So, I had to try and get rid of my fears in order for to interact with him very well.

4. Do students believe that classroom learning provides sufficient preparation for the workplace?

Student 1

For labs and the practical, that did actually help with my vacation work because we were expected to analyze and collect data and so on and so forth. So, with the labs it did help. The other modules did help but not as much as the practical side of the cause.

Student 2

What we learned in school, I can say it was necessary. It created some foundation that we needed. I can say if we didn't have that foundation, it was gonna be, like, um, I don't know. Like it was gonna take a long time for us to understand all the things that were going on there. But since we had foundation, we understood most of the things that were happening there

Student 3

The project that I was dealing with was thermodynamics related. So, the content that was taught in class, I was exposed to the practical side of it. So, I was dealing with the project of heat exchangers, which is content we did in thermos two, and then we advanced to thermos three and refrigeration.

Student 4

Most of what they do there is based on our third-year program. So, if maybe you go there knowing that you did the third-year causes, I think it would be much better.

Student 5

There were some things that we did, for example we did AutoCAD in class, which was applicable there in the workplace, because during our presentations we were supposed to draw some of the things and present them. Also, we did design, we did presentations on design which really helped in preparing us for the presentations that we were doing there, in the mine.

III. DISCUSSIONS

The findings of this research indicate that some of the students had no clear expectations regarding the vacation work program. They just embraced the opportunity that was given to them. This could indicate that perhaps they had no idea what to expect from the program, implying that their understanding about the vacation work prom is limited. This would then, be an encouragement to educate students about the vacation work program in their first year of study. However, Somme appear to have had solid expectations regarding the vacation work program. This implies that they could have known about what the program entails beforehand, before they participated in one, and were therefore better prepared for the workplace.

All the students indicated that they were satisfied with their experience during the vacation work. It appears that the people they got to interact with while there played a huge role in that. They have emphasized how the people they got to work with were so welcoming and helpful. This highlights the importance of feeling welcomed in the work environment, towards the success of the vacation work program.

The challenges that the students faced seem to be unique to each student. However, it appears that the students were able to adapt to their work environment despite these challenges.

The conclusion that can be drawn from the data concerning the preparedness of the students, more especially regarding what they have learned in the classroom, is that their formal education had to some extend prepared them for the workplace. They gave examples of specific modules that they took at university, that they believe gave them the foundation they needed, to better be able to adapt and perform in the workplace.

IV. CONCLUSION AND RECOMMENDATIONS

This study was aimed at investigating the perspectives of engineering students from UJ who took part in a vacation work program. How those perspectives could have impacted them during their placement and what impact that has on the vacation work program.

It is clear, that some of the students had no prior knowledge or understanding of what the vacation work program entails. This means they went into the work environment without being fully prepared. They were however, with time and the help of their colleagues, able to adapt.

The recommendations made were that collaboration with more companies must be fostered to allow more students to take part in the vocation work program. This will also aid in the collection and analysis of more data to help further improve the program. The other recommendation was that students should be educated about vacation work program in their first year of study. This will ensure that when they get to their final year they are prepared and well equipped to participate in the program.

REFERENCES

[1] H. Allahar, "Major global megatrends: implications for advanced and emerging countries," Research Journali's Journal of Management, vol. 2, no. 8, pp. 2347-8217, 2014.

[2] K. Buratin, P. Carver and B. Sunuti, "The effectiveness of work-integrated learning in developing student work skills: a case study of Thailand," International Journal of Work-Integrated Learning, vol. 20, no. 2, pp. 127-146, 2019.

[3] T. Boronova, A. Kobicheva and N. E. Olkhovic, "The design of integrated learning model for CLIL-learners," in IOP Conference Series: Materials Science and Engineering, 2020.

[4] J. F. Agwa-Ejon and A. Pradhan, "The impact of work integrated learning on engineering education," in 2017 IEEE Global Engineering Education Conference (EDUCON), Athens, Greece, 2017.

[5] H. Milliken, B. A. Dean and M. J. Eady, "The value of embedding work-integrated learning and other transitionary supports into the first year curriculum: perspectives of first year subject coordinators," The Journal of Teaching and Learning for Graduate Employability, vol. 12, no. 2, pp. 51-64, 2021.

[6] S. Doel, "Fostering student reflection during engineering internships ," in Biennial Asia�Pacific Conference on Cooperative Education , Manly, Australia , 2008.

[7] T. Clarke, N. Lloyd, P. Megan and S. Male, "Towards praxis: a practice architecture analysis of the work-integrated learning placement experiences of three Australian engineering students," Studies In Continuing Education, vol. 43, no. 3, p. 343–359, 2021.

[8] S. Mutereko and V. Wedekind, "Work integrated learning for engineering qualifications: a spanner in the works?," Journal of Education and Work, vol. 29, no. 8, p. 902–921, 2016.

[9] L. Gregory, H. Ada and P. T. Judene, "Surveying design skill development in work-integrated learning experiences: a review of the literature," in Cambridge University Press, Gothenburg, Sweden, 2021.

[10] G. Atkinson, J. Misko and J. Stanwick, "Work integrated learning in STEM disciplines: the employer perspective," National Centre for Vocational Education Research , 2015.

[11] B. V. Prabhu and S. A. Kudva, "Success of student internship in engineering industry: a faculty perspective," Higher Education for the Future, vol. 3, no. 2, pp. 164-182, 2016.

[12] S. Renganathan, Z. A. B. A. Karim and C. S. Li, "Students' perception of industrial internship programme," Education + Training, vol. 54, no. 2/3, pp. 180-191, 2011.

[13] B. S. Knouse and G. Fontenot, "Benefits of the business college internship: a research review," Journal of Employment Counseling, vol. 45, pp. 61-66, 2008.

[14] C. P. Maertz, P. A. Stoeberl and J. Marks, "Building successful internships: lessons from the research for interns, schools, and employers," Career Development International, vol. 19, no. 1, pp. 123- 142, 2014.

[15] J. M. Nunley, A. Pugh, N. Romero and R. A. J. Seals, "College major, internship experience, and employment opportunities: estimates from a résumé audit," Labour Economics, vol. 38, p. 37–46, 2016.

[16] A. C. Yin, Learning on the job: cooperative education, internships and engineering problem-solving skills, Ann Arbor, Michigan: UMI Dissertation Publishing, 2009.

[17] V. K. Narayanan, P. M. Olk and C. V. Fukami, "Determinants of internship effectiveness: an exploratory model"," The Academy of Management Learning and Education, vol. 9, no. 1, pp. 61-80, 2010.

[18] J. P. Pollack and P. D. Freda, "Humor, learning and socialization in middle level classrooms," The Clearing House: A Journal of Education Strategies, Issues and Ideas, vol. 70, no. 4, pp. 176-178, 2012.

[19] P. M. Jenlink, "Situated cognotion theory," in Humor, learning and socialization in middle level classroom, vol. 70, Information Age Publishing, 2012, pp. 176-178.

[20] J. Jawitz, J. Case and N. Ahmed, "Smile nicely, make the tea-but will I ever be taken seriously? Engineering students' experiences of vacation work," International Journal of Engineering Education, vol. 21, no. 1, pp. 134-138, 2005.

[21] M. Borrego and E. P. A. C. T. Douglas, "Quantitative, qualitative, and mixed research methods in engineering education," Journal of Engineering Education, vol. 98, no. 1, pp. 53-66, 2009.

[22] S. M. Zehr and R. Korte, "Student internship experiences: learning about the workplace," Education + Training, vol. 62, no. 3, pp. 311- 324, 2020.

[23] N. T. Vo, L. H. P. Le and V. T. T. Lam, "Challenges for student satisfaction of internship program in hospitality and tourism industry in Vietnam," Journal of Quality Assurance in Hospitality & Tourism, no. https://doi.org/10.1080/1528008X.2021.1964414, pp. 1-27, 2021.

Technical papers

Role of empathy to identify unmet needs in Indian villages through service learning program: A case of the Unnat Bharat Abhiyan Program

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***Abstract* — Service learning in India is witnessing a large- scale adoption in higher education through the Unnat Bharat Abhiyan (UBA) program, a national-level service-learning program launched by India's Ministry of Education to promote community engagement and foster social responsibility among undergraduate students. The mission of UBA is to enable higher education institutions to partner with communities who live in rural India and engage in service-learning activities. The program advocates to build long-term engagement between academic institutions and nearby communities so that they could collaborate toward sustainable reciprocal partnerships. One of the goals of UBA is to establish linkages between academia and the community so that the knowledge created in the institutions could be targeted to solve complex societal problems. Higher education institutions that are part of this service-learning initiative were encouraged to do field studies through household surveys and informal interaction with the community members with a goal to identify unmet needs in the community. However, it was observed through prior research that the members of the community are only comfortable sharing their problems after faculty and students gain their trust. The paper presents a case study of a rural immersion experience that was introduced as part of the Unnat Bharat Abhiyan program at a private engineering institution in India. The 2-day rural immersion experience was designed to facilitate discussions among faculty and students with the community's various stakeholders, build trustworthy relationships, and empathize with their problems. The study employed a qualitative approach to investigate how students who were part of the rural immersion exercise described their experiences in the villages. Seven focus group discussions were conducted with 28 students who shared their highlights from visiting the villages and the process taken by them to identify unmet needs in the community. Thematic analysis was conducted to analyze the data and the results revealed the role of empathy in critically identifying challenges faced by the community members. The paper at the end presents the list of unmet needs identified by the students because of the rural immersion experience.**

Keywords — Service Learning, Community Engagement, Engineering Education, Rural Development, Empathy

I. INTRODUCTION

India with a population more than 1.3 billion people has 70% of its population residing in rural areas. Estimates from the last census conducted in 2011 report around 80 million people living in more than 600,000 villages across India [1]. India is celebrating its 75th year of Independence in 2022 and has witnessed significant development in that period. However, most of this development was focused on the promotion of rapid urbanization which is evident with the increase in urban population from 17.92% to 35% between 1960 - 2017 . Most of the urban migration was caused due to lack of access to basic amenities, education and healthcare services, and employment opportunities coupled with growing opportunities in urban cities [2]. With 70% of its population living in rural India, it is imperative for India to rethink its strategy for development and growth through the promotion of sustainable development of rural India. Reduced dependency on urban India and industrialization for economic growth will also help India reduce its overall percentage of carbon emissions emitted thereby reducing the possibilities for disasters caused due to climate change.

The Unnat Bharat Abhiyan (UBA) program is a national level service learning initiative, which was launched by the Indian Ministry of Education in 2014 to encourage higher education institutions to contribute and play a role in the transformation of rural India [3]. The program encouraged long-term partnerships between academic institutions and five nearby villages so the knowledge created in institutions can be strategically aligned to solve unmet needs in the nearby communities. They promoted HEIs to build strategic partnerships with a goal to contribute to the socio-economic development of nearby villages. Students who are part of the Unnat Bharat Abhiyan program get a chance to experience rural India, engage with the community members, and appreciate its contribution the development and economy of the country. The Unnat Bharat Abhiyan program promotes the fostering of reciprocal partnerships with the community members based on elements trust and mutual respect.

While higher education institutions implement the Unnat Bharat Abhiyan program, it is important for the faculty and students to visit the communities and interact with them to experience their lifestyles. Students should be provided multiple opportunities to engage with the community members to understand and get to know with their most pressing challenges. This paper investigates students' experience with community members as part of a rural immersion experience taken up by a private engineering-focused institution in India as part of their Unnat Bharat Abhiyan program. We conducted a qualitative case-study to understand students experience with the community members and the role of the rural immersion experience in identifying unmet needs in the partner communities. Focus group discussions were conducted with students who participated in the rural immersion experience to investigate the process followed to identify unmet needs in the villages. Results from the study can used by the other institutions who are intending to implement the Unnat Bharat Abhiyan program while they engage with nearby villages to identify unmet needs in the community..

II. LITERATURE REVIEW

A. Service Learning in Engineeering

Service-learning is defined as a credit-bearing educational experience in which students participate in an organized service activity that meets identified community needs and reflect on the service activity in such a way as to gain further understanding of the course content, a broader appreciation of the discipline, and enhanced sense of civic responsibility [4]. The role of reflection is considered to be critical to service learning as it provides students with the opportunity to bridge service and learning [5]. Service- learning in the last few decades has been promoted as an approach for higher education institutions to enable meaningful community engagement. Service-learning has witnessed widespread adoption from multiple disciplines including medicine, law, social sciences, engineering etc. While the pedagogy was first widely implemented in medical education, the adoption in engineering education was reported since at the start of the 21st century. Two of the earliest service-learning initiatives in engineering include the Engineering Projects in Community Service (EPICS) at Purdue University and Engineers Without Borders. In the last two decades, several other service-learning programs have been in engineering institutions across the globe as it has been reported to help students achieve the various graduate attributes required by ABET [6]. India has also witnessed an increase in community engagement as many engineering institutions have started to adopt service-learning as a pedagogy in the last decade [7]

B. Integration of Service Learning in Engineering Education to contribute Rural Development of India

The genesis of conversations on the engineering and technology for rural development began at Indian Institute of Technology (IIT) Delhi in 1972 through informal discussions among enthusiastic under-graduate and post-graduate students along with some faculty. The informal group was later constituted as "Science for People" that conducted multiple meeting at Indian National Science Academy to explore the role of engineering towards societal development. Two years later, the theme for the Indian National Science Government was "Science for Rural Development" where faculty from IIT Delhi conceptualized an idea to establish an in-formal Rural Technology cell. The rural development cell was upgraded to a full-fledged Center for Rural Development and Technology with a goal to use science and technology to solve grassroot level problems in rural India. The Rural Technology Action Group (RuTAG) was established by IIT Delhi in 2009 to encourage collaborations and build partnerships with seven other IITs across the country [8].

In 2014, IIT Delhi under the leadership of the Ministry of Education launched the Unnat Bharat Abhiyan program (translated in English to "Holistic Development of India") to provide opportunities for faculty and students in higher education institutions to engage with people in rural India and contribute to their socio-economic development [9]. The UBA program encouraged higher education institutions to identify development challenges in rural partner communities and develop science and technology solutions to accelerate sustainable growth in the villages. The goal was the leverage the knowledge base of higher education institutions to identify and customize existing technologies or create new innovations that cater to the needs of people in rural India. IIT Delhi spearheaded the UBA program as the national coordinating institute along with the support of several regional coordinating institutions (RCIs). The RCI's were responsible to promote the UBA program among nearby institutions and encourage to join the program as participating institutions. To join the UBA program, each participating institution was expected to partner with 5 nearby villages and collaborate with relevant stakeholders to propose suitable science and technology solutions aimed to improve the social and economic well-being of the rural communities..

C. Participatory Approach to Service Learning for Implementation of Unnat Bharat Abhiyan Program

The vision of UBA to accelerate the development of rural India through engagement with higher education institutions is an ambitious effort as 65% of the population reside in rural India. It is therefore important for institutions to build sustainable and reciprocal partnerships that would last long-term. Participatory approach is therefore recommended to institutions during the implementation of the UBA program as a way to build trust and mutual respect with members in the partner villages [10]. Participatory approach to community engagement during the UBA program would also provide opportunities for faculty and students to engage with the community members and empathize the challenges that continue to impede their socio-economic development. The need to experience empathy could be considered critical during the identification of challenges and unmet needs in the partner villages as empathy is known to have the capacity to share feelings of concern and care towards others [11].

III. METHODOLOGY

A. Context of the Study

The goal of this study is to investigate the experience of students who were part of a rural immersion experience conducted as part of the UBA program at a private engineering institution in India. The institution has established a Center for Innovation and Social Transformation (CIST) to drive all community engagement programs activities, one of them being the UBA program. CIST had conducted 1-week Ideathon on Rural Development to encourage students to think innovatively and come up with ideas that could boost socio- economic development of our partner villages. The Ideathon was divided into two phases: Phase 1 - Rural immersion and appreciation, and Phase 2 - Problem exploration and ideation. In the first phase, students visited our partner villages and interacted with different members of the community. Students when arrived in the village were welcomed by the village leaders such as sarpanch and panchayat secretary (village heads) followed by a tour of the village by gram nayak's who were our local community ambassadors. Students spent two days in the village where they interacted with elderly people, women, farmers and farm-labours, youth, children, skilled professionals, and entrepreneurs. The goal of the visits was to get immersed in the partner villages and learn about the realities of rural India. After the village visits, students were encouraged to reflect on their experiences of interreact with different stakeholders and explore opportunities that have the potential to accelerate their socio-economic development. This study aims to investigate the experience of students during the rural immersion experience and understand how they identified unmet needs in the community.

B. Research Questions.

The study aims to investigate and analyse the following research questions:

- How did students describe their experience with the community members as part of the rural immersion experience?
- What was the role of empathy in the process of identifying unmet needs in the community?

C. Methodology, Data Collection and Analysis

A qualitive case-study approach was employed to design the research study as the goal was to understand students' experiences during their visits to the villages [12]. The case in the study was the rural immersion experience as the goal was to examine the experiences of students during the visits to the villages. We intended to observe how the rural immersion experiences influenced students' approach and decision-making while identifying unmet needs in the community. The unit of analysis are the individual experiences of students who participated in the Ideathon and were part of the rural immersion experiences.

Qualitive data was collected through focus group discussions with students who visited the villages as part of the program. Seven focus group discussions were conducted with four students in each group. Students were selected for the study based on convenience sampling and the sample consisted of 20% of the overall number of students who participated in the Ideathon. Participants for the focus group discussion were selected through convenience sampling as the Ideathon was conducted as a co-curricular activity and only a few students attended the program and showed interest to be part of the research study. The gender representation of students in the focus groups were 55% male and 45% female. All the students were pursuing their 2nd year or 3rd year of under graduation in engineering. Student participants belonged to multiple engineering majors such as electrical, mechanical, civil, and computer science. All the data was audio recorded and transcribed into text, which was later analysed using thematic analysis. A thematic analysis approach was used to analyse data as it would allow us to summarize and present different aspects of students' experiences in the villages through various themes [13]. The subsequent section presents the themes emerged from the data analysis along with relevant quotes from students in the focus group discussions.

IV. RESULTS

There were four themes that emerged from the thematic analysis of data collected through the focus group discussions. The themes are presented below along with the relevant quotes from the semi-structured interviews.

A. Theme J - Experiencing rural India villages in its true essense helped students develop a sense of appreciation and graditute towards community members

During the visit to the villages, the students interacted with various stakeholders present in the village. Students in the focus group discussed about the sense of appreciation they developed for people who lived in the partner villages as they were welcoming to the students who interacted with them. One student mentioned: *"I was really happy because they are interacting with us like a family member, and they shared with us their problems like we were their child. I appreciated that a lot about the culture in rural communities. It increased my motivation to solve some of the problems shared by the women".* Students through the interaction with different community members learnt about the social realities, culture, and traditions of the villages. As farming is the predominant livelihood for most individuals in the villages, students reflected on the contribution of the farmers for the social and economic development of urban India: *"We spent almost 4 hours interacting with few farmers and they showed us their farm where they cultivate their crops and explained to us the entire process involved in farming. I did not know about* *the amount of time and effort required to engage in farming and provide us with supply of food. The experience increased my respect for all the farmers who work very hard in our country".*

B. Theme 2 - Students problem-solving mindset limited their opportunity to build a bond with the community members

During the focus group discussions, we observed that many students went to the village with a problem-solving mindset which influenced students' conversations with the various community members. Students reported their engagement with different community members where they immediately started to ask them about the challenges they faced in their everyday realities and livelihoods. One student mentioned - *"firstly we went to the farms and asked the farmers what type of difficulties they are facing. During the interaction, we got to know that they are facing many health issues such as body and knee pains as they're spending lot of time bending and cutting some vegetables on the ground".* We then decided to come up with a solution to solve this problem and help the farmers". While some of community members openly shared about their problems, there were also other groups of community members who refused to interact with the students and share their challenges. This could be attributed to the reality that the village members never met the students before and would therefore be hesitant to share their problems with strangers who they do not trust. Students problem-solving mindset was therefore a limitation while they interacted with some community members, as they could have got more information from them if they first spent time to get to know each other.

C. Theme 3 - Village visits allowed students to experience the problems encountered by the community members in the real context

Students who were able to interact with different villages members shared that the visits to the villages helped them to experience the problem faced in the real context. Some students reported to have experienced the problem themselves: *"We also plucked the weeds around the field with the farm labor We started facing some pain in the arm and knees in just ten minutes of doing that work, so we could understand how painful their work was".* Other students mentioned that the experience of village visits gave them the opportunity to better understand the problem as they were able to interact with the end users and ask additional questions accordingly. For example, one student said *"When I met a farmer and started talking to them, we have observed that the crops at the borders of the farm were not healthy as crops in the middle. We first thought it was some issue with the soil but when we asked the farmer, he told us that the crops in the borders are often destroyed by animals such as pigs, wild boars etc. Being present at the farm physically therefore helped us better understand the problem".* Few students reported different type of experiences where they developed concern for the farmers as they broke down in front of them while sharing their problems: *"He took us all to his main field and showed us the seeds he is using for farming. He showed us the crops already cultivated in his farm to highlight different in the quality of crops because of inconsistency in quality of seeds. The farmers buy seeds from the nearby markets but cannot find out the quality before cultivation. Due to this, many of them are facing issues and the farmer talking to us started crying because they feel helpless even after putting a lot of work. Sometimes half of their crops are not good due to bad quality seeds which they incur significant financial losses".*

D. Theme 4 - Change in students' mindset about role of engineers towards the betterment of society

The last theme observed during the student focus group discussions was a change in mindset among some of them on their role in the society. This was an important theme as reflections included as part of service-learning experiences allow students are expected to bridge service and learning. One student reflected on their role in the society and said: *"Before the village visits, I was not thinking about all those things [community engagement and development}. I had a goal to get a good job and settle in my life. But after the village visits, it gave me an opportunity to think about others, to think about the problems of the villages and how can I use the learning from the college to solve them".* Another student reiterated a similar reflection: *"During the Ideathon, I realized the real meaning of engineering. It is to be able to solve the problems of others".* It was therefore observed that there was a transformation in the mindset of few students on the role of engineering in the society, which can be attributed to the concern and care they reported to develop for community members during the village visits.

V. DISCUSSION

A. Role of Empathy in Identifying Unmet Needs in the Villages

Empathy represents a nuanced and sensitive understanding of other's internal state and often described as an orientation where an individual is able to imagine how another person feels of thinks or imagine how one would feel and think in another's situation [14]. Empathy is considered to be a nuanced phenomenon which have affective and behavioural components, and the affective components can be automatically activated through certain experiences [15]. Batson identified 8 distinct but related phenomenon that have been referred to as empathy:

1. Knowing another person's internal state, including his or her thoughts and feelings.
2. Adopting the posture or matching the neural responses of an observed other.
3. Coming to feel as another person's feels.
4. Intuiting or projecting oneself into another's situation.
5. Imagining how another is thinking and feeling.
6. Imagining how one would think and feel in the other's place.
7. Feeling distress at witnessing another person's suffering.

8. Feeling for another person is suffering

Batson separated these different phenomena into two distinct groups: group 1 where one comes to develop empathic understanding of others and group 2 where one will act based on that understanding. Phenomenon 1 helps an individual build empathic understanding while phenomenon 2-6 represent the way in which empathic understanding is developed. Finally, phenomenon 7 and 8 help explain why a certain individual would act based on their empathic understanding.

Students in the focus group discussions reported their experiences of feel a range of emotions when they visited the partner villages as part of the Unnat Bharat Abhiyan program. The village visits allowed the students to interact with the community members and experience their problems in the real-world context. Through the community interaction, students were able to experience phenomenon 1, as they were able to know about the thoughts and feelings of the people they met. However, some students mentioned in the interviews that the rural immersion experiences enabled them to feel the pain experienced by community members, which can be considered as phenomenon 3 in the list provided by Babson. In theme 3, students reported their experience of feeling distressed by looking at the suffering of others. All these feelings of empathy experienced by students would have only been possible through the visit to the partner villages and interaction with various community members. Direct observation of end users is considered as an important technique that could be utilized by students to build empathic understanding [16]. Students submitted their problem statements after the end of the rural immersion experiences, and we noticed a range of problems identified by them. However, not all the students had identified unmet needs in the community as a good number of students reported problem statements that they believed were important to solve. We believe only those students who were able to build an empathetic understanding and connection with the community members identified grass root problems in the partner villages that were not being solved by anyone else. Empathic concern (phenomenon 7 and 8) could be considered to be critical to students' commitment to engage in community-oriented projects and to view them beyond just "projects" and as an opportunity to facilitate socio-economic development and as a result impact change. Table 1 list the different unmet needs identified by students in the partner villages during the rural immersion experiences.

TABLE 1: *Unmet needs identified in the partner villages*

S. No.	Unmet need identified
1	Low financial returns from sale of harvested crops due to multiple middlemen present in the supply chain
2	Unavailability of storage facilities to store perishable crops is forcing the farmers to sell crops in the market on the same day even though at a lower selling price.
3	Unable to cultivate crops such as sweet potato and corn that give best financial returns due to problems with pigs and wild boards who destroy the crops.
4	Inconsistent quality of seeds leading to reduction of farm produce
5	Low shelf-life of flowers after plucking is leading to almost 40% wastage prior to being sold
6	Unavailability of waste management systems which is causing hazardous living environment of community members
7	Drop in enrollment ratio in government primary school due to unavailability of kindergarten school in the village
8	Increase in long term physical injuries to farmers labors who cut and pick vegetables on the ground

VI. CONCLUSION

The study investigated the experiences of engineering students as part of a national service learning program where they visited partner villages to engage with the community members and identify unmet needs. Results from the study highlighted the role of empathy as the students identified problems in the community. Students reported the visit to the villages enabled them to feel the distress shared by the community members as they could witness the problems in real context. The study highlights the neccessity of organizing rural immersion experiences for students who are part of the Unnat Bharat Abhiyan program, as an approach to be able to empathise with the members of the villages and identify those unmet needs that could accelerate their socio-economic development. Without the identification of unmet needs in the community, students and faculty can risk identifying problem statements that are not the need of the hour. Development of solutions for such problem statements will lead to no grassroot impact in the partner communities and would therefore result in wastage of time and resources of all the stakeholders involbed in the project.

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REFERENCES

[1] C. Chandramouli and R. General, "Census of India," Rural urban distribution of population, provisional population total. New Delhi: Office of the Registrar General and Census Commissioner, India, 2011.

[2] P. Datta, "Urbanization in India," 2007.

[3] DS. Bandi, S. M. Naik, "Unnat Bharat Abhiyan, A Government of India Initiative Complementing Service Learning in Engineering," JEET, vol. 34, no. 0, pp. 633-636, Jan. 2021, doi: 10.16920/jeet/2021/v34i0/157234.

[4] R. G. Bringle and J. A. Hatcher, "Implementing Service Learning in Higher Education," The Journal of Higher Education, vol. 67, no. 2, pp. 221-239, 1996, doi: 10.2307/2943981.

[5] S. M. Dustker, B. S. Reddy, R. Kandakatla, G. H. Joshi, and W. C. Oakes, "Role of Reflection in Service Learning-based Engineering Programs: A Cross-cultural Exploratory and Comparative Case Study in India and the USA," Jul. 2021. Accessed: Aug. 03, 2021. [Online]. Available: https://peer.asee.org/role-of-reflection-in-service-learning- based-engineering-programs-a-cross-cultural-exploratory-and- comparative-case-study-in-india-and-the-usa

[6] W. Oakes, "Service-Learning in Engineering: A Resource Guidebook," p. 91.

[7] S. Bandi, S. M. Dustker, R. Kandakatla, W. Oakes, and S. Kotabagi, "Enablers and Barriers to Implementing Service-Learning in India - A Case-Study of Two Service-learning Models Integrated into Undergraduate Engineering Curriculum," in 202J World Engineering Education ForumIGlobal Engineering

Deans Council (WEEFIGEDC), Nov. 2021, pp. 241-249. doi: 10.1109/WEEF/GEDC53299.2021.9657399.

[8] S. K. Saha and M. Ravi, Rural Technology Development and Delivery: RuTAG and Its Synergy with Other Initiatives. Springer, 2019.

[9] V. Deore, A. Shinde, H. Shinde, and S. S. S. Waghmare, "Study on Importance, Procedure, and Scope of Unnat Bharat Abhiyan-A Scoping Review," 2022.

[10] D. Radhakrishnan, R. Kandakatla, and D. A. Delaine, "Participatory Approach to Engineering Service Learning Programs - Quality Framework for the Implementation of Unnat Bharat Abhiyan Program in Indian Engineering Institution," in 2022 IEEE Global Engineering Education Conference (EDUCON), Mar. 2022, pp. 863-872. doi: 10.1109/EDUCON52537.2022.9766735.

[11] D. N. Sochacka, D. J. Walther, and D. S. Miller, "Fostering Empathy in Engineering Education," p. 5.

[12] A. B. Starman, "The case study as a type of qualitative research," Journal of Contemporary Educational Studies I Sodobna Pedagogika, vol. 64, no. 1, pp. 28-43, Mar. 2013.

[13] V. Braun and V. Clarke, "Using thematic analysis in psychology," Qualitative Research in Psychology, vol. 3, no. 2, pp. 77-101, Jan. 2006, doi: 10.1191/1478088706qp063oa.

[14] C. D. Batson, S. Early, and G. Salvarani, "Perspective Taking: Imagining How Another Feels Versus Imaging How You Would Feel," Pers Soc Psychol Bull, vol. 23, no. 7, pp. 751-758, Jul. 1997, doi: 10.1177/0146167297237008.

[15] C. D. Batson, "These things called empathy: Eight related but distinct phenomena," in The social neuroscience of empathy, Cambridge, MA, US: MIT Press, 2009, pp. 3-15. doi: 10.7551/mitpress/9780262012973.003.0002.

[16] J. L. Hess and N. D. Fila, "The manifestation of empathy within design: findings from a service-learning course," CoDesign, vol. 12, no. 1-2, pp. 93-111, Apr. 2016, doi: 10.1080/15710882.2015.1135243.

Technical papers

Level and drivers of students' satisfaction with their vacation work experience

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Abstract — **Industrial work experience is an important part of the training of engineering students. Not only does it entrench learning, it may also give the students a window into what their professional life may be like, hence, the importance of students being satisfied with their training experience. There, however, isn't much reported on what the students feel about their experience during this training and what factors might be driving such experience. Using Atlas.ti, thematic coding and text analysis were done to analyse the reflection written by the students of Industrial Engineering about their vacation work. It was found that majority of the students reported being happy with their vacation work experience and would like to return where they did the training for future purposes. Factors contributing to this satisfaction were also explored and documented.**

Keywords — Industrial engineering education, vacation work experience, thematic analysis, job satisfaction

I. BACKGROUND

Industrial work experience (also called student vacation work) is a requirement for the training of engineering students as stipulated by all regulators of Engineering studies worldwide, which is the Engineering Council of South Africa (ECSA) in the case of South Africa. This experience could easily motivate students to want to continue in the profession or feel disappointed, as the first contact with the industry may be important in shaping the student's perception of their profession. It is important, therefore, to understand how satisfied the students are with their vacation work experience, and to understand what factors may be responsible for such satisfaction, or dissatisfaction where such exists.

The aim of this research is to understand the general level of satisfaction among the students undertaking vacation work in a department of Industrial Engineering, and to identify what factors may be the main drivers of such satisfaction or dissatisfaction with their work experience. The research question, therefore, is: "how satisfied are the students with their vacation work experience, and what factors might be responsible for such?".

The concept of industrial training can be said to have originated in the 1700s during the industrial revolution. The industrial revolution introduced steam engines, power-driven machinery, and new system of production. The industrial revolution saw the end to craftsmanship, and the new working class needed to embrace knowledge and understand the latest technologies via industrial training. Between 1824 and 1830, the concept of applying higher learning to technical environments soon began to flourish in the United States. By the 1900s, it was quickly evident that engineering students needed to enhance their education by having practical experience and industry training to become effective workers in the workplace of their specified trade once they had completed their degree [1].

Student work experience programmes are a win-win situation for all parties involved. Researchers have conducted studies proving that such programmes are beneficial to students, host companies/employers, and higher education institutions [2]. Students need the experience, and companies are looking for skilled individuals to work for them. Work Based Learning (WBL), which is also synonymous to student vacation work, is beneficial for all parties involved; students, the university institution, and the employer, according to [3]. From the students' perspective: (1) WBL develops students' skills. Students can balance their academic and professional performance simultaneously; (2) WBL motivates students to learn from their experience; (3) it enables students to think creatively and analytically, and; and (4) it helps build competence, self-confidence, and increased teamwork ability. Strong evidence shows how WBL of various kinds are effective for both undergraduate students and work organizations. WBL can provide the students with personal and professional growth, learn from workplace dynamics and workplace issues, gain experience and technical skills, increased confidence, increased competence, and assuredness [4].

It is evident that WBL is a highly valued component for an undergraduate student's learning experience at the higher education level. Students' perceptions of WBL are overwhelmingly positive. On average, 70% of students had a positive attitude towards work experience [5] while Riggio et al. showed that the students rated the internship work experience favourably. The students had positive attitudes to learning through practical experience during the internship and concluded that for students who participated in WBL programmes, it positively impacted their careers [6].
There have not been many publications on the satisfaction of engineering students with their industry learning experience, and this work is a contribution to that field. The majority of the reports on work satisfaction of students on industrial training has been in the field of tourism, hence, some of this are presented ahead of those from other fields of study. Hussein and La Lopa [7] sought to determine factors that influence the satisfaction of Tourism students during their internship programme in the US; Marinakou and Giousmpasoglou [8], surveyed 116 Tourism students that had completed their

internship in various places in Greece to understand their satisfaction with their work; Kukreti and Dani [9] studied the role of University support and organizational environment in the satisfaction of Tourism students during internship in India; and Stansbie et. al. [10], utilised the job characteristics model in analysing the design of internship jobs and the impact on the satisfaction of the students of Tourism in the US, and also reported various factors contributing to the satisfaction of the interns.

Outside the Tourism area, the work of Simisaye et al.[11] was done in the field of library studies in Nigeria, while Jaradat [12] studied internship among computer science students in Jordan. Finding such work done among engineering students seems not too common, but there is Nogueira et al [13] that did a confirmatory factor analysis of the perception and satisfaction of engineering students about their internship experience in Portugal using the scale called the Work Experience Questionnaire (WEQ), confirmed the scale validity, and also discussed the impacts of gender, company size and compensation on the result obtained.

II. METHODOLOGY

This study employed qualitative analysis by performing thematic analysis using text coding with Atlas.ti. Thematic analysis is the process of identifying any patterns that might exist to find a description of the phenomenon being explored. The advantage of this approach is that it develops themes without the need to generate theory, however, the disadvantage is that it may lack depth [14]. Since the purpose of this research is not to create any theory, per se, but to simply understand student sentiments, we consider this approach sufficient. The unit of analysis is a student record and 684 records were submitted. It should be stated that a student may have up to two records as each student submits reports for two modules, one in their third year and the second in the fourth.

The text data used for the analysis was obtained from the report document submitted online by students for 2018 and 2019. Data is cleaned up and prepared for coding. The coding was done in two stages as suggested by Saldana [15], after which themes were identified. Three steps fall under the data reduction phase, namely: Step 1, which is the initial coding, where the data that is ready for analysis is exported to Atlas.ti for further analysis. Codes were generated using literature and reviewing the data, and they were developed by considering each line, phrase, sentence, and paragraph. A total of 190 codes were generated at this stage. Step 2 involves sorting. In this step, categories (or groups) are created. Step 3 or themes creation is where themes are generated from the categories previously developed. The themes are created using thematic analysis. Figure 1 presents a section of the code groups created in Atlas.ti preparatory to thematic analysis.

III. FINDINGS

Table 1 shows the themes derived from the code groups after analysis. Skills gained during the vacation work is about the main benefit mentioned by the students consequent to their vacation work experience. Soft skills were the most frequently mentioned skills that students gained throughout their work experience. The soft skills include leadership skills, people skills, and interpersonal skills. WBL encouraged social learning in the work setting. The majority of the students were able to develop interpersonal skills such as confidently interacting with both their supervisors and their colleagues. One student mentioned that the experience helped build their professional character.

The students frequently mentioned self-confidence, which leads to increased competency. A fair number of students mentioned that they gained various technical skills such as simulation, systems design, report writing, and worked on various coding and programming software, which are relevant to their undergraduate studies. The industry training also gives the students an opportunity the think creatively and to gain analytical skills such as data analysis, creative and innovative thinking. A significant number of students also mentioned organizational skills like communication, teamwork, professionalism in the workplace, working under pressure, time management, and project management skills. Communication skills were the most mentioned as being gained from the experience because the students were required to communicate with their peers, whether in group settings or simply communicating with their mentors/ supervisors to receive feedback.

Other main benefits of the vacation work reported by students include: being able to apply what they were taught practically, as an overwhelming number of students felt that they could apply what they were taught in their first 2 or 3 years in university; opportunity for students to gain insight into the industry they were working in and learn more about the company they were working at; the experience allowed students to improve on the skills that they had already acquired in their undergraduate studies; and the opportunity to learn in the workplace, which enriched their theoretical knowledge.

The second theme evaluates factors affecting the Job satisfaction levels of students and a number of this was mentioned. However, the most prominent factors mentioned include putting theory to practice, participating and contributing to projects, working under supervision or guidance, and exposure to real-life problems. Others include participating in the workplace routines such as attending meetings; being given work experience and being actively involved in projects.

The level of satisfaction was further investigated by the desirability of students to return, where 82.86% of students desired to return to the company where they did their industrial training, 16.53% did not wish to return, and the rest would return under certain conditions, suggesting that majority of the students were happy to return. Some prominent factors that have been identified as reasons for satisfaction and wanting to return include: students were treated with respect and taken seriously as an employee and that was a good enough reason for them to desire to return to the company; more work opportunities being available as more projects were yet to be explored; the good company culture they experienced; the workplace environment that was good, supportive and friendly towards the students; the student's interest in the career field and wanting to explore more; opportunities to implement solutions proposed by student in the future; and future impact they believe they can make on or through the company.

The sentiments and attitudes of students to the vacation work experience was positive overall, although there were a few reservations. Generally, most students that desired not to return to their companies did so, not necessarily because of unhappiness with the company, although there was a particular case of such. The students also reported about various challenges, but generally considered such surmountable. Some of the issues mentioned include working on their own, learning to communicate and work in teams or groups, especially when the team members are at different levels of experience and possess diverse skill sets, and initially feeling intimidated with the work that needed to be done and the people they met. From literature, work dynamics was mentioned as one of the challenges encountered by students.

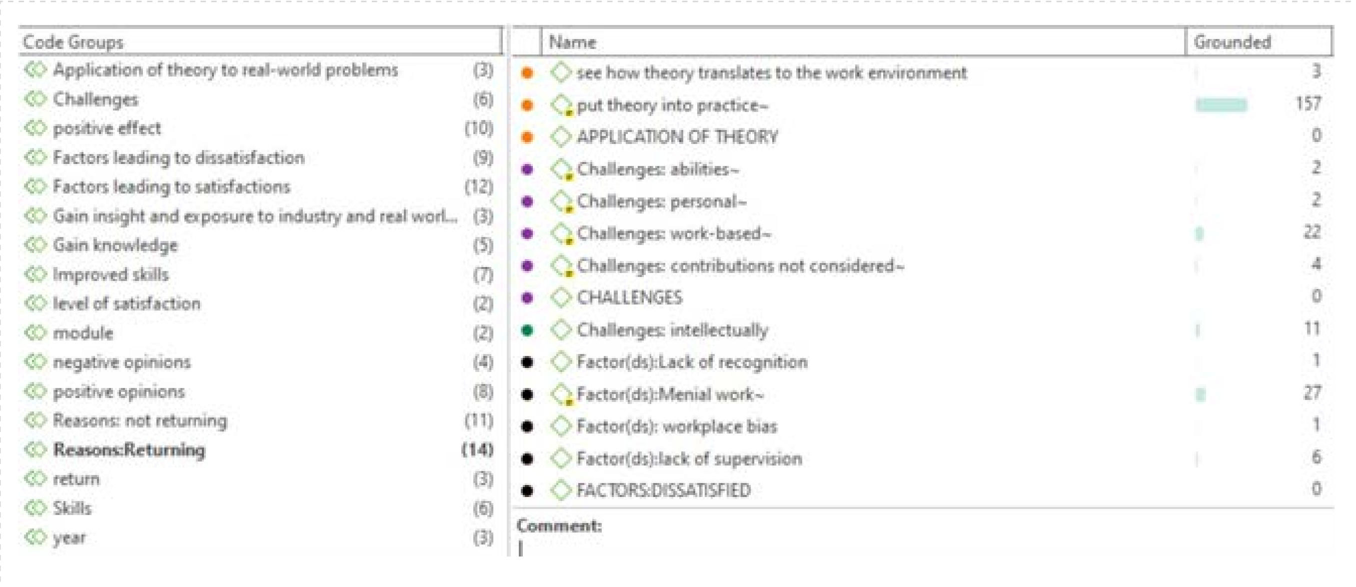

FIGURE 1: *A section showing code groups created from sorting and grouping*

TABLE 1: *Emergent themes and code groups*

Code groups	Emergent themes
• Gained skills • Application of theory into practice • Gain insights and exposure • Improved skills • Learning in the workplace	Student benefits
• Factors leading to satisfaction • Factors leading to dissatisfaction	Job satisfaction levels
• Positive opinions • Negative opinions	Attitudes
• Reasons for returning • Reasons for not returning	What made the experience a success
• Challenges	Challenges

Without enough knowledge or skills, students start to compare themselves to their colleagues who work full time, but overall the students seemed to have adjusted well.

IV. CONCLUSION

Vacation work (or Industrial training) experience is the first window the engineering students have into what the future may look like for them, and it has the potential to make them interested in or discouraged with the field, yet, not much about the students' opinion about it has been documented. In this study, the documented reflections about the vacation work experience of Industrial Engineering students was analysed using text coding and thematic analysis. The key themes from the reflections were identified, and the general sentiment of the students about their training experience and perceived benefit of the programme was found to be generally positive. Furthermore, factors that contribute to such satisfaction were identified, and the findings seem consistent with what has been found in literature about students of some other programmes other than engineering. It is, therefore, concluded that the students also feel vacation work contributes positively to their preparation for professional practice and helps with their understanding of the concepts taught in the University.

REFERENCES

[1] Mafe, O. A., 2010. Academia.edu. [Online] Available at: https://www.academia.edu/9914910/EFFECTIVENESS_OF_SIWES_WITH_RESPECT_TO_CHEMICAL ENGINEERING [Accessed 28 September 2021].

[2] Coll, R. K. et al., 2011. An exploration of the pedagogies employed to integrate knowledge in work integrated learning. The Journal of Cooperative Education and Internships., 43(1), pp. 14-35.

[3] Murtazin, K., Shvets, O. & Piho, G., 2020. Literature Review on Work- Based Learning. Uppsala, IEEE Frontiers in Education Conference, FIE.

[4] Lester, S. & Costley, C., 2010. Work-based learning at higher education level: value, practice and critique. Studies in Higher Education, 35(5), pp. 561-575.

[5] Willams, W., 2008. Assessing the value of cooperative education.. Journal of Cooperative Education., 28(2), pp. 32-55.

[6] Riggio, R., Kubiak, C., Taylor, S. & Neale, P., 1994. Evaluation of a cooperative education program with an emphasis in industrial/organizational psychology.. Journal of Cooperative Education, 29(1), pp. 59-66.

[7] Hussien F.M. & La Lopa M. (2018) The determinants of student satisfaction with internship programs in the hospitality industry: A case study in the USA, Journal of Human Resources in Hospitality & Tourism, 17:4, 502-527,

[8] Marinakou E. and Giousmpasoglou C. (2013), An Investigation of Student Satisfaction From Hospitality Internship Programs in Greece, Journal of Tourism and Hospitality Management, Vol. 1, No. 3, 103- 112

[9] Kukreti R, Dani R. (2020) Analyzing Role of University/Institute Support and Organizational Environment in Industrial Training Satisfaction of Hospitality Students: with Reference to Uttarakhand, International Journal of Recent Technology and Engineering, Vol-8 Iss-6, 549-554

[10] Stansbie, P. Nash R. and Jack K. (2013) Internship Design and Its Impact on Student Satisfaction and Intrinsic Motivation, Journal of Hospitality & Tourism Education, 25:4, 157-168

[11] Simisaye AO, Awodoyin AF, Osisanwo TA, (2018) Influence of gender on satisfaction of library school students with SIWES in Tai Solarin University of education, Middlebelt Journal of Library and Information Science, Vol. 16, 25-34,

[12] Jaradat DM (2017), Internship training in computer science: Exploring student satisfaction levels, Evaluation and Program Planning 63 (2017) 109–115

[13] Nogueira, T.; Magano, J.; Fontão, E.; Sousa, M.; Leite, Â. (2021) Engineering Students' Industrial Internship Experience Perception and Satisfaction: Work Experience Scale Validation. Educ. Sci. 2021, 11, 671.

[14] Smith, J. & Firth, J., 2011. Qualitative data analysis: the framework approach. Nurse Researcher, 18(2), pp. 52-62.

[15] Saldana, J., 2013. The coding manual for qualitative researchers. 2nd ed. n.d.: SAGE.

Technical papers

The impact of emergency remote teaching on postgraduate engineering students

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Abstract — **Emergency Remote Teaching (ERT) resulted in postgraduate (PG) students moving from working closely within institutions, to working from home. The implicit assumption was that PG students would adapt more easily to ERT measures than undergraduate students, as a result of being more mature, academically experienced, and more resilient. This study sought to explore how ERT implemented during Covid-19 lockdowns impacted on the progress of PG students, and to provide a nuanced view on the factors that lead to student success. Through considering roads to success, enablers, as well as blocks and bottlenecks, the experience of ERT might provide insights into how to structure future (in person) PG experiences for improved productivity, self-efficacy and progress. A collation of three surveys, analysed using consideration of factors split into the cognitive, affective and systemic, highlighted factors that influence wellbeing and productivity and the relationship between the two. Respondents provide insights into how Higher Education institutions might improve support to their postgraduate cohorts. Within the systemic arena, PG students noted that success requires sufficient access to physical infrastructure, data, power and other physical enablers. In the cognitive space, respondents highlighted (amongst other points) that the blurring of work times and non-work times can result in unproductive (and stressful) time wasted; an idea which can be pulled through to future PG students: clearly delineate work and leisure times. The area which was reported to have the largest impact on PG student success was in the affective space. PG students require support (from peers, supervisors, friends and family) to thrive. The normal PG program evidently does well at supporting both systemic and cognitive needs in postgraduates, however, further attention might be paid to their affective needs.**

Keywords — ERT, Mental Health, Engineering Education, Postgraduate Students, South Africa

I. INTRODUCTION

Professional higher education programmes, such as the Health Sciences and Engineering, are increasingly designed around the holistic achievement of graduate competencies so as to develop the necessary knowledge, skills and citizenship (DHET, 2013). Such programmes are highly dependent on access to technologies, equipment and practical experience, features that are integrated into their curricula and facilitated by educators, who have a mandate to provide holistic support of student learning across three domains: the cognitive, affective and systemic [1]. At the onset of the Covid-19 pandemic, initial strategies for contact-based institutions in South Africa (the research site) saw a primary focus on putting systems (systemic support) in place to enable students to access, engage with and complete the learning objectives in their courses. By the second pandemic year, 2021, it had become clear that poorly resourced environments and differentiated digital fluency levels were impacting significantly on student participation and success [2]. These conditions manifested both in the cognitive and affective domains. On the one hand, perceptions of increased workload, lack of active participation and non-invigilated assessment conditions suggest that learning objectives (cognitive domain) may not have been optimally achieved. On the other hand, increasing reports of poor student (and staff) wellbeing [3] reveal a significant gap in the affective support necessary for academic success.

While most of the available studies tended to focus on undergraduate student needs and experiences of Emergency Remote Teaching (ERT) [4], there has been little formal focus on the impact of ERT on academic staff and postgraduates (PGs), particularly in fields requiring practical technologies for teaching, learning and research, such as engineering. It was against this context that a group of engineering educators at a research-intensive institution in South Africa partnered with the South African Society for Engineering Education (SASEE) in conducting an anonymous survey of Engineering Educators and PG students across (and beyond) South Africa on the impact of ERT, particularly since many engineering educators carry the additional burden of completing their doctoral studies. The rationale was that investigating and sharing (as a broad community of practice) the impact of ERT on educators and PGs could inform future engineering education and capacity building strategies. The insights received from the national survey led to a faculty focus on its PGs, with the intention of interrogating how these PGs experienced and tackled problems such as the lack of access to required equipment and technologies (among other challenges). If our engineering PGs are the very basis of the knowledge-generating innovative capacity required to tackle Sustainable Development Goal challenges, and the professional field is characterised as one in which practitioners 'solve complex problems', then the ERT conditions offer an ideal opportunity to develop a more informed understanding of PG problem-solving strategies, enablements and constraints.

Drawing on three different surveys, this paper presents the qualitative data from 88 PG participant responses, using a holistic analytical model to differentiate between and relate the cognitive, affective and systemic dimensions of the PG learning experience during the Covid-era. Given the consistent focus in the literature on the systemic implications of ERT, this paper focuses specifically on themes that have emerged in the data under the broad category of the affective domain. Of particular interest has been the uncovering of a more nuanced picture of how PG students cope with, and grow through, disruptions to research, potentially allowing supervisors an understanding of their thought processes and strategies. The broad research question is: *What are the internal and external factors that enable a PG student to cope with, grow through and learn to deal with disruptions?*

II. THE LITERATURE IN CONTEXT

The majority of the reported teaching and learning interventions and investigations were primarily focused on undergraduate (UG) students and much has since been written in the undergraduate teaching and learning space [5]–[16]. However, postgraduate (PG) students' needs and circumstances are very different, and the impact of the pandemic on these students remains underexplored. Some research touches on PG experiences and challenges, such as access to training environments and completion of dissertations in a health sciences environment [17], and issues of isolation, anxiety and depression, which were also experienced in a New Zealand engineering case study [18].

A study by Asgari [19] indicates that 30% of engineering students experience challenges balancing academic work and life. In the study, 50% indicated a lack of motivation or did not have access to a private space. Participants report experiencing focus problems, privacy or access to quiet spaces in homes, as well as anxiety around being recorded or watched. The study cites environmental conditions such as students needing to become breadwinners in families (where parents lost jobs). In many instances, the kinds of challenges reported during and post-ERT were amplifications of existing conditions and constraints, which impacted significantly on students who were already disadvantaged, under pressure, and underrepresented. A large collaborative multi- institutional study on the rapid shift to online teaching in South Africa described the assumption of digital fluency for both students and staff as the biggest threat to a socially just education system [2]. This report presents similar findings to the Asgari study in which 25% of the engineering students surveyed did not have access to reliable internet, thus widening the digital equity gap between students. Significant numbers of PhD and Master students (35.5% and 18% respectively) indicate delayed graduation, compared to 7.6% of UGs. Students indicated that online learning resulted in lack of peer support, focus, engagement, and clear guidelines from instructors, also citing time-management issues [19].

For engineering PGs in technology-dependent fields or stages of data generation/gathering, the systemic issue of access to equipment and laboratories resulted in a domino effect, impacting motivation and perceptions of productivity and value. Although institutions, industry, and government proactively responded to student needs in the provision of laptops, data bundles and zero-rated online learning sites [2], access to appropriate infrastructure, hardware and software for PG research purposes required different strategies entirely. Educators reframed project scopes and foci to enable more theoretical or conceptual engagement. Although designed to enable PG students to continue with their projects, these shifts were not without consequences.
As part of a holistic, collaborative programme renewal strategy [20] in an Engineering Faculty at a research-intensive university - the site of this research study - a group of engineering education researchers became particularly interested in the emerging phenomenon of the ERT impact on student mental health and wellbeing [21]. These studies have begun to highlight the synergistic and causal relationship between conditions, motivation, persistence and academic achievement [22]. This paper aims to contribute to the literature on the experience of ERT for PGs in a Global South and emerging economy context, where socio-economic progress is inextricably tied to the development of motivated, insightful and equipped problem-solvers who are to take leading and innovative roles in our society.

III. THEORETICAL & METHODOLOGY CONSIDERATIONS

The study is theoretically framed by a holistic overarching model which links Bloom's cognitive, affective and psychomotor educational objectives (1956) to the epistemological, ontological and praxis curriculum dimensions [23], which require educators to provide cognitive, affective and systemic (CAS) support. This holistic view of education manifests in the Graduate Attributes listed as desirable across professional qualifications, such as Engineering, including knowledge, practices and dispositions enabling legitimate socio-economic participation. This CAS model [24] has been used as an analytical framework to interrogate the anonymous responses to online surveys across a range of relevant ERT studies between September 2020 and July 2021. The three qualitative surveys on which this paper draws are informed by the CAS model, and were intended to determine how ERT impacted PG students in their professional, personal and practical lives.

This study used an empirical approach analysing data from three different sets of surveys of which two were run within the Engineering Faculty and one was run on a national level. Firstly, a survey was sent out amongst postgraduate engineering students to find out what their successes and challenges were in continuing their research under ERT circumstances. The survey questions were: What measures did you/were put in place to accommodate the change in working environment? What communication measures did you/were put in place to accommodate the change in working conditions? Can you describe some of your main challenges during ERT? Can you describe some of your main successes during ERT?

In addition, inputs were drawn from data on postgraduate students' well-being and productivity based on a faculty-wide Academic Stress Management survey conducted at the beginning of 2021. Lastly, responses from academic staff members, who are supervisors and in many cases enrolled for doctorate programme themselves, have been analysed and used in this study.

TABLE I: *Survey details*

Survey	Context	Response Rate (N=)	Time	Code
Emergency Remote Teaching (PG)	Faculty	20 PG's	May 2021	FEP
Academic Stress Management (UG and PG)	Faculty	732 of which 56 PG's	March 2021	FSP
Emergency Remote Teaching (Staff and PG)	Faculty	58 of which 12 PG's	September-October 2020	NEP

A conventional content analysis approach was followed by first consolidating all data from the surveys. Individual responses were then coded for specific concepts, and grouped using the CAS dimensions. Meaningful quotes, illustrating the different emergent themes, were included in the discussion to support the findings.

A. Systemic

As was to be expected, the initial ERT environmental and communication system related constraints received significant feedback on all survey instruments. Students report systemic issues such as access to laboratories, equipment, and connectivity, as well as adaptation of research methods to suit lockdown limitations: *'Due to the **vigorously restricted lab access** during lockdown (even after the university was reopened), experiments could not continue as planned, and I had to make **major compromises** in my methodology. The nature of my project (bioreactor fermentations) required me to enter daily to sample and monitor my setup. A good 20% of my experimental data could not be used as equipment stopped working while I was not allowed inside'. [FEP5]'Internet access in more remote areas are a challenge, since in Ermelo, Bethal (where I am from) and Potchefstroom (where I currently stay) have **internet and power problems**'.* [FEP19]

These conditions resulted in research delays, sometimes as a result of time management issues and sometimes as an inevitable offshoot of reduced access to physical facilities, as indicated by students and their supervisors alike. Such delays have a further systemic ripple effect on institutions in that faculties do not receive the output subsidies when students do not graduate within expected times. In addition, the systemic environment impacted on significantly on people's well- being (Vischer 2007). *'I had to work from my apartment. It is **small as compared to the office space**. And it is very lonely as compared to the office space.'* [NEP47]

In the South African context, access to private physical space is certainly not a given. Many students, asked to spend constructive time working from home, would have had to share limited working space, in ways which may not be conducive to productive or uninterrupted work. Combined with variations in the supply of power and connectivity, this gradient in accessibility of a productive physical space further entrenches socio-economic barriers - barriers which are at least partially reduced when working space is provided in the university setting.

B. Cognitive

The original intention of the various surveys was to capacitate academics to be able to support both their UG and PG students. As such, most responses were initially focussed on the provision of systemic tools to enable effective communication, efficient digital work systems and the requisite technologies for practicals and experiments. This means that the possible cognitive constraints and enablements need to be deduced from survey questions such as the general perceptions of 'challenges' and 'successes' or specific questions such as perceptions and descriptions of productivity in relation to time and workload constraints.

a) Challenges: Respondents suggested that during ERT an unhealthy blurring of productive time and what should have been 'down-time' occurred, contributing to stress:*'I met my deadlines and worked really hard. I found it difficult to switch off after 17:00 when working at home. I worked late hours and slept late. **Developed a bad routine,** but got the project proposal done'. [FEP6] 'We had no choice but to adapt. I am fortunate to have stable internet and a quiet place to work at home. If there is however some **noise or disturbances that I cannot control**, I wake up earlier to work and/or work late in the evening when there are no disturbances (ie like the neighbours building on at their house)'.* [FEP10]

An often-mentioned downside of work from home is the prevalence of distractions, and the effect such interruptions have on productivity. Further, the requirement or pressure to remain productive was reported to result in negative health effects. *'**Productivity was my main challenge**. I had too many outside stimulations caused by working from home. I had **many distractions**.' [FEP12]'I struggled to be productive, which meant that **I would sit for hours in front of the computer** and [...] **get minimum work done**. I met my deadlines in terms of assignments; however, thesis related deadlines (like project proposal dates) I did not achieve'.* [FEP12]

One significant limitation to ERT was the separation from in-person advice from supervisors. Online communication sometimes was reported to not be enough, or not a good replacement: *'Uncertainty surrounding my topic, makes me feel stressed and a bit restricted. Meetings over online platforms with my supervisor, I am* ***more comfortable with meetings in person*** *and feel that I would be able to better explain where I am at and discuss the challenges I'm facing and how to resolve them.' [FEP16]*

b) ***Successes:*** Despite the difficult circumstances, many PG students reported significant successes, rising to the additional challenge with tenacity: *'I* ***published 2 articles in 2020****, so I'm pretty happy with that. Hopefully I can complete the rest of my project successfully in order to graduate in March 2021'. [FEP1]'The* ***ability to work on my own*** *without the supervision of others around me, per se, is a great gift and talent which I learnt last year, and am taking in my stride for this year 2021'.* [FEP2]

Some respondents noted that the tenacity applied in the difficult situation of ERT will have continued value: *'I would like to remember that life and projects do not always go your way and* ***adapt in future to face unforeseen challenges****'.* [FEP5]

Adaptation to a new mode of work also unsurprisingly gave rise to the development of new sets of skills, for instance in the effective use of software to facilitate remote work: *'The use of MS teams/ Zoom were the effective system I would like to maintain and improve virtually working'.* [FEP9]

The increased ability for students to control their own time was reported to not only be a burden but also to result in the self-discovery of softer positive approaches to mental exertion: 'I have experienced that you actually have a lot more 'freedom' when working at home. If you have an hour where you cannot concentrate, rather take your 'lunch hour break' at that hour and do something fun and get back to concentrating after that hour. I would like to maintain the pace at which I am working at'. [FEP10]

A number of respondents expressed optimism about the skills and tenacity learned during ERT, and envisioned the application of such skills in future endeavours: *'Just being able to do my master's thesis, having supervisors with extremely high calibre and being connected to Stellenbosch University is an achievement in itself. I'm excited about the prospects of the value my research can add to the country's conversation'.* [FEP15]

C. Affective

During analysis, it was noted that a significant portion of the commentary from respondents was regarding affective themes. To help direct the discussion of this, the analysis of affective factors is divided into sub-themes: Individual Emotional Responses, Support Systems and Social Environment.

a) ***Individual Emotional Responses:*** Respondents often noted the negative emotional impact of only working from home: *'Isolation (which led to a mild depression)' [FEP5]'... Lack of personal interaction with peers and university community - I feel lonely. Getting organised and planning effectively (communicating via email only with support staff and lecturers) - impersonal and no connection.* [FEP15]

b) ***Support Systems:*** A significant aspect of PG studies is the community of peers, colleagues, researchers one usually works with, and the particular relationship with one's supervisor. During ERT this community was severely interrupted, which many respondents spoke to: *'I feel that I* ***need more interaction with peers*** *to discuss research to stimulate ideas'. [FEP16] '****Communication*** *with my study leader became problematic due to loss of in-person contact'.* [FEP14]

Some had further networks of support which could (at least partially) ameliorate isolation from the academic community: *'I communicated with my supervisor when I needed help on the academic front and I am fortunate enough to have parents and siblings who were there if I needed any emotional support'. [FEP6]'Friends try checking up on me to help me through.'* [FEP4]

c) ***Social Environment:*** Tying in with the previous affective themes, the social environment PG students found themselves during ERT (unsurprisingly) had a significant impact on the work and well-being. Many spoke to familial relationships as supportive of mental health during ERT: *'Having my family around is beneficial as I have someone to talk to for emotional support'. [FEP7] '...Respect when I say that I need to work and they do not expect me to do other things... partner at home and live in a rural community which is close-knit'. [FEP8]'Extremely supportive mother and father during 'work hours''.* [FEP10]

Although, not without some negative impacts of blurring the lines between 'workspace' and 'social-space': *'My parents and siblings are very supportive. However, working at home is problematic as I cannot separate my work and sleeping space which is an issue when it comes to mental health for me...'* [FEP16]

IV. DISCUSSION

Combined data analyses indicate that affective support is possibly the key factor in student success generally. A quantification of the survey responses to indicate positive or negative sentiments around productivity and associated factors such as equipment, support and health (figure 1) reveals the following:

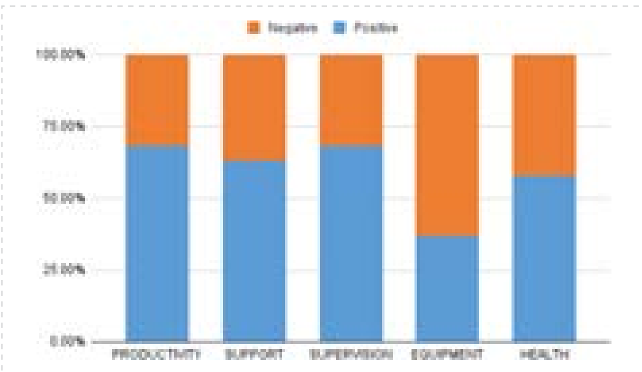

FIGURE 1 *Positive/ negative rated themes by PG*

The majority of the responses around equipment were elicited from Chemical and Process Engineering PGs who experienced significant systemic constraints during the lockdown periods, in that they could not access their laboratories and required equipment. When reporting on both challenges and successes experienced, the survey data show a clear relationship between positive perceptions of support and the concomitant experience of productivity. The PG students who experienced a more affectively supportive environment were also able to adapt to sudden disruptions to their study programmes and were therefore also academically more successful. The formal PG support system is represented by supervisors, and these play a crucial role in provide support: *'… If they genuinely care about the students, are reasonable in adjusting deadlines …, are approachable, and check up on how we are doing it really makes a big difference to the stress experienced by the students…'.* [FSP107]

However, as one PG student puts it, good supervisor support can be by way of simply checking that a student is *"on the right track or point[ing] them in the right direction…. Students might just need to hear that they're doing a good job in order to boost their confidence. A lack of confidence can cause a drop in motivation only inducing more stress".* [FSP152]

Supervisor feedback suggests that 'support' can be interpreted in multiple ways. Supervisors can be motivating, be providing an external expectation and pressure, or approach the supervisory relationship in a more pastoral light, concerned with the PG student's well-being. In most cases supervisors cover multiple supporting roles, from mentor to advocate to evaluator to confidant.

The informal support system can be considered to be comprised of those who represent meaningful relationships in the immediate environment, such as significant others, family members, and friends. In ERT such relationships became increasingly important, particularly as they were needed to step into the gap left from removal from the academic support environment. However, such an overlap of private life and work life can also result in complicating roles. For instance, some female PG students living with family noted that they were asked to assist with caregiving responsibilities (for instance, to attend to younger siblings). Many PG students did not have access to separate, quiet, dedicated working space, but rather had to make do in crowded homes. A differential between students who come from homes of means, and those who come from less advantaged backgrounds was therefore evident, potentially resulting in reductions in productivity with concomitant academic implications.

Dodd et al. [3]report similar findings: "They identified gender and subjective social status differences in mental health, with female students and students with lower subjective social status more affected by low wellbeing. This demonstrates that, although the pandemic has been handled differently worldwide, and COVID-19 prevalence is vastly different across countries, the experience of university students may be comparable. Gender differences in COVID- 19 related worries have been shown, with female university students scoring significantly higher than male students for depression, anxiety and stress during Covid"

Perhaps surprisingly, many of the comments were positive about the ERT experience, with many PG students reporting good productivity, and feeling supported during working from home. Some aspects of this experience might be adapted for more normal times, as ERT comes to an end and working from the university becomes the norm once more. A significant number of comments related to supporting the affective domain for improved mental well-being and improved productivity. It appears that the academic program is particularly good at putting in place systemic tools for good work, and the cognitive development of PG students is a major focus; however, the affective is perhaps neglected. This gap in intentionality was highlighted during ERT and becomes clear when looking at the commentary from PG students. Although the government and national bodies appear intent on addressing mainly the systemic issues arising from the Covid-era educational experience in SA, the impact of the affective on PG students' success has real implications (for instance on throughput rates). We should not ignore what the panellists on the national forum (28 June 2022) reported as a potential looming wave of post-traumatic stress disorder (PTSD) in SA Higher Education.

A key issue in academic institutions understanding how well they are performing in this aspect of PG training is the tendency of PG students (and other actors in the academic space!) under-reporting or being afraid to admit to not coping. *'It can be extremely difficult to admit you need help…'* [FSP219]

The pressurised space of PG training suffers from the stigma associated with any indications of unmet needs in the affective space. This has implications for PG students' success, and limits their ability to rise to the challenge of research. To quote Dodd [3]: "Psychological distress negatively impacts student learning, participation, and their experience of university life, so it is important for universities to understand the student experience of particular stressors to better support their psychological wellbeing"

V. CONCLUSION

This paper makes a methodological contribution to both the impact of ERT on PG researchers and the relationships between the cognitive, affective and systemic dimensions of learning support and student success. Furthermore, it is one of the few investigations that report success factors under conditions of ERT specifically in the postgraduate space, and is applicable across different disciplines. Major themes which emerged from the several survey data-sets used in this article can be considered within the framework of cognitive, affective and systemic dimensions. A majority of governmental and institutional concern was placed on the systemic - with many approaches attempted to bridge systemic gaps, such as access to data or computers. The systemic did prove a major hindrance during ERT for PG students needing access to physical infrastructure (such as laboratories). The systemic also disproportionately impacted PG students from less advantaged backgrounds - with space and home infrastructure becoming limiting. With regard to the cognitive realm, PG students reported both positive and negative impacts of ERT - some found success in focussing on PG work, while others battled to be productive. Overlapping issues of missing the connection to peers, stilted interaction with supervisors, and a blurring between work time and non-work time limited success. Consideration of these themes during return to in-person studies might result in improved productivity in students. However, of the three dimensions used to frame the results, the clearest message emerged through consideration of the affective. Students achieve more, are more productive, if they experience support in this arena. The ongoing PG academic program would benefit from increased consideration of the affective well- being of PG students, to correspond with strong support in the systemic and cognitive realms. The incredibly disruptive period of ERT has allowed for consideration of PG academic activities, where areas of support in the cognitive, affective and systemic are strong, and where further work and introspection might be warranted. Survey results such as those presented in this article provide (sometimes surprising) insights into the success of PG students.

REFERENCES

[1] A. Tait, "Planning Student Support for Open and Distance Learning," Open Learning: The Journal of Open, Distance and e- Learning, vol. 15, no. 3, pp. 287–299, Nov. 2000, doi: 10.1080/713688410.

[2] L. Czerniewicz et al., "A Wake-Up Call: Equity, Inequality and Covid-19 Emergency Remote Teaching and Learning," Postdigital Science and Education, vol. 2, no. 3, pp. 946–967, Oct. 2020, doi: 10.1007/s42438-020-00187-4.

[3] R. H. Dodd, K. Dadaczynski, O. Okan, K. J. McCaffery, and K. Pickles, "Psychological Wellbeing and Academic Experience of University Students in Australia during COVID-19.," Int J Environ Res Public Health, vol. 18, no. 3, Jan. 2021, doi: 10.3390/ijerph18030866.

[4] C. B. Hodges, B. B. Lockee, S. Moore, and T. Trust, "The Difference Between Emergency Remote Teaching and Online Learning," Mar. 27, 2020. http://er.educause.edu/articles/2020/3/the-difference- between- emergency-remote-teaching-and-online-learning (accessed Jul. 30, 2022).

[5] L. A. Gelles, S. M. Lord, G. D. Hoople, D. A. Chen, and J. A. Mejia, "Compassionate flexibility and self-discipline: Student adaptation to emergency remote teaching in an integrated engineering energy course during covid-19," Education Sciences, vol. 10, no. 11, pp. 1–23, Nov. 2020, doi: 10.3390/educsci10110304.

[6] W. E. Copeland et al., "Impact of COVID-19 Pandemic on College Student Mental Health and Wellness," 2021. [Online]. Available: www.jaacap.org

[7] K. A. Douglas, A. C. Johnston, J. P. Martin, T. Short, and R. A. Soto-Pérez, "How engineering instructors supported students during emergency remote instruction: A case comparison," Computer Applications in Engineering Education, vol. 30,no.3,pp. 934-955, May 2022, doi: 10.1002/cae.22495.

[8] S. L. Gares, J. K. Kariuki, and B. P. Rempel, "Community Matters: Student-Instructor Relationships Foster Student Motivation and Engagement in an Emergency Remote Teaching Environment," Journal of Chemical Education, vol. 97, no. 9, pp. 3332–3335, Sep. 2020, doi: 10.1021/acs.jchemed.0c00635.

[9] K. A. Jeffery and C. F. Bauer, "Students' responses to emergency remote online teaching reveal critical factors for all teaching," Journal of Chemical Education, vol. 97, no. 9, pp. 2472–2485, Sep. 2020, doi: 10.1021/acs.jchemed.0c00736.

[10] L. Hudson, P. Engel-Hills, and C. Winberg, "The potential of a simulated workplace environment for emergency remote teaching," International Journal of Work-Integrated Learning, vol. 21, no. 5, pp. 559–572, 2020.

[11] S. Nogales-Delgado, S. R. Suero, and J. M. E. Martín, "COVID-19 outbreak: Insights about teaching tasks in a chemical engineering laboratory," Education Sciences, vol. 10, no. 9, pp. 1–13, Sep. 2020, doi: 10.3390/educsci10090226.

[12] R. J. Petillion and W. S. McNeil, "Student experiences of emergency remote teaching: Impacts of instructor practice on student learning, engagement, and wellbeing," Journal of Chemical Education, vol. 97, no. 9, pp. 2486–2493, Sep. 2020, doi: 10.1021/acs.jchemed.0c00733.

[13] M. C. Pierce, "Don't Waste a Crisis: Opportunities to Enhance BME Student Learning Through COVID-19," Biomedical Engineering Education, vol. 1, no. 1, pp. 155–158, Jan. 2021, doi: 10.1007/s43683-020-00021-0.

[14] B. R. Wilcox and M. Vignal, "Understanding the student experience with emergency remote teaching," in Physics Education Research Conference Proceedings, 2020, pp. 581–586. doi: 10.1119/perc.2020.pr.Wilcox.

[15] B. Wilcox and M. Vignal, "Recommendations for emergency remote teaching based on the student experience," The Physics Teacher, vol. 58, no. 6, pp. 374– 375, Sep. 2020, doi: 10.1119/10.0001828.

[16] C. Zhou, "Lessons from the unexpected adoption of online teaching for an undergraduate genetics course with lab classes,"Biochemistry and Molecular Biology Education, vol. 48, no. 5, pp. 460–463, Sep. 2020, doi: 10.1002/bmb.21400.

[17] G. K. Upadhyaya, V. K. Jain, K. P. Iyengar, M. K. Patralekh, and A. Vaish, "Impact of COVID-19 on post-graduate orthopaedic training in Delhi-NCR," Journal of Clinical Orthopaedics and Trauma, vol. 11, pp. S687–S695, Oct. 2020, doi: 10.1016/j.jcot.2020.07.018.

[18] B. H. W. Guo, M. Milke, and R. Jin, "Civil engineering students' perceptions of emergency remote teaching: a case study in New Zealand," European Journal of Engineering Education, 2022, doi: 10.1080/03043797.2022.2031896.

[19] S. Asgari, J. Trajkovic, M. Rahmani, W. Zhang, R. C. Lo, and A. Sciortino, "An observational study of engineering online education during the COVID-19 pandemic," PLoS ONE, vol. 16, no. 4 April, Apr. 2021, doi: 10.1371/journal.pone.0250041.

[20] K. Wolff, D. Blaine, and C. Lewis, "A cumulative learning approach to developing scholarship of teaching and learning in an engineering community of practice," in 2021 World Engineering Education Forum/Global Engineering Deans Council (WEEF/GEDC), Nov. 2021, pp. 310–318. doi: 10.1109/WEEF/GEDC53299.2021.9657274.

[21] N. Korsten, K. Wolff, and T. Booysen, "Time for mentally healthy engineering students," IEEE, 2021.

[22] E. L. Deci and R. M. Ryan, "Self-Determination Theory," in Handbook of Theories of Social Psychology: Volume 1, 1 Oliver's Yard, 55 City Road, London EC1Y 1SP United Kingdom : SAGE Publications Ltd, 2012, pp. 416–437. doi: 10.4135/9781446249215.n21.

[23] R. Barnett, "Supercomplexity and the Curriculum," Studies in Higher Education, vol. 25, no. 3, pp. 255–265, Oct. 2000, doi: 10.1080/713696156.

[24] J. Gilmore, K. Wolff, and M. Bladergroen, "The night before the test: Electrical engineering students' use of online resources to prepare for assessment," 2017. [Online]. Available: https://www.researchgate.net/publication/317670400

[25] J. C. Vischer, Space meets status: Designing workplace performance. Taylor and Francis, 2007.

[26] Higher Education Leadership and Management forum, Student and staff experiences during the pandemic. June 28, 2022.

Technical papers

Using entrepreneurially-minded online discussions to drive educator-focused community of practice

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Abstract — **Study abroad experiences are a common way for university students to acquire knowledge and competence through the experiential learning associated with embedding oneself in another country. However, limited formal opportunities are available to faculty interested in benchmarking best teaching practices throughout the world. The purpose of this paper is to provide one approach to an educator-focused faculty professional development experience by showcasing how entrepreneurially-minded online discussions helped effectively prepare nine engineering and technology faculty participants for a 15-day NSF-funded renewable energy- focused "study abroad-like" experience in Germany. The short- term project goal was to improve curricula and pedagogy in the U.S. by soliciting best practices in content, teaching, certifications, articulation, and career pathways in renewable energy, energy management, and energy storage. The long-term project goal was to advance the American renewable energy workforce and to increase the technical competence of the U.S. in the energy storage sector.**

Keywords — entrepreneurial mindset, online discussions, professional development, best practices, study abroad

I. INTRODUCTION

A. Problem Identification

Professional development is essential in all areas of practice to keep up with the current trends and optimize opportunities to improve efficiency, effectiveness, and work- life balance. From a faculty perspective, research has found that instructional professional development, in particular, positively impacts student learning [1]. Here, instructional professional development can be carried out according to directed activities, specific programs, or organizational development strategies [2]. Moreover, instructional professional development can be done on one's own institutional turf or through other institutions, domestic and abroad [3, 4]. Given the increased globalization and accreditation of higher education degree opportunities, the potential and need to learn from other countries and cultures is higher than it has ever been in history. As a result, many United States institutions of higher education are placing greater priority on integrating intercultural competence into instructional practices to better prepare students to enter today's globalized world [5, 6]. Yet, a problem remains in that there are limited instructor-focused professional development opportunities for faculty to understand best practices at other institutions, in particular, institutions outside the United States.

B. Current Approaches to the Problem (And Gaps)

Several programs exist to aid in instructor-focused professional development opportunities with institutions outside the United States. Yet, gaps exist. First, the primary opportunity for faculty in the United States to learn from other countries is through the immersive and academic Fulbright program. Faculty can apply to participate in the Fulbright program with the goal to conduct research, teach, and/or consult in a foreign country; each year 800 American scholars are sent annually to 130 different countries [7]. The duration of the program varies between 2 months and a year. Although this provides a great experience for faculty, unfortunately, the program is limited to American citizens. Here, it is important to note that a significant percentage of faculty employed by United States higher education institutions are foreigners. Therefore, the Fulbright program offers limited access and equity throughout the higher education landscape. In addition, for those with families, the longer duration of the program comes with a high family investment which presents yet another challenge. Second, other options for professional development abroad exist in that faculty can develop and lead a study abroad experience for students within their institution. Typically, these experiences are developed with limited resources and aim to focus on student growth and learning. Although observing student growth can be beneficial, faculty can miss out on a higher level of intellectual understanding often obtained through peer discussion with other faculty members. Third, faculty can also attend conferences abroad, which are undoubtedly beneficial for professional development [8]. However, time in these instances is limited, and often lack deeper reflections with peers and being challenged by others. Finally, the internet offers access to various sources of information pertaining to today's globalized world. Here, faculty can gain perspectives by consuming media related to the topic area. However, there is a gap with this option since it is missing out on the perspectives of others and being challenged or praised by peer faculty members, and offers limited interaction with actual foreign counterparts to gain deeper insights.

C. Proposed Solution and Contribution

The purpose of this study is to showcase one approach to solving the problem around limited professional development opportunities for faculty to understand best practices at other institutions, in particular, institutions outside the United States. This approach includes the formation and implementation of an instructor-focused community of practice that integrates reflection and perspective sharing via entrepreneurially-minded online discussions. For these online discussions, incorporating the entrepreneurial mindset was intentional in that it allowed faculty participants the ability to develop a skill set towards discovering, evaluating, and exploiting opportunities [9]. Although the context of this study was for the entrepreneurially-minded online discussions to complement and prepare faculty for a 15-day NSF-funded "faculty study abroad" experience focused on renewable energy best practices for teaching renewable energy in Germany, the community of practice and entrepreneurially-minded online discussions can just as easily be implemented without the extensive travel component. The guiding research question is as follows: *How can entrepreneurially-minded online discussions be used to support skill attainment in an educator-focused community of practice?*

II. LITERATURE REVIEW

A. Faculty Community of Practice

The concept of a community of practice has evolved in recent years, yet remains grounded in the notation that learning is a social enterprise [10]. Barab et al. define community of practices as "a persistent, sustaining social network of individuals who share and develop an overlapping knowledge base, set of beliefs, values, history, and experiences focused on a common practice and/or enterprise" [11]. Community of practices has been used for faculty professional development in many academic areas such as health and STEM (science, technology, engineering, math), and it can take many forms and focus areas [12, 13]. Implementing an effective community of practice can come with challenges, some of which are that most higher education institutions have focused on the transmission of existing knowledge instead of the development of new knowledge [14]. Furthermore, many smaller institutions lack a culture of professional development, especially when it comes to teaching, which can make it difficult to implement a community of practice due to the lack of expert members in the organization [15]. Another challenge associated with implementing a community of practices is related to program ownership and sustainability, where all members benefit and remain engaged over time [16]. On the other hand, a faculty community of practice can also come with many benefits. It allows for professional growth and development through collective learning, and the community of practice can be established in a single institution or a multi-institution, and be offered in a formal or informal setting [17]. Professors can benefit from participating in a community of practices, especially with there are opportunities for co-creation and peer evaluation. Yet, more research is needed to understand the practical improvements for community of practices aimed to improve STEM education [18].

B. Online Discussions

Online discussions are based on a digital platform that allows students and teachers to have active asynchronous communications regardless of each participant's location and time [19]. A benefit of online discussions is that they can serve as a compliment, or in some cases, substitute for face- to-face interaction between participants (educators and students), in an attempt to support a higher order of constructivist learning and the creation of community [20]. Although the adoption and implementation of online discussions have evolved in recent years (especially due to the COVID-19 pandemic), challenges exist. One of the biggest challenges revolves around using an intrinsic motivation to encourage students to actively participate in the discussions. In addition, since face-to-face interaction is limited, it can be difficult to interpret social cues through the written verbiage of participants, and difficult to assess student learning [20]. However, the assessment of student learning, in particular, can be aided through the use of rubrics in online discussions [21, 22]. Many of these challenges and more are supported and summarized by Kearns [23] who establishes that the three main problems with e-learning through online discussions are as follows: (1) the physical distance between the participants, (2) the adaptation to the use of technology for communication, and (3) the management of time and workload. To combat these challenges, the literature offers best practices and recommendations for effectively implementing online discussions. Some of the recommended strategies to achieve more in-depth discussions are asking students to connect the concepts studied to personal or professional experiences [24]. This can encourage and motivate students to participate by reflecting upon their own experiences to establish relevancy. Ultimately, the use of online discussions have demonstrated the ability to improve learning experiences with little effort (on behalf of the instructor) outside the classroom [25].

C. Entrepreneurial Minded Learning

As a mindset is a mental attitude or inclination, an entrepreneurial mindset is thus defined as "the inclination to discover, evaluate, and exploit opportunities" [9]. Here, it is important to note that developing one's entrepreneurial mindset is not just for startups; instead, it can benefit people from all disciplinary backgrounds in thinking more strategically and focusing more on value creation when working within an organization or even in one's personal life. Entrepreneurial Minded Learning (EML) has been defined as "a pedagogical approach emphasizing discovery, opportunity identification, and value creation, while building on other active pedagogies such as problem-based learning" [26]. Studies have shown that the integration of EML in higher education increases the likelihood to take calculated risks, improves the performance of learning technical objectives, and promotes social curiosity [27]. As a first step to prepare for online teaching, the study by Guo, Santiago, Phillips and Kasley [28] implemented the flipped-classroom method integrated with EML in an engineering course, getting positive feedback from students. With the efforts of the Kern Entrepreneurship Education Network (KEEN), EML has been integrated into engineering-focused online discussions across several institutions.

According to Bosman and Fernhaber [29], there are four requirements for EML integration into online discussions: (1) implicit context, (2) target professional skills, (3) promote mindset, and (4) grounded in backward course design. Additionally, there are four essential design components associated with the above requirements. First, an EML discussion prompt should integrate the course content into the entrepreneurial process (as identified in the learning objective). Second, an EML discussion prompt should require communication and collaboration (via the hook, initial prompt, and response prompt). Third, an EML discussion prompt should promote ongoing practices, reflections, and feedback (which shows itself in the initial prompt and response prompt). Finally, a learning activity should promote backward course design by ensuring alignment of learning goals, learning objectives, learning activities, and learning assessment [9].

III. METHODS

A. Study Design and Participants

This study used five entrepreneurially-minded online discussion sessions to help effectively prepare faculty participants for a 15-day NSF-funded renewable energy-focused "study abroad-like" experience. The intended outcome of the learning experience (entrepreneurially- minded online discussions and immersive trip) was to improve curricula and pedagogy in the U.S. by soliciting best practices in content, teaching, certifications, articulation, and career pathways in renewable energy, energy management, and energy storage in Germany. The trip started in Frankfurt and ended in Munich, including several visits with industry, education, and government organizations in between. The online discussions were completed in the semester prior to the in-person two-week "study-abroad like" experience where the educators benchmarked best practices. The ultimate goal was to advance the American renewable energy workforce and to increase the technical competence of the U.S. in the energy storage sector. Details related to the overall experience and lessons learned (with the exception of the online discussions) have already been published and disseminated [30, 31].

Participants included nine United States engineering and technology faculty teaching renewable energy. Seven of the participants were faculty who worked at community colleges (who offer two-year associate's degrees and four-year bachelor's degrees in renewable energy), one participant was a teacher who worked at a high school (which offered renewable energy-focused coursework), and one participant was a university faculty member working at a university (which offered many renewable energy-focused degrees, courses, and research opportunities at various academic levels including undergraduate and graduate). Although the main focus was on improving community college-level degree programs, the rationale behind including a high school teacher and university-level professor was to consider and optimize pipeline opportunities for incoming high school graduates and students considering transfer from a community college to university upon completion of a two- year associate's degree.

B. Data Collection

Five entrepreneurially-minded online discussion sessions were used to encourage participants to better understand the renewable energy and energy storage landscape in Germany, and to get participants thinking about how it may impact their teaching practices. As shown below, and in alignment with the text, "Teaching the Entrepreneurial Mindset to Engineers", all discussion prompts include a learning objective, hook, initial prompt (including three online discussion questions to choose from), and response prompt [9]. The online discussion questions are summarized below. All sessions included 2-6 media items (articles, videos, or websites) to hook the participant. In addition, all sessions included the following initial prompt and response prompt:

- Initial Prompt: Post in response to a question prompt of your choice. Select at least ONE question to address.
- Response Prompt: Respond to at least two posts of your peers. Read through the responses to the three question prompts. Post a response to at least TWO posts.

Discussion Session 1: German Governance

- Learning Objective: At the end of this discussion session, participants will be able to demonstrate an understanding of German Governance efforts.
- Question #1 Greening of Germany: In the article "How Germany Became Europe's Green Leader", one of the key points the authors make is that "many sustainability policies in Germany were first implemented at a small geographic scale or with a small scope." Please describe grassroots initiatives or actions around energy sustainability in your region that resulted in policymaking dialogue or action. Were these efforts effective? Why or why not?
- Question #2 Political Alliances: The two articles about the recent German elections explain how the number of political parties, as well as their size and influence, continues to fluctuate and lends context to the notion that a single party majority does not exist and that policymaking is reliant on - and has been the result of cross-party alliances. Describe any bipartisan efforts - local, state, or national - that you know of where avowed members of separate parties have worked together to influence energy policy. How did these alliances come to pass and what were the results of these efforts? Do you envision these types of alliances increasing in the future, or decreasing?
- Question #3 The Freiburg Model: The articles on Freiburg - a city we will have the good fortune of visiting over several days describe several benefits that result from fully embracing a green city model. Which of these outcomes or benefits do you think would be the most compelling to your students, why? Most persuasive to your local/regional policymakers, why?

Discussion Session 2: Energy Policy and Its Impacts

- Learning Objective: At the end of this discussion session, participants will be able to demonstrate an understanding of German energy policy and its impacts.
- Question #1 Infographics and Visualizations: The chapters and articles frequently utilize well-crafted visuals to depict data on energy generation, use, and trends. Which was your favorite infographic and why? How would you use it with your students? Note the article/chapter and page so we can find it.
- Question #2 Technology: Chapter 3 - "Technology as a Key Issue" - presents summaries of established technologies and then explores less settled issues with German energy production and distribution (grid expansion, baseload power, storage, smart grid growth, feed-in tariffs). When reading through this chapter, were there any assumptions or predictions you found questionable? If so, describe your reservations.

- Question #3 Policy: Chapter 2 –"Policies for Green Energy" - describes several laws and programs that have increased the viability of the Energiewende. If you could dictate that any one of these could be imported and adopted by the U.S., which would you choose? Why?

Discussion Session 3: German Education System

- Learning Objective: At the end of this discussion session, participants will be able to demonstrate an understanding of the German education system.
- Question #1 Secondary Schooling Options: On the diagram entitled "Basic Structure of the Education System of Germany", there are five options for schooling depicted for students at age 15-18. Select one that interests you, briefly describe entrance requirement(s) and credential(s) awarded upon completion. Then describe any pros and cons you envision secondary students may encounter by attending this particular school.
- Question #2 Paths and Directions: According to the reading, "grades 5 & 6 constitute a phase of a particular promotion, supervision, and orientation with regard to the pupil's future educational path and its particular direction". If you were asked to identify good candidates for jobs in your particular sector at age 10 or 11, what characteristics, attributes, or abilities would you use to estimate future success? Tell us your sector and then indicate education, skills, or traits you have found to be beneficial to your students' success.
- Question #3 Strengths of Educational System: Describe what you found appealing in a system that starts students on distinct educational pathways in grade school.

Discussion Session 4: Vocational Education and Training

- Learning Objective: At the end of this discussion session, participants will be able to demonstrate an understanding of the German vocational education and training program.
- Question #1 VET and Higher Education: Select a VET program of your choosing and write a short summary explaining what you've learned. How might this specific VET program be integrated into higher education here in the United States?
- Question #2 VET Sustainability: Select a VET program of your choosing and write a short summary explaining what you've learned. How do Germans pay for and recruit for this VET program? What similar approaches can be done here in the United States?
- Question #3 VET Outcomes: Select a VET program of your choosing and write a short summary explaining what you've learned. How are the VET program outcomes established? What similar approaches can be done here in the United States?

Discussion Session 5: Energy Storage

- Learning Objective: At the end of this discussion session, participants will be able to demonstrate an understanding of the German approach to energy storage.
- Question #1 Course Offerings: Post your key takeaways from the readings. How or where might the topic of energy storage fit into your course(s)?
- Question #2 Program Offerings: Post your key takeaways from the readings. How or where might the topic of energy storage fit into your program offering(s)?
- Question #3 Extracurricular Offerings: Post your key takeaways from the readings. How or where might the topic of energy storage fit into your extracurricular offering(s)?

C. Data Analysis

Thematic analysis was used to analyze the online discussion posts. According to Braun and Clark [32], a thematic analysis is a foundational qualitative method for discovering patterns within the data. It should be conducted using a step-by-step process. The two authors (and researchers) first individually become thoroughly familiar with the data to generate initial codes. The NVivo 12 qualitative analysis software was used to code the reflections. Then the two authors came together to review their findings and come to an agreement. Upon the completion of coding, themes were generated. As a final step, the lead author revised the themes and wrote the report. Due to the qualitative nature of the research, the goal of the analysis was to explore potential themes within the data. The researchers debated the strengths and weaknesses between strictly conceptualizing themes without quotes and heavily using quotes to provide readers with evidence. It was decided to merge the two philosophies and meet in the middle. Quotes were drawn from the data to allow readers to make their own judgments on credibility, accuracy, and fairness [33].

IV. RESULTS AND DISCUSSION

Analysis of the entrepreneurially-minded online discussions resulted in three key themes: (1) Multiple Stakeholders, (2) Value Creation and (3) Sustainability.

A. Multiple Stakeholders

Considering the perspective of multiple stakeholders is important for developing the entrepreneurial mindset, and understanding influence and decision-making power on an international scale. Example quotes are as follows:

- *Storage is a growing field where **code officials, firefighters, fire marshals, plan reviewers, and electrical inspectors** are particularly hungry for information on storage. Continuing education programs that **target these groups** would do well with offering courses in this rapidly emerging technology.*
- *I expect the push and pull will continue to occur as progress moves towards the goal of 100% renewables. It will be important to continue to find ways to **bring all sides to the table** in order to find ways to keep moving the ball further down the field.*
- *The mandate [which requires all new residential construction to include a photovoltaic system] was developed in consultation with the **homebuilding industry** and the **Public Utility Commission.***
- *Much of that work had to be done through **local stakeholders**, which promotes input, buy-in, and staying power.*
- *The more I read about the policies for green energy, I too am very interested in the political indicators as you. I hope that we can hear from people that are **pro and con** for these policies. I would like to know more about **both sides' perspectives**.*

- *Financing the German vocational education and training (VET) system is not a simple calculation to see who pays how much. The* ***three parties that contribute towards financing*** *the VET system in Germany are the companies, the public sector and the trainees themselves.*

B. Value Proposition

Highlighting the focus on value proposition is important for developing the entrepreneurial mindset, and understanding the potential for impact on an international scale. Example quotes are as follows:

- *The overall project is focused on getting more veterans into the solar industry. Recognized apprenticeship programs have* ***incentives for employers and also allow veterans*** *to access GI Bill benefits like housing and school supply stipends.*
- *Having a fully online program for both energy efficiency and water conservation, virtual internships will be a* ***valuable resource*** *for students who are not able to secure the internship required by both programs.*
- *What I find particularly interesting about Chatham Park is that they clearly* ***understand people's desire*** *to live in more sustainable communities.*
- *It makes sense that if a new high paying occupation – energy storage manufacturing – were introduced, it would* ***satisfy a number of the barriers that cause resistance*** *to eliminating coal as a US fuel resource.*
- *Solar Installers of Washington is an organization* ***created to organize*** *local solar companies and* ***influence*** *energy policy and legislation.*
- *The* ***outcome or benefit*** *resulting from fully embracing a green city model that would be* ***most persuasive*** *to my local and regional policymakers might be "fesa" where Freiburg citizens get a* ***return on their investment*** *of over 6 million euros in installing nine windmills, eight photovoltaic arrays, one hydropower plant, and a major energy conservation retrofit project at a public school.*

C. Sustainability

Discussing sustainability is important for developing the entrepreneurial mindset, and understanding long-term outcomes and implications on an international scale. Example quotes are as follows:

- *The purpose of the Sustainable Business Initiative Task Force was to identify, support, and propose deliberate steps that, by 2020, can make Eugene one of the nation's most* ***sustainable mid-size communities****.*
- *The sustainability office has a commission that oversees the work of the office to some degree. They have monthly public meetings where they* ***update their progress on projects, milestones****, and new project recommendations brought to them by staff and the public.*
- *Whether there is a* ***"long-term" and "comprehensive" policy framework*** *for these requirements is debatable.*
- *While storage and renewable energy technologies help solve for power generation and intermittency, we need to* ***consider the life-cycle cost analysis*** *for every product.*
- *The part that stuck with me as much as anything is the* ***unintended social/environmental consequences*** *of large-scale battery adoption. It makes you stop and think about the true* ***"sustainability"*** *of battery production.*
- *I love that Germany is not only focusing upon building renovations, but that they are stepping back to see the forest from the trees by* ***investigating how entire neighborhoods and city districts could also become more energy-efficient.*** *The United States could greatly benefit from implementing a similar program.*

D. Summary and Implications

In summary, analysis of the entrepreneurially-minded online discussions, related to benchmarking best teaching practices related to renewable energy and storage in Germany, resulted in three key themes: (1) Multiple Stakeholders, (2) Value Creation, and (3) Sustainability. This section will respond to the research question and provide implications for moving forward.

How can entrepreneurially-minded online discussions be used to support skill attainment in an educator-focused community of practice?

Benchmarking has been very popular within industry as it allows organizations to learn from each other and grow together in an attempt to discover and implement "best practices", yet, it has infrequently been used within higher education [34]. As such, providing a compare and contrast to the literature is difficult. Yet, we are optimistic as the results align well with entrepreneurial and strategic thinking, which has done well in the for-profit world.

Identifying and considering the perspectives of **multiple stakeholders** is important in industry to ensure the return on investment for improving supply chain efforts (working with many suppliers), optimizing human resources (through employee relations and benefits), and maximizing quality (by means of customer satisfaction). Similarly, when making improvements to teaching and learning practices, it is also important for educators to identify and consider the perspectives of multiple stakeholders to ensure educator return on investment for improving content sourcing (via publisher resources and other information likely found online), updating pedagogical approaches (via assistance from a center for teaching and learning), enhancing technology engagement (via learning management system capabilities), and maximizing quality (by means of attainment of student learning objectives).

Validating a **value proposition** is important in industry to ensure the return on investment for the bundle of products and/or services offered through a company. When validating the value proposition design, businesses should be concerned with customer desirability (Do they want this?), business viability (Should we do this?), and technology feasibility (Can we do this?) [35]. Similarly, when making improvements to teaching and learning practices, it is important for educators to validate the value proposition. From the customer desirability perspective, it is important for educators to consider both the learning outcome and potential for student satisfaction and engagement. From a business viability perspective, it is important for educators to find an optimal balance of teaching efficiency and teaching effectiveness. From a technology feasibility perspective, it is important for educators to understand their own capabilities, as well as technology and procedural capabilities related to teaching and learning.

Promoting **sustainability** is important to industry because it ensures internal and external processes and procedures will sustain the business (and its suppliers, employees, and customers) in the long term. Similarly, when making improvements to teaching and learning practices, it is important for educators to consider sustainability. Instead of re-creating the proverbial wheel each semester, best practices and lessons learned should be carried over each semester.

V. CONCLUSIONS

In conclusion, the purpose of this study was to showcase one approach to solving the problem around limited professional development opportunities for faculty to understand best practices at other institutions, in particular, institutions outside the United States. This approach includes the formation and implementation of an educator-focused community of practice that integrates reflection and perspective sharing via entrepreneurially-minded online discussions. Although the context of this study was for the entrepreneurially-minded online discussions to complement and prepare faculty for a 15-day NSF-funded "faculty study abroad" experience focused on renewable energy best practices for teaching renewable energy in Germany, the community of practice and online discussions can just as easily be implemented without the extensive travel component. Therefore, this study can be used as a guide for professional development facilitators (e.g., centers for teaching and learning, instructional designers, and lead faculty) who wish to implement their own instructor-focused professional development experiences. These experiences can be stand-alone, where they only include online discussion sessions, or can use the online discussion sessions as a complement to in-person training.

REFERENCES

[1] C. Rutz, W. Condon, E. R. Iverson, C. A. Manduca, and G. Willett, "Faculty professional development and student learning: What is the relationship?," Change: The Magazine of Higher Learning, vol. 44, pp. 40- 47, 2012.

[2] R. S. Caffarella and L. F. Zinn, "Professional development for faculty: A conceptual framework of barriers and supports," Innovative Higher Education, vol. 23, pp. 241-254, 1999.

[3] S. R. Asada, "The Role of Faculty in the Comprehensive Internationalization of Higher Education: Perspectives from Japan and the US: The Role of Faculty in the Internationalization of US Higher Education," 2021.

[4] J. Knight, "Internationalization remodeled: Definition, approaches, and rationales," Journal of studies in international education, vol. 8, pp. 5-31, 2004.

[5] P. G. Altbach, L. Reisberg, and L. E. Rumbley, "Tracking a global academic revolution," Change: The Magazine of Higher Learning, vol. 42, pp. 30-39, 2010.

[6] I. I. Munene, "Outsiders within: Isolation of international faculty in an American university," Research in Post-Compulsory Education, vol. 19, pp. 450-467, 2014.

[7] United States Department of State. (May 2). Fulbright U.S. Scholar Program. Available: https://exchanges.state.gov/us/program/fulbright-us-scholar-program

[8] F. Tan and L. Nabb, "The Effects of Attending Annual Professional Conferences on the Personal Development of International Faculty," American Association for Adult and Continuing Education, 2021.

[9] L. Bosman and S. Fernhaber, Teaching the entrepreneurial mindset to engineers. Switzerland: Springer International Publishing, 2018.

[10] E. Wenger, "How we learn. Communities of practice. The social fabric of a learning organization," in The Healthcare forum journal, 1996, pp. 20-26.

[11] S. Barab, J. MaKinster, and R. Scheckler, "Characterizing system dualities: Building online community," Designing for virtual communities in the service of learning, pp. 53-90, 2004.

[12] Y. Steinert, "Faculty development: from workshops to communities of practice," Medical teacher, vol. 32, pp. 425-428, 2010.

[13] E. D. Crede, M. Borrego, and L. D. McNair, "Application of community of practice theory to the preparation of engineering graduate students for faculty careers," Advances in Engineering Education, vol. 2, p. n2, 2010.

[14] S. Buckley and A. Du Toit, "Academics leave your ivory tower: Form communities of practice," Educational Studies, vol. 36, pp. 493-503, 2010.

[15] M. L. Blanton and D. A. Stylianou, "Interpreting a community of practice perspective in discipline-specific professional development in higher education," Innovative Higher Education, vol. 34, pp. 79-92, 2009.

[16] M. A. de Carvalho-Filho, R. A. Tio, and Y. Steinert, "Twelve tips for implementing a community of practice for faculty development," Medical teacher, vol. 42, pp. 143-149, 2020.

[17] J. R. Reilly, C. Vandenhouten, S. Gallagher-Lepak, and P. Ralston-Berg, "Faculty development for e-learning: A multi-campus community of practice (COP) approach," Journal of Asynchronous Learning Networks, vol. 16, pp. 99-110, 2012.

[18] T. R. Kelley, J. G. Knowles, J. D. Holland, and J. Han, "Increasing high school teachers self-efficacy for integrated STEM instruction through a collaborative community of practice," International Journal of STEM Education, vol. 7, pp. 1-13, 2020.

[19] S. L. Markel and E. E. ECI, "Technology and education online discussion forums," Online journal of distance learning administration, vol. 4, 2001.

[20] S. J. Levine, "The online discussion board," New directions for adult and continuing education, vol. 2007, pp. 67-74, 2007.

[21] D. L. Baker, "Designing and orchestrating online discussions," MERLOT Journal of Online Learning and Teaching, vol. 7, pp. 401-411, 2011.

[22] P. K. Gilbert and N. Dabbagh, "How to structure online discussions for meaningful discourse: A case study," British Journal of Educational Technology, vol. 36, pp. 5-18, 2005.

[23] L. R. Kearns, "Student assessment in online learning: Challenges and effective practices," Journal of Online Learning and Teaching, vol. 8, p. 198, 2012.

[24] L. Muilenburg and Z. L. Berge, "A framework for designing questions for online learning," The American Journal of Distance Education. Retrieved February, vol. 9, p. 2007, 2000.

[25] E. Murphy and E. Coleman, "Graduate students' experiences of challenges in online asynchronous discussions," Canadian Journal of Learning and Technology/La revue canadienne de l'apprentissage et de la technologie, vol. 30, 2004.

[26] J. Wheadon and N. Duval-Couetil, "Elements of entrepreneurially minded learning: KEEN white paper," The Journal of Engineering Entrepreneurship, pp. 17-25, 2016.

[27] D. M. Grzybowski, X. Tang, E. Park, A. Leonard, J. DeLano, and K. Zhao, "Integration of Entrepreneurial-minded Learning," in 2020 ASEE Virtual Annual Conference Content Access, 2020.

[28] J. Guo, J. Santiago, P. Phillips, and K. Kasley, "Combining flipped classroom and integrating entrepreneurial minded learning in DC circuit analysis and design course," in Annual ASEE Conference and Exposition, 2019.

[29] L. Bosman and S. Fernhaber, "Applying authentic learning through cultivation of the entrepreneurial mindset in the engineering classroom," Education Sciences, vol. 9, p. 7, 2019.

[30] L. Bosman, J. Brinker, and K. Walz, "A comparison of the renewable energy and energy storage sectors in Germany and the United States, and recommendations for engineering teaching practices," in Energy Conversion and Conservation Division. ASEE Annual Conference Proceedings, Montreal, CA Paper, 2020.

[31] M. Slowinski, G. Temple, and K. Walz, "International Faculty Professional Development: Utilizing Hybrid Environments to Deepen Learning and Grow Community," Paper presented at the Energy Conversion and Conservation Division. ASEE Annual Conference Proceedings, Montreal, CA Paper., 2020.

[32] V. Braun and V. Clarke, "Using thematic analysis in psychology," Qualitative research in psychology, vol. 3, pp. 77-101, 2006.

[33] A. Corden and R. Sainsbury, Using verbatim quotations in reporting qualitative social research: researchers' views: York: University of York, 2006.

[34] D. M. Billings, H. R. Connors, and D. J. Skiba, "Benchmarking Best Practices in Web-Based Nursing Courses," Advances in Nursing Science, vol. 23, pp. 41-52, 2001.

[35] P. C. Brown, H. L. Roediger, and M. A. McDaniel, Make it stick: Harvard University Press, 2014.

Technical papers

Training beyond the classroom: Case study of the impact of a undergraduate teaching assistantship program

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***Abstract* — In an effort to continue to help provide various and thriving experiences to engineering undergraduates and help increase retention, a mid-size university uses a high impact practice of using peer teachers in the classroom. It is a standard practice to use graduate teaching assistants in most areas of higher education, especially in engineering classes, discussions, labs or just to hold office hours and grade. However, an increasing number of universities have adopted and leveraged undergraduate teaching assistants as it demonstrates to effectively improve students' grades, retention, student self- efficacy, and provide some financial relief to academic institutions [1]. The impact of using peer teachers is especially evident in the first and second years in engineering. Students who participate in the role are third year or above demonstrate expertise, leadership, and an interest in teaching as part of their development. At a mid-size minority serving institution, an undergraduate teaching assistant (termed as teaching fellow) was developed informally in 2005 in the mechanical and chemical engineering department and expanded in 2017 to the entire College of Engineering and Informational Technology. In this case study, alumni and current teaching fellows were interviewed to assess the impact of their experiences and how it influenced their educational experience in their major and current career. Several themes were discovered to include increased professional and personal skill sets, self-efficacy in engineering, motivation to participate in the program, impact on career, creation of community and improvements needed to the program. A few teaching fellows decided to continue to be a p12 teacher.**

Keywords — undergraduate teaching, recruitment, retention, graduate teaching, professional development

I. INTRODUCTION

Knowing the needs of our society to provide quality engineering education takes creative solutions and seeks new practices that will ultimately produce a quality engineer. This requires understanding that Faculty and Graduate Teaching Assistants are not enough to help develop students not only feel prepared, but to persist in their programs, especially in institutions with large class sizes.

At the University of Maryland, Baltimore County (UMBC) mid-sized university, minority serving institution, teaching innovation is encouraged. Back in 2005 a new idea of adopting undergraduates as teaching assistants was considered and implemented in the chemical and mechanical engineering departments. Since this time, the College of Engineering and Informational Technology (COEIT) has embraced the success of this model encouraging other departments to infuse it into their classrooms.

In this first look, case study paper, a scoped focus of current and past teaching fellows was interviewed, providing a preliminary perspective into these students' lives. This serves as the launching point to help develop deeper qualitative and quantitative measures for a future longitudinal study.

II. BACKGROUND

In higher education, faculty may have a number of responsibilities that distract from their ability to provide quality attention to the students. While the faculty are adept at providing content knowledge for their students, oftentimes the students may be unable to connect with their instructors (whether it be lack of time, large class size or more). This can cause the student to view the faculty as untenable and just a lecturer in front of the room. To help bridge this relationship gap, offering further assistance to students, teaching assistants are utilized. While it may be important for graduate students to be teaching assistants in laboratory courses, since they have a familiarity with the equipment and the expertise, undergraduate students make a strong case as a replacement, especially for the underclass courses. This population may have just taken the class, are familiar with the university environment and can serve as a peer mentor.

Several institutions have adopted this idea of using undergraduate peer teachers (or teaching fellows) instead of, or an add to, the common graduate teaching assistant. At UMBC, unlike other institutions, these teaching fellows serve in similar capacities, like a graduate teaching assistant, in the classroom. However, their academic schedule tends to be more cumbersome and they will receive less pay than their graduate peers. Teaching fellows (TF) at UMBC tend to only work around 10 hours per week.

Although all teaching assistants and fellows are invited, only the TF's are required to attend professional development that is run through the COEIT. These students engage with faculty and learn best and high impact practices in teaching, classroom management, Title IX, cultural awareness and will engage with other teaching fellows in and outside of their department.

For the past decade, this program has flourished, starting informally in 2005, to a more comprehensive and college wide initiative. These students are seen as an extension of the faculty, engaging in the art and innovation of engineering and computing education. Students from this program are now in high demand as graduate students and future engineers. They tend to not only perform stronger in their teaching assistantship, but in their ability to research and show greater potential to be a future faculty member. Due to the unique skill set these undergraduates obtain, a nationally recognized certification, traditionally a graduate student exclusive opportunity, is being offered starting Fall 2022. Undergraduate TF's will earn this certification by taking a one-credit scholarship of teaching, research and learning course in the Fall and Spring semesters.

These observable positive outcomes of community and impact on career trajectory motivated a need to study and find what is making this program effective, the impact on both the current and past teaching fellows and how can this program be developed further.

A. Aim and Research Question

How has a program for undergraduate teaching fellows impacted the growth and development of an engineering student in their academic program and career?

Themes from this study will be used to develop and facilitate a broader and deeper mix methodology assessment of the program.

III. LITERATURE REVIEW

In undergraduate education, the students historically do not have an active role in their academic department. Instead, teaching faculty and graduate students are responsible for providing content knowledge and mentorship to the students. As a new initiative to answer lack of support, personnel and resources, the psychology departments at the University of Scranton [2] and Indiana University East [3] began utilizing undergraduates as teaching assistants (UTA), in the late 1990's. At many universities, undergraduate teaching assistants are deemed UTA's whereas at UMBC, they are classified as teaching fellows.

A. Motivation to become a teaching fellow

Students choose to become a teaching assistant or fellow for many reasons. Some may have an interest in teaching, while some may simply want to develop a better understanding of the course content. One study in 2016 [4] found that graduate teaching assistants (GTAs) were less likely to opt for formal teaching and pedagogical training, whereas UTAs, not under the pressures of graduate schoolwork, are uniquely motivated to provide what is best for the students. One undergraduate student reported "want[ing] my peers to have a better learning experience than I had in general chemistry" [4]. Many UTAs are willing to put forth more effort in their role as they just completed the coursework, and they empathize with their peers [5]. With this motivation, many institutions find undergraduate students to be more effective in the classroom.

B. Benefits of being a teaching fellow

For UTAs, the benefits of the program are vast and widespread. At one institution, a survey was administered [5] asking UTA's their perceived benefits of being a teaching assistant. One student explained that they viewed academia as a potential future career choice and thought that being a teaching assistant would be helpful to understand the profession. Many referenced wanting to develop specific skill sets to include observational and interpersonal, leadership, and communication, confidence in both teaching and mentoring, and general skills. The UTA's overall felt that they received a comprehensive experience and the job "...was fun and rewarding, and honestly, I would do I all over again!" [5].

C. Teaching fellows improving higher education

An introductory computer science course [6] began using UTAs in 2002 and immediately noticed a positive change in course. Not only did the UTAs provide meaningful feedback to the instructors, but the students in the course felt that the UTAs were more approachable and fairer than previous GTAs. A 2013 study [7] found that it was more important to recruit UTAs who were helpful, responsive, flexible, and willing to establish a rapport with their students. When asked to rank their experience with their teaching assistant using a 5-point scale, the median score for GTAs was 1.9, while the median score to UTAs was 3.0. Additionally, the failure rate for the course in which the UTA program was initiated decreased by twenty percent.

UTA's also demonstrated to be effective when they were present during lecture time. In the case of a computer science program, the UTAs were able to keep track of the course material and provide more relevant examples during their discussion through their perspective [6, 8]. Aside from requiring lecture attendance, UTAs often meet with the faculty and collaborated with other peer teaching assistants. Using undergraduate students as teaching assistants creates a unique community that provides authentic learning in the classroom, provides deeper connection in the culture and understanding diverse learners developing improve pedagogical practices.

IV. METHODOLOGY

Using qualitative methodology, well-formulated questions were developed to capture the impact of this program in current students and alumnus academic and non- academic lives. In this approved internal review board assessment, several alumni and current teaching fellows were invited to participate in a 30-60 minute interview. Demographic information is shown in Table 1.

TABLE 1: *Demographics of Interviewed Participants*

Variable	Value	Frequency	Percent
Gender*	Male	6	60
	Female	4	40
Unit	Mechanical Engineering	8	80
	Chemical Engineering	2	20
Graduate Status	Third year	2	20
	Fourth Year	3	30
	Fifth Year	2	20
	Graduated	3	30
Ethnic**	African American/Black	1	10
	White/Caucasian	5	50
	Asian	1	10
Total		**10**	**100**

* No participants classified as non-binary

** Other ethnic groups were removed if none were reported in the data set

Data gathered was evaluated using grounded theory, open coding techniques and themes were generated and classified [13].

V. RESULTS

Ten students volunteered to participate in 30 to 60 min one on one interviews related to their experiences as being either current or previous (alum) teaching fellows. After careful assessment, several themes were identified that were commonly discussed including development of professional and personal skill sets, self-efficacy in engineering, motivation and participation in the program, impact on career, community and improvements needed for the program.

A. Professional and Interpersonal Skills

Students frequently referred to their communication skills increasing, especially in presentations and in group work with their peers.

1. Communication

A reoccurring positive mentioned outcome of the program was their improved confidence in their ability to communicate more effectively. Many of the participants discussed, as example, in their ability to give presentations in class, such as these two-undergraduate stated *"I'm a lot more comfortable speaking in front of people. Like, when I did my introduction in this semester, no shakes when I even when I did my presentation for 204 last semesters. I was good….[T]hat is something I didn't even realize that, but yeah, so presentation skills have definitely improved from this experience."* - Participant 2

"…the biggest examples that I've gotten from actually being a TF is presentation skills. Like, we have to go up in front of 60 students and present a problem and I feel very comfortable talking in large crowds now because at first, I was really nervous about hosting discussions with so many people and speaking in front of so many people." – Participant 4

An alumnus teaching fellow mentioned that in their current career they felt that the program helped them to overcome fears of public speaking. *"I think that being a teaching fellow helped me get over some of my fears of public speaking and discussing my personal skills and knowledge with others".* - Participant 10

Many also mentioned how they even communicated with their peers better making them more comfortable and approachable.

"Just the tone of my voice and the way that I approach things and so I kind of learn the subtleties of that and how to make myself more inviting. So people will want to come ask me for help because at the end of the day, that's what I'm here for as the TF.". -Participant 2

"I think it's really helped me to communicate with people… because being a TF, students have come to me for questions and asking me to explain and elaborate on assignments. And so I've had to really sit down and talk with students 1 on 1 and explain things in depth. And so that's given me a different perspective on how to approach a problem." -Participant 3

2. Working in Groups/Teams

Many of the students felt that this experience helped improve their ability to work with a diverse set of their peers both in and outside of the classroom. Participant nine, who is currently employed in industry, explained their experience helped to create better relationships. *"…I have been able to help and work with my coworkers on projects using my engineering experience and developed relationships with them to form a community at work."* - Participant 9 Alumni

Teaching fellows learn to explain and communicate engineering concepts in a more effective way. This has helped working with their peers, such as in group projects as participant 3 explained. *"Understand how to solve a problem [better]. I think I definitely use that a lot … that's something that has come up in group projects a lot, being able to communicate what's going on with a certain project."* - Participant 3

Participant 8 elaborated and referenced how the experience helped articulate their ideas and related to their professional development. *"It helps students be able to articulate. It helps me to be able to articulate my ideas. And communicate them to a group of students, and it really helped me kind of work on those professional skills that are valuable. No matter what career you go into if you're an engineer [or] sitting in a cubicle."* - Participant 8

3. Time management

Time management was mentioned frequently by many of the participants as an increased professional skill set. Teaching fellows, depending on their assigned class, are usually expected to lead and facilitate an assigned discussion or lab period, grade, hold office hours and potentially have weekly meetings with their faculty supervisor. Along with these tasks, it's expected they are continuing to perform well in their studies. Participant 2 discussed that:

"[In] teaching I still have to prepare and so the preparation time, I have to know to block out time for that after blocking out time for grading. I have to be attentive in my emails, but I was already good at that but [I am even better now]." They also discussed how they formulated a methodology, explaining their classroom management practices in their assigned class engineering 101 *"I even have a method where if I see something that's for ENES [Engineering 101]. I mark it with a label [when it comes in]... so it doesn't get lost in, like, all the emails that I have. And so, like, every couple of days I'll just go back to the tags so I can know if I answered [the] emails or not.... just scheduling overall and knowing how to manage my time has improved a lot."*

4. Interviewing Skills

Students in this program felt they were able to interview, whether for a job or research-based interview, in a more confident and effective way. Participant 8 discussed how they were able to effectively earn a position due to feeling more confident in their ability to talk to not only students, but faculty and industry personnel as well. *"I definitely wouldn't have been as comfortable with interviewing if I hadn't been a teaching fellow. And probably would not have applied for jobs that required a security clearance." - Participant #8*

Participant 2 also mentioned their confidence in interviewing to include during their interview for this research. *"... I feel like it helped me grow a lot. And I'm a lot more comfortable talking like even [in] this interview." - Participant 2*

B. Self-Efficacy in Engineering (Confidence)

1. Course Material

Both the undergraduates and alumni professionals felt it helped in their engineering self-efficacy and confidence in their ability as an expert in the field of engineering. Participant 10 talked about how in industry, they felt more confident than their peers to effectively articulate their technical knowledge in their company. *"It made me more confident personally and in my expertise."* -Participant 10

Participant 8 reflected on what their engineering statics professor explained and how teaching will only increase their engineering knowledge, abilities, and career choice. *"One good thing my statics professor ever told me [was], what you learn, [you will retain] 70% or 80% the 1st time you take the class. Then the 1st time you teach the material to somebody else, you're retaining [and] and rebuilding those neurological pathways. So, if you're being a teaching fellow for class, even if you're going into engineering. You know, you are building those neurological pathways, you are. Reinforcing those concepts, those materials, which is why it's a benefit of being an undergrad teaching fellow, and it also helped me reinforce the fact that I like teaching and I like to explain things to kids."* - Participant 8

C. Motivation and Participation in the Program

Most of the participants mentioned their motivation in wanting to "help people." The opportunity to not only have an on campus financial position was useful, but to also engage with the community and give back to their fellow peers was attractive. *"I wanted to help fellow students understand certain topics...cause that it's very fulfilling to need to. Like, when other people don't understand something, and then we can explain to them and where they understand, and they're like, "oh, I get it now."* - Participant 7

"....actually I really like helping people and I've done tutoring in the past and I've actually done a few teaching things as well..." - Participant 2

Participant 4 further explained that they decided to continue as teaching fellow not only to continue to help the students but appreciated what it was like to be the instructor. *"I returned to being a TF, because I really just enjoyed my job last semester. I thought it was a really good time being on the other side per se. You don't really understand what it's like as a teacher, when you're on the other side grading things and hosting office hours, and just trying to help students and I just enjoyed it so much..."* - Participant 4

Another mention was the financial aspect. Many of the participants appreciated the convenience to work on campus, working in their discipline and within their department.

I really felt like I was helping them [students]learn the material by being able to talk to them more on a student to student basis. And it's also a nice form of extra income without having to put in too many hours, which is something that I really like. - Participant 3

Several participants also mentioned how a faculty member recommended them to the program. Participant 8 discussed how *"I've been turning around the idea of being kind of like a teacher for a while. I was good at explaining things in my study group to other students. So I thought, why not give this a shot and I really liked all my engineering classes."* A faculty member and their researcher sought them out and offered them the opportunity to be a teaching fellow.

D. Impact on Career

1. Potential of going into academia

Some of the participants also mentioned that the program encouraged them to consider or even go into teaching or professorship (graduate school)

"So, I think that was one of the things that really kind of got me into teaching and I don't think I would have been a teacher if I had gone to one of those other schools and didn't get the opportunity to become a teaching fellow. " - Participant 8

Many students from this program have at least considered or have moved forward into graduate positions. In future studies, a deeper evaluation will provide a more precise understanding of the trajectory, due to this opportunity. Participant 6 shares their thought process of becoming a professor due to this opportunity.

"And there was always something in the back of my mind that said, maybe going to be a professor or something would

be something that would be interesting. So I found that I liked teaching people and the process of helping people understand subjects and everything. It's definitely something that's kind of helped me to consider maybe becoming a teacher, but becoming a professor is something also." -Participant 6

Participant 3 also explains how graduate school has become an option due to their experiences as a teaching fellow. *"I think I am possibly considering grad school a little bit more now than I used to just because I do enjoy teaching so much that I'm talking to my professors and others."* - Participant 3

Students also mentioned that they are, at most, considering going to graduate school part time and going into industry full time. *"...get either get my PhD and also [go] into a industry position. So I'm kind of dipping my feet in both things."* - Participant 4

2. Deterred from academia

Many of the students mentioned how they experienced the stress and overwhelming experience of teaching. They also observed their faculty members and the pressure of being a professor. This motivated one of the participants to consider entering industry rather than academia. Although participant 4 is considering both careers, during the pandemic, they could tell their mentor was dealing with a lot of stress. *" It impacted my career choice in the sense that, like, I'm working with the professors, I see how stressed they are. And it actually kind of deterred me from being an academic. So I'm kind of moving towards being in industry, because I see the amount of stress that professors go and like, the amount of just time and effort they put into, putting in the curriculum and just helping students."* - Participant 4

E. Community

A highlight of the program is how the teaching fellows become more engaged in the department with faculty, staff and students. Many students form lifelong friendships and mentors with faculty they work with in the semester. *"I really enjoyed teaching, but I felt like I still had room for improvement and also liked the connections I made within our department... [I] got to know a lot of the professors and really enjoyed mentoring the younger students"* - Participant 8

"[I received] a deeper connection with my peers. I really widen the peer base I didn't have." -Participant 5

Participant one mentioned the more authentic relationships through office hours and class time. *"Work[ing] one on one with people to, like, help them personally develop throughout the course. And that kind of goes with the same for office hours, too. Like the 1 on 1 time."* - Participant 1

Several participants also reference how the students in their sections were more comfortable with them over the instructor. Participant 10 explained that they would get a lot of questions *".. when it's somebody closer to their age, they feel like they're able to kind of, like, talk to you a little bit more and ask you more questions."* Participant 10 really enjoyed being able to help *"sharing your passion of engineering"* during office hours and more exclusive time with the students.

F. Improvements to the program

1. Variability of instructor

Some of the teaching fellows felt that depending on the instructor, they were either over or underutilized. *I feel like in some of the courses I've done,I've felt underutilized. And then in other courses, I've felt over utilized.* - Participant 5

A few also mentioned feeling overworked and how a need for higher pay. *"[What] I don't like about being a TF is that we're a little overworked for 60 students. Okay, we're definitely working more than 10 hours a week. Because there's only like, 3 of us for, like, 60 kids and, you know, it's an upper level, chemical engineering class. So it's very demanding.[If I]can be honest, [we are] overworked and underpaid, but we do it because we love it."*-Participant 4

VI. CONCLUSION/FUTURE WORK

In this case study assessment, themes found will be used to help develop a richer, longitudinal work. This program has impacted more than a decade worth of students who have attested their time int this program to their current careers. The unique and non-traditional pathway this program provides encourages a student to be confident in their engineering abilities, grow themselves into leadership positions and even discover their options to potentially go into research and academia. To assess and evaluate this further, future studies will include:

- Developing a quantitative assessment that will help understand a deeper and broader audience.
- Use the dataset to inform faculty of how to supervise a TF.
- Create better programmatic training for faculty and undergraduate teaching fellows
- Provide a bridge from teaching fellow to doctorate as a future programmatic initiative. Currently a new class is being offered at UMBC where students can earn a newly developed undergraduate Center for the Integration of Research, Teaching and Learning (CIRTL) associate certification. This is a widely recognized program in the United States.

REFERENCES

[1] Philipp, Stephanie B., Thomas R. Tretter, and Christine V. Rich. "Undergraduate teaching assistant impact on student academic achievement." The Electronic Journal for Research in Science & Mathematics Education 20.2 (2016).

[2] T. P. Hogan, J. C. Norcross, J. T. Cannon, and C. P. Karpiak, "Working with and Training Undergraduates as Teaching Assistants," Teaching of Psychology, vol. 34, no. 3, pp. 187–190, Jul. 2007. 10

[3] R. E. Osborne, J. Norman, and T. Basford, "Utilizing Undergraduate Teaching Assistants: An Untapped Resource," in Eleventh Annual Conference on Undergraduate Teaching of Psychology, 1997, pp. 27– 33

[4] S. Philipp, T. Tretter, and C. Rich, "Research and teaching: Development of undergraduate teaching assistants as effective instructors in STEM courses," Journal of College Science Teaching, vol. 045, no. 03, Jan. 2016.

[5] R. M. Nichols and M. Lupascu, "Undergraduate teaching assistants in Asia: A singapore case study," International Journal of Educational Research, vol. 104, p. 101647, 2020.

[6] A. Decker, P. Ventura, and C. Egert, "Through the looking Glass: Reflections on Using Undergraduate Teaching Assistants in CS1," ACM SIGCSE Bulletin, vol. 38, no. 1, pp. 46–50, 2006.

[7] T. Filz and R. A. Gurung, "Student perceptions of undergraduate teaching assistants," Teaching of Psychology, vol. 40, no. 1, pp. 48– 51, Nov. 2012. 9

[8] P. E. Dickson, "Using undergraduate teaching assistants in a small college environment," Proceedings of the 42nd ACM technical symposium on Computer science education - SIGCSE '11, Mar. 2011.

[9] J. Ryan, "Graduate teaching assistants; critical colleagues or casual components in the undergraduate laboratory learning? an exploration of the role of the postgraduate teacher in the Sciences," European Journal of Science and Mathematics Education, vol. 2, no. 2, pp. 98– 105, 2014. 2

[10] F. Nasser-Abu Alhija and B. Fresko, "Graduate teaching assistants: Motives, difficulties and professional interactions and their relationship to perceived benefits," Higher Education Research & Development, vol. 39, no. 3, pp. 546–560, Oct. 2019. 3

[11] J. W. Colvin and M. Ashman, "Roles, risks, and benefits of peer mentoring relationships in Higher Education," Mentoring & Tutoring: Partnership in Learning, vol. 18, no. 2, pp. 121–134, May 2010. 4

[12] V. Muzaka, "The niche of graduate teaching assistants (GTAS): Perceptions and reflections," Teaching in Higher Education, vol. 14, no. 1, pp. 1–12, Feb. 2009. 11

[13] J. Creswell 2003. "Research design: Qualitative, quantitative, and mixed methods approaches." Thousand Oaks, CA: Sage Publications.

Technical papers

Emulation tool diversity for future engineering education

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***Abstract* — Engineering academia makes use of emulation and simulation i.e software tools. These software tools should evolve to meet the new demands of provisioning of quality engineering education. This requires additional research consideration and is addressed in the presented research. The research proposes the evolution of simulation and emulation tools and describes a model wherein the intelligence is integrated in future emulation and simulation tools used in engineering education and research. The incorporation of intelligence in this case leads to a notion of emulation and simulation tool diversity. In this case, the diversity implies the choice of simulation and emulation tool that meets the learning preferences of an individual. In addition, the research presents a framework wherein the proposed solution executes its function within the environment of a higher education institution. This is done for the cases of a constrained and non– constrained engineering faculty in a higher education institution.**

Keywords – Emulation; Simulation; Computing Modelling; Engineering Education; Tool Diversity;

I. INTRODUCTION

Laboratory and workshop sessions play an important role in Engineering Education. Advances in computing technology have also enabled the use of computing tools, software product and packages in providing engineering education. Examples of such tools in Engineering are ANSYS, FEKO, AGI STK 9, Octave, Scilab, LabVIEW and MATLAB. The tools find applications in system modelling [1], simulation [2], emulation [3] and prototyping [4].

The use of software packages in engineering education brings the challenges associated with software design and development into the domain of engineering education. These important aspects are associated with the details of the graphical user interface (GUI), and the interface layout. The concerned design details influence the ease of using the concerned software by the student studying engineering sciences. Additional factors that also influence student's choice of simulation package is the ease of using the application programming interface (API) associated with the software package being used in engineering education.

In addition, software packages being used in engineering education are being developed by multiple players in the educational technology industry. This often occurs in a pattern where there are pairs of licensed and license free educational software packages. This can be seen in MATLAB (licensed for technical computing) and Scilab (open-source license–free software used for technical computing). The pattern of developing licensed and license free educational software for executing the similar tasks is becoming increasingly popular in engineering education [5]. The increased availability of engineering education software results in more competition among educational technology software product providers.

Furthermore, the increase in the number of education software occurs in tandem with an evolving preference for the use of computing based educational technology among engineering students. It is also important that the educational software meet the preferences of the engineering student in a given context. Some important parameters requiring consideration include: (1) Cognitive Load, (2) Hardware and Software Dependency requirements, (3) Ease of API use. Some of the considered student related parameters are: (1) Age, (2) Handedness Preference, (3) Academic Performance, and (4) Course of Study (within the engineering discipline). The influence of the software use and student associated parameters in delivering excellent engineering education should also be considered. In this case, the engineering education is delivered via the selected engineering education software tool.

The discussion in [6–8] considers the role of software in engineering education. Broo et al. [6] considers the need to realize the evolution of engineering software from the perspective preparing the future engineering graduates for the industry and job market. This is done considering the emergence of new initiatives such as Industry 4.0 and Industry 5.0. Daun et al. [7] identify the role of software as being important in Engineering education. The discussion recognizes the need to provide engineering students with the right tools enabling the selection of the right software. The discussion in [7] recognizes that the engineering education industry takes up the challenge of ensuring that staff are effective in meeting the software requirements of engineering education. Hence, it is important to enable students have the right tools that considers their preferences in engineering software. The dimensionality of the ease of access of educational technology on student preference is considered in [8]. However, the discussion in [6 – 8] has not considered the state of student's mental alertness during the conduct of a session requiring the use of software in engineering education. However, software configuration set– up and layout influences mental alertness and cognitive load as seen in [9–10]. However, the cognitive load is not considered in existing work [6 – 8].

The research being presented makes a main contribution as regards the design of a framework enabling the provisioning of high-quality engineering education. This is also done in a manner that considers the cognitive load.

The paper's main contribution lies in the conceptual design of a framework enabling the selection of education software for engineering students. The selection is done considering the occurrence of visual fatigue as indicator of student's preference for the use of the concerned software. The proposed solution describes a conceptual kernel that utilizes the convolutional neural network as the learning tool for detecting the occurrence of visual fatigue. This information is used to trigger a decision- making process enabling the selection of engineering education simulation software with reduced cognitive load.

In addition, the discussion in the paper proposes the design of intelligent computer educational technology software for providing engineering education. The proposed engineering education software uses the individual's visual inputs to evaluate the mood of the engineering student and researcher. In this case, the proposed engineering education software is deployed with an embedded convolutional neural network (CNN). The CNN provides a suitable framework that can be developed and deployed to enable the software to make an inference on the preference of the software to a concerned student. The presented research also proposes the activation of computing entity, visual (image sensor i.e., web camera) and its integration with the in–session engineering education software. This option in the case when the engineering education software does not have an embedded CNN feature. The CNN has been considered because of its wide appeal for use in computing vision applications [11–14]. The research proposes and presents the computing architecture enabling the selection of the most suitable engineering education software. This selection enables the realization of the goals of the simulation and emulation tool diversity. In addition, presented research describes a domain specific application of the proposed simulation and emulation tool diversity. The concerned domain is that of observing transmission control protocol (TCP). TCP is the dominant transport protocol used over the internet and in communication networks. In this case, suitable enterprise (licensed) and open source (license free) software products have been identified and considered.

The rest of the research is organized as follows: Section II describes the context of the problem being addressed. Section III presents the proposed simulation and emulation diversity. It also discusses the novel engineering education software (the utilized computing educational technology) in the context of the proposed simulation and emulation diversity. Section IV presents the architecture of the proposed solution. Section V describes the case where the proposed framework is applied to the TCP context. The conclusion is in Section VI.

II. PROBLEM DESCRIPTION

The addressed challenge is described in this section. The scenario being considered is one in which there are multiple vendors developing and deploying computing based engineering education technology to the faculty of engineering within a given university. The considered faculty of engineering has multiple and different engineering courses.

The considered engineering faculty has a diverse set of students with varying learning needs alongside their preferences. In the considered scenario, the engineering faculty seeks to make a multi–objective decision in selecting the most suitable computing educational software technology. The criteria involved in the decision making focuses only on enhancing the student learning experience. The relevant criteria being considered in this regard are: (1) Student Volume and (2) Student Preference. In this case, the student volume is the number of students that have been observed to prefer the use of a given computing educational technology and software. The student preference is described by the total number of student usage hours associated with a given computing educational technology and software being used for engineering. In the consideration, the criteria and parameters of the student volume and preference can be obtained from the process of beta testing and deployment phase where deemed necessary.

III. ENGINEERING EDUCATION SOFTWARE

The discussion here is divided into two aspects. The first aspect describes the tool kernel for the considered simulation and emulation tool. The second aspect discusses the integration aspects of the proposed solution.

A. Simulation and Emulation Tool Kernel

The presented research proposes that the simulation and emulation tools should involve and benefit from the incorporation of artificial intelligence. In this case, the evolution of simulation and emulation tools is not limited to artificial intelligence tools that help in writing code and engaging in software development. This is because artificial intelligence features such as IntelliSense in Microsoft Visual Studio [15–16] are common. The use of intelligent tools for determining individual preference for a given tool requires additional consideration.

The proposed simulation and emulation tool comprises sensory input acquisition entity, embedded machine learning program, decision making entity and decision execution entity. The sensory input acquisition entity senses the feeling of the individual when using a given simulation and emulation entity. The embedded machine learning program predicts the mood of the user i.e. student and researcher. This is done without the awareness of the student. Nevertheless, the application makes an ethical use of data. The decision making entity enables determination of action influencing the continued use of the emulation and simulation tool by the user in the given instance. The decision execution entity implements the decision that is the output of the decision making entity.

The components of the sensory input acquisition entity, embedded machine learning program, decision making entity and decision execution entity are the basic components of the proposed simulation and emulation tool. These components are separate and act as additional features that are packaged into the installation file or executable of the associated simulation and emulation software product being used for engineering related education and research.

In the proposed simulation and emulation tool kernel, the installation file and executables comprises three main components. These are the: (1) package and executable file for the simulation and emulation tool, (2) installation file for the novel components i.e activator for sensory input acquisition, machine learning solution, and (3) linker file executable. The linker file executable connects and enables communications between the executable files for the executable, alongside the installed novel components.

B. Integration Aspects

The proposed simulation and emulation diversity paradigm is presented in this section. The simulation and emulation diversity paradigm (SEDP) comprises multiple engineering related courses and modules. The tasks have been pre–determined and scheduled during the process of curriculum development. In SEDP, the computing and engineering educational software are organized in a heterogeneous task specific suite. The scenario being described is in Figure 1.

In Figure 1, given educational software can be found to be suitable for multiple tasks, modules and courses. The courses in Figure 1 are associated with only one engineering programme. As shown in Figure 1, the tasks can be executed on one computing entity or on multiple computing entities. Furthermore, the case in the scenario presented in Figure 1 considers the case of only one engineering programme. Nevertheless, the proposed SEDP can be used in the case of multiple engineering courses. In this case, SEDP is used in constrained and non–constrained engineering faculty contexts.

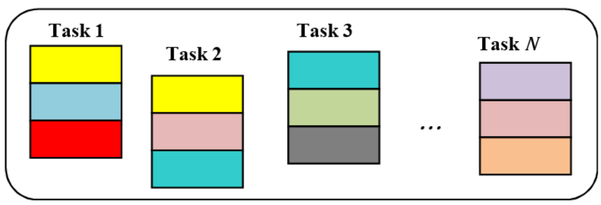

FIGURE 1: *Task–Specific Software in groups.*

The non–constrained faculty context is one in which the concerned higher education institution (HEI) has a significant teaching and learning budget to facilitate the acquisition of different types of learning software for different engineering disciplines. The non–constrained faculty also has significant computing entities and resources to host the engineering education software. The case of the constrained faculty context is one in which the HEI is not able to embark on an extensive acquisition of licensed learning software alongside significant number of computing entities for hosting the concerned software. The use of SEDP in a non–constrained HEI context and constrained HEI context are shown in Figures 2 and 3, respectively.

Figure 2 shows how the non–constrained HEI deploys a large base of computing entities. In this case, different engineering disciplines have been considered. In addition, engineering discipline A makes use of a high performance computing core. The scenario in Figure 3 considers three engineering disciplines. These engineering disciplines use similar software and share similar computing entities. The context in Figure 3 applies to a case comprising engineering disciplines, computing entities and software products.

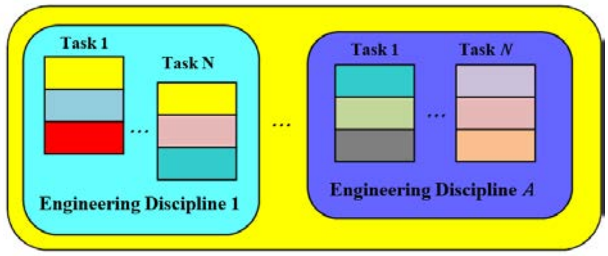

FIGURE 2: *SEDP in the non – constrained HEI context.*

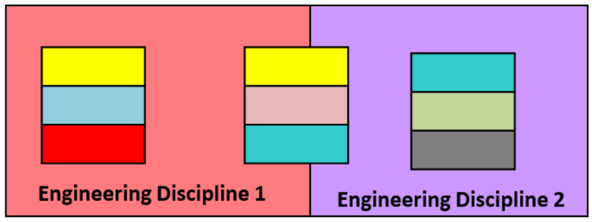

FIGURE 3: *SEDP in the constrained HEI context.*

C. Enabling Architecture

The proposed model of the engineering education software is presented in this section. It is divided into two parts. The first part focuses on the design of the novel engineering education software incorporating the SEDP framework. The second aspect discusses the interaction between components of the proposed novel engineering education software.

D. Novel SEDP Framework

The proposed engineering software acquires user mood inputs, execute inference using acquired inputs, and make decisions. The decision making is associated with the continued use of the software. The proposed solution functions in the Integrated and Non– integrated modes.

In the integrated mode, the engineering education software is equipped with an eye feature acquisition solution. The eye feature acquisition solution makes use of the camera onboard the computing entity. The input in this computing vision system serves as an input to the CNN in the software. This input enables the CNN to make decision enabling the suitability of the concerned software to the student's preferences.

The non–integrated mode comprises engineering education software that does not have a pre–installed CNN and a visual cue acquisition entity. Instead, the proposed solution makes use of third party software. The third-party software is instantiated when the engineering education software is being used and deployed by the individual. In the integrated mode and non–integrated mode, the CNN is used to make individual based mood decisions. The decision in this case is driven by visual input. The use of the proposed solution enables the execution of the following decisions: (1) use of alternative engineering education software and (2) deciding to retrain the CNN in the integrated and non–integrated modes.

E. Component Identification and Relation

The discussion here presents the system architecture for the nonintegrated and integrated solution. The flowchart in Figure 4 considers the nonintegrated and integrated solutions.

In Figure 4, visual fatigue in the student is examined via the camera before the initiation of the proposed solution. This enables the instructor to detect fatigue and tiredness before a session begins. In addition, this helps in ensuring that a false positive as regards the occurrence of visual fatigue is avoided. In addition, multiple engineering education software solutions have an associated cognitive load parameter. This parameter is determined by the concerned developers during the software development process.

The cognitive load parameter is determined by the number of eye movements and pupils observed in developers during software testing during the software development process. A parameter perspective of the cognitive load and its relation to eye movement and pupil dilation can be found in [17]. This is also applicable to the case of the computing software due to the reliance on the eyes as an agent of obtaining input.

The flowchart is operational in the context that the associated cognitive load for each software has been determined by the developer for each software. This is evaluated during the software development process. In this case, the selected and destination software is one having a low cognitive load. The cognitive load can be obtained by using the cognitive load of developers associated with a given product.

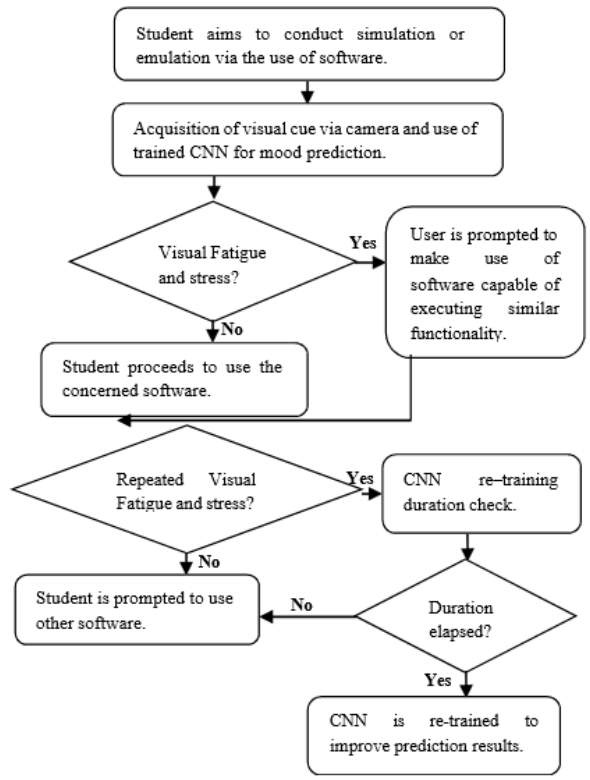

FIGURE 4: Decision making process for the proposed algorithm.

The flowchart in Figure 4 applies to the integrated and non–integrated solutions. However, the role of the flowchart in each of the integrated and non–integrated solutions differ. The integrated solution is accessible and used as a single entity. The single entity comprises multiple sub–entities. These are the: (1) Camera Activation Sub-entity (CASE), (2) Intelligence activation sub–entity (IASE), (3) Decision sub – entity (DSE) and (4) Adaptation Sub–entity (ASE). The relation between these sub–entities for the case of the integrated solutions is shown in Figure 5.

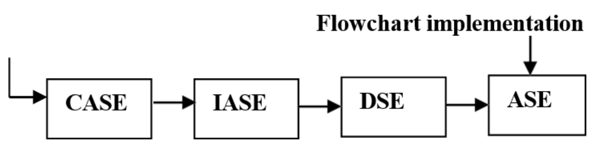

FIGURE 5: Architecture of proposed solution in integrated mode.

In the non–integrated approach, the entities CASE, IAS, DSE and ASE (implementing the flowchart) are also utilized. However, the sub–entities in this case are from different developers and providers. Hence, the communication between them is realized using communication agents. These communication agents enable the realization of inter–operability of the multi–provider components i.e., the CASE, IASE, DSE and ASE is shown in Figure 6.

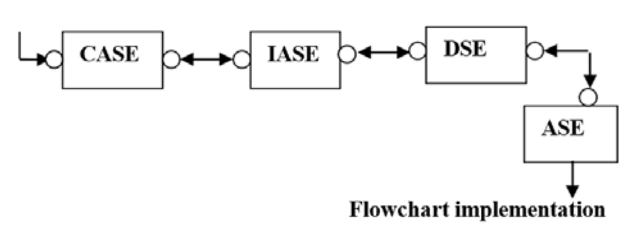

FIGURE 6: Architecture of the solution in non–integrated mode.

F. Software and Student Related Parameters

The use of the proposed framework should consider how given software is considered suitable for the individual. This is done considering the age, handedness preference, academic performance and the course of study. In addition, the availability of software requirements and hardware dependencies alongside the cognitive load is considered. Student details are associated with each use epoch of the engineering education software. These details are acquired in the pre–deployment (beta testing) phase and the post–deployment phase.

The details acquired in the pre–deployment phase are used to determine the suitability of a given engineering education software. The concerned details are the: age, handedness preference, academic performance and the course of study. These details are associated with the student volume and preference. The merge of this data is executed in a database associated with a use context. The database executes a search procedure and determines the best software considering the student's details. This is done given that the computing entity has sufficient hardware and software resources.

In the pre–deployment phase, the suitability of each of the engineering education software for varying student profile is determined. This is done prior to the deployment for formal student use in the higher education institution (HEI). The suitability of engineering education software for different task and student profile is determined. During the beta testing, large number of individuals is provided with a beta version of the concerned software. The individuals provide information related to the student's details and is deemed acceptable due to the increasing use of beta version of the software for product refinement prior to production deployment as seen in [18–20]. The execution of the tasks in the pre–deployment phase enables the realization of insights useful for enhanced software use in the post–deployment phase by the student. The insights acquired in the pre–deployment phase act as data to enable intelligent operation in the post–deployment phase. The pre–deployment and post–deployment phases are specific to each simulation and emulation software package. The insights for each tool are aggregated in a tool cognition engine (TCE). The TCE functions as a cognitive layer enabling pre- deployment to post-deployment phase communication as shown in Figure 7.

The scenario in Figure 7 shows pre–deployment to post-deployment relations. The cognition layer hosts the TCE and the aggregator AG. The aggregator AG comprises a list of insights and shares the content with the simulator selection entity (SSE). The SSE is able to decide which engineering education package (simulator and emulator software) to be selected. In executing this function, the SSE also receives the details associated with the concerned student via the login details on the concerned computing entity i.e. laptop, desktop personal computer, high performance computer or a tablet. In Figure 7, the pre–deployment phase constitutes the exploratory phase. This phase enables the acquisition of data and resulting intelligence that can be used in the deployed system (post– deployment phase). The execution of the processes of exploration, data acquisition and intelligence aggregation are recognized phases in the design of cognitive and intelligent systems [21–23]. Hence, the realization of the proposed solution and framework is feasible.

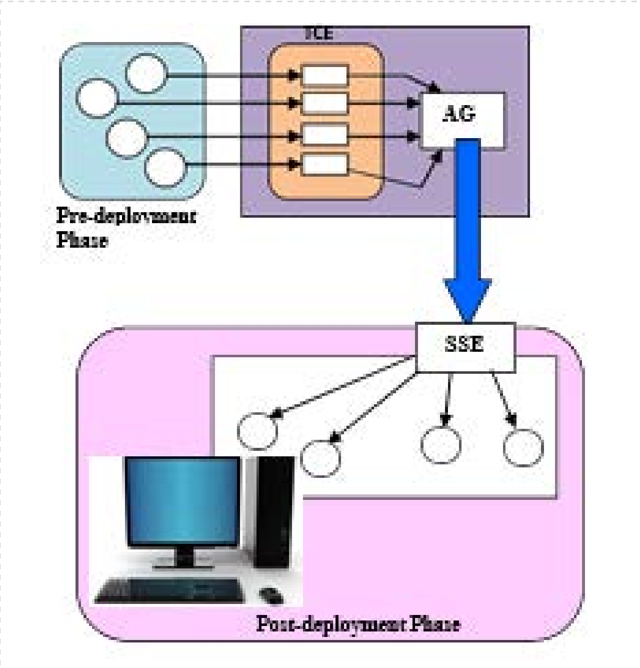

FIGURE 7: Relations between the pre–deployment phase and post–deployment phase in the proposed framework.

IV. APPLICATION TO THE TCP CONTEXT

The proposed framework can be applied in the context of observing the behaviour and performance of the transmission control protocol (TCP). TCP behaviour can be observed in the MATLAB simulation package [24] and in the network simulator–2 (ns–2) [25]. A comparison of the evaluation procedure considering MATLAB and ns–2 using self–defined criteria is shown in Table 1.

The information in Table 1 presents the concept of a teaching capability perspective considering MATLAB and ns–2. A user specific utilization comparison has not been done. This is because of the non–availability of data as specified in the proposed framework. Nevertheless, the comparison in Table 1 shows that the use of ns–2 is more beneficial than MATLAB when TCP–internet protocol (IP) relation observations are important.

TABLE 1: *Comparison of MATLAB and ns-2.*

Criteria	MATLAB [23]	ns–2 [24]
Software Licensing	Licensed	Open Source
Supporting Operating Systems	Windows, Linux	
System Model	Fixed Network Topology with changing conditions	Flexible Topology (Symmetric and Non–Symmetric)
System Consideration	Limited as TCP– IP relations are not considered	Significant as TCP–IP relations are considered.
Communication Network – System Consideration	Limited as interactions with closely relating layers are not considered.	Wide as relations with adjacent layers are considered.

V. CONCLUSION

The discussion in the paper presents a framework that aims to deliver improved education in engineering related courses. The proposed framework considers undergraduate and postgraduate engineering students. In addition, the presented research identifies entities and proposes a computing architecture enabling the realization of the functionality in the proposed framework. The computing architecture considers the case of constrained and non–constrained higher education institutions. In addition, the presented research describes different operational modes that benefits from the inclusion of intelligent capabilities. Future work will focus on data acquisition with the aim of realizing the user diversity and preferences that have been implied in the presented research. In addition, the determination of a suitable learning framework and execution of training using the recognized convolutional neural network will also be addressed in future research.

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REFERENCES

[1] S.Suslov and D.Katalavesky, 'Modelling and Simulation Toolset' in Evolving Toolboz for Complex Project Management, Chapter 19, Oct 2019, pp 417 – 448

[2] F.Cuzma-Rodriguez, A Umaquinga-Criollo, L.Suarez-Zambrano, H.Fernango-Endera, H. Dominguez-Limaico and M. Mediavilla- Valverde, 'Simulation Tools for Engineering Problems. Case Study', International Conference on Applied Tecnologies, 2019, pp 271 – 285.

[3] C.Calcaterra, A. Carmanini, A.Marotta, U.Bucci, and D.Cassioli, 'Max Hadoop: An Efficient Scalable Emulation Tool to Test SDN Protocols in Emulated Hadoop Environments', Journal of Network and Systems Management, Vol. 28, 2020, pp. 1610 – 1638.

[4] T.Devis and M.Manuel, 'Hardware-efficient auto-reconfigurable hearing aids and using 3 level octave interpolated filters for auditory compensation applications', Physical and Engineering Sciences in Medicine, Vol. 44, 2021, pp 785 – 798.

[5] Y.Liu , A. Vijay, S.M.Tommasini and D.Wiznia, 'Hands – on – engineering courses in the COVID – 19 pandemic: adapting medical device desig of remote learning', Physical and Engineering Sciences in Medicine, 2021, 10.1007/s13246-020-00967-z, pp 1 – 6.

[6] D. Gürdür Broo, O. Kaynak, and S. M. Sait, "Rethinking engineering education at the age of industry 5.0," Journal of Industrial Information Integration, vol. 25, p. 100311, Jan. 2022, doi: 10.1016/j.jii.2021.100311.

[7] M.Daun, A. M. Grubb, V.Stenkova, and B.Tenbergen, "A systematic literature review of requirements engineering education," Requirements Engineering, May 2022, doi: 10.1007/s00766-022-00381-9.

[8] E. Corral Abad, M. J. Gómez García, E. Diez-Jimenez, P. M. Moreno-Marcos, and C. Castejón Sisamon, "Improving the learning of engineering students with interactive teaching applications," Computer Applications in Engineering Education, vol. 29, no. 6, pp. 1665–1674, Apr. 2021, doi: 10.1002/cae.22415.

[9] S. Brdnik, T. Heričko, and B. Šumak, "Intelligent User Interfaces and Their Evaluation: A Systematic Mapping Study," Sensors, vol. 22, no. 15, p. 5830, Aug. 2022, doi: 10.3390/s22155830.

[10] A. Skulmowski and K. M. Xu, "Understanding Cognitive Load in Digital and Online Learning: a New Perspective on Extraneous Cognitive Load," Educational Psychology Review, Jun. 2021, doi: 10.1007/s10648-021-09624-7.

[11] D.Bhatt, C.Patel, H.Talsania, J.Patel, R.Vaghela, S.Pandya, K.Modi and H.Ghavyat, 'CNN variants for computer vision : History, Architecture, Applications, Challenges and Future Scope', Electronics, 2021, 10, 2470, pp 1 – 28.

[12] I.H.Sarker, 'Deep Learning: A Comprehensive overview on techniques, taxonomy applications and research directions', SN Computer Science, 2021, Vol. 20, Article No. 420.

[13] G.Mukherjee, B.Tudu, and A.Chatterjee, 'A convolutional neural network – driven computer vision system toward identification of species and maturity stage of medicinal leaves: case studies with Neem, Tulsi and Kalmegh leaves', Soft Computing, Nov. 2021, Vol. 25, No. 3, pp 1 – 20.

[14] A.Esteva, K.Chou, S.Yeung, N.Naik, A.Madani, A.Mothaghi, Y.Liu, E.Topol, J.Dean, and R.Socher, 'Deep Learning-enabled medical computer vision', npj Digital Medicine, Vol. 4, 2021, Article Number 5.

[15] https://devblogs.microsoft.com/visualstudio/ai-assisted-intellisense-for- your-teams-codebase/

[16] https://code.visualstudio.com/docs/editor/intellisense

[17] G. Prabhakar, A. Mukhopadhyay, L. Murthy, M. Modiksha, D. Sachin, and P. Biswas, "Cognitive load estimation using ocular parameters in automotive," Transportation Engineering, vol. 2, p. 100008, Dec. 2020, doi: 10.1016/j.treng.2020.100008.

[18] R.Unseld, 'Alpha, beta, gamma, delta,…', ATZelectronics worldwide, 2021, Vol. 16, No. 3, pp 3.

[19] J.Dabrowski, E.Letier, A.Perini, and A.Susi, 'Analysing app reviews for software engineering: a systematic literature review', Empirical Software Engineering, 2022, Vol 27, 43.

[20] Z.Jiang, K.P.Scheibe and S.Nilakamta and X.Qu, 'The Economics of public beta testing', Decision Sciences, April 2016, Vol. 48, No. 1, pp 1 – 53.

[21] S.Haykin, 'Cognitive Radio: Brain Empowered Wireless Communications', IEEE Journal on Selected Areas in Communications, Vol. 23, No. 2, Feb 2005, pp 201 – 220.

[22] M.T.Cox, Z.Mohammad, S. Kondrakunta, V.R.Gogineni, D.Dannenhauer and O.Larue, 'Computational Metacognition', Proceedings of the Ninth Annual Conference on Advances in Cognitive Systems, 2021, arxiv.org/ftp/arxiv/papers/2201/2201.12885.pdf

[23] H.Schneider, 'Navigation Map-Based Artificial Intelligence', AI, 2022, Vol. 3, pp 434 – 464.

[24] M.Aljubayri, T.Peng, and M.Shikh-Bahael, 'Reduce Delay of multipath TCP in IoT s', Wireless Networks, Vol.27, 2021, pp 4189 – 4198.

[25] J.Huang, S.Wang, S.Li, S.Zou, J.Hu and J.Wang, 'HTPC: heterogeneous traffic – aware partition coding for random packet spraying in data center networks', Journal of Cloud Computing: Advances, Systems and Applications, 2021, Vol. 10, No. 10, pp 1 – 16.

Technical papers

Enabling epistemic transitions by integrating virtual and physical laboratory experiences

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***Abstract* — As engineering students return to their faculties after the pandemic-induced disruption of conventional teaching, there are new opportunities – and a renewed impetus – to get maximum value out of expensive, yet essential, laboratory practicals (LPs). This paper considers the opportunities associated with the integration of virtual practicals (VPs), which were developed as critical supplements during the pandemic, and the traditional LPs typically part of engineering modules. Reflecting on an implementation in an engineering undergraduate control systems module, and through the lens of Legitimation Code Theory, the paper presents the proposed integration as enabling key epistemic transitions - encouraging conceptual and contextual navigation of different forms of knowledge. Drawing from student and lecturer feedback, the paper concludes that the integrated approach shows promise for effective teaching and learning in the post-pandemic era, but that it requires critical consideration and careful planning in the design and presentation of such initiatives, and continuous monitoring of student progress and understanding, to be successful.**

Keywords — Hybrid learning; control systems; laboratory practicals; virtual practicals; Legitimation Code Theory

I. INTRODUCTION

There is increasing pressure on engineering educators to enable students to develop holistic 4th Industrial Revolution (4IR) skills. These are skills required to engage productively in complex problem-solving situations, which include a broad range of stakeholders, dynamically evolving technologies and a triple bottom line ethic: the solution must benefit people, planet and profit [1]. In order to navigate such real-world problem-solving situations, students need to be systematically stretched into more open-ended problem-solving thinking [2]. Industry complaints abound around graduate inability to cope with complexity [3][4], and particularly lament the lack of Science, Technology, Engineering and Mathematics (STEM) technical skills required to tackle Sustainable Development Goals [5].

Engineering Education is concerned with enabling students to build on a foundation of the natural and mathematical sciences as they move into a range of engineering sciences, coupled with tools, technologies and techniques, which are intended to provide solutions for society. As such, training has always sought to bridge theory and practice through the use of available technical resources such as engineering workshops and laboratories. However, as student numbers in tertiary education continue to increase, and technical resources become more sophisticated and expensive, engineering educators are required to be innovative in enabling practical learning that is both viable and successful in enabling students to apply their knowledge in practice. Practicals in fields such as automation are particularly challenging, given not only the expense of appropriate hardware and software, but their rapidly evolving nature. Engineering educators world over have increasingly begun to integrate more affordable simulated or virtual systems to enable students to develop practical skills related to automation and control [6].

The initial hard lockdowns during the COVID-19 pandemic had a significant impact on engineering student practical learning, as entire cohorts could not access laboratories or practical equipment necessary to apply their theoretical learning. Emergency Remote Teaching (ERT) [7] accelerated the need for and development of materials and platforms for remote/online teaching and learning in all aspects of engineering curricula – even for aspects related to the exposure to and engagement with practical problems and applications. A particular challenge for educators was to develop ways in which students could be immersed in real-world type learning opportunities to connect their theory to practice. As engineering students began to return to their faculties in 2022, educators have been in a unique position to consolidate opportunities presented during ERT with new opportunities – and a renewed impetus – to get maximum value out of expensive, yet essential, laboratory practicals (LPs) and the remote/online variants offered during ERT.

Given the reality of massification in tertiary education and the affordances of effective remote/online learning technologies, this paper considers the opportunities associated with the integration of virtual practicals (VPs) – developed as critical supplements during ERT – and the traditional LPs typically part of engineering modules. An "Introduction to feedback control" module, offered at third-year level to mechanical and mechatronic students, is presented as a case study. The paper motivates the value of the proposed integration through the lens of Legitimation Code Theory and the epistemic plane (based on the work of Maton [8], as modified by Wolff [9]). The integration of VPs and LPs supports a strategy to enable epistemic code shifting and stretching, which is deemed a critical step towards a holistic learning experience and developing more effective problem solvers.

II. THEORETICAL & METHODOLOGICAL FRAMING IN CONTEXT

The engineering faculty at a research-intensive institution in South Africa is engaged in funded programme renewal initiatives. Under the Recommended Engineering Education Practices (REEP) banner [10], a number of case studies have explicitly addressed bridging theory and practice from a theoretically informed perspective, most notably through the use of a Legitimation Code Theory (LCT) heuristic called the Semantic Wave [8]: the explicit, iterative and cumulative movement between abstract concepts and concrete contexts [10]. Two key drivers in this context are resource efficiency and supporting scaffolded, deeper learning. Several REEP initiatives see the effective use of affordable and accessible tools or technologies to scaffold student learning, such as the inclusion of pumps and pipes in a competitive group exercise for a fluid mechanics course [11] or stretching student perspectives into real world appreciation of the mining industry through site visits [12].

The focus of this paper is a third year mechanical and mechatronic engineering course on feedback control, typically offered to a class of more than 200 students. Lecturer observations indicate that students struggle with relating control theory to practical application. Control theory relies on mathematical representations and manipulations to support and simplify analysis, but this mathematical abstraction often poses a barrier to the understanding of the mechanisms and implications of realising control in practice. A consequence of this barrier is that even when students pass the module well, they are often not confident in how to implement their learnings in the real world control challenges that they may face in further studies or industry. A strategic approach to teaching and learning is thus required to aid students in overcoming the complexity of the theory and supporting their understanding of the practical application.

The theory informing professional education contexts is essentially the building of increasingly complex concepts over time and, simultaneously, applying these concepts to practical contexts. Shay et al [13] describe this increasing complexity in engineering as 'epistemic transitions' from the natural and mathematical sciences into engineering sciences, which then shift into application, design and management practices using appropriate technologies. At each stage of the epistemic chain there are artefacts that mediate learning, such as texts, tools and stakeholders. Learning across these epistemic transitions, therefore, is accomplished through adopting the Vygotskian

[14] concept of mediated constructivist learning. It is important to differentiate between 'knowledge building' from scratch, as it were, (which is often how constructivism is interpreted) and building understanding by recognising different forms of knowledge at different levels of complexity. Selecting appropriate artefacts to support learning at different epistemic stages is key in professional education.
Legitimation Code Theory offers a set of analytical instruments through which to interpret knowledge practices. The epistemic plane differentiates between concepts and approaches. Simply put, the epistemic plane helps us to see the differences between accepted/ambiguous concepts and fixed/open-ended approaches. In this paper, we use descriptors such as Principles, Procedures, Possibilities and People & Places to identify the different epistemic modes of thinking [9]. Principles are about accepted phenomena and their associated fixed approaches; Procedures are less about a specific phenomenon or concept, but rather focus on fixed methods that could apply to a number of concepts; Possibilities are more open-ended approaches depending on the situation, but where the phenomenon or concept is accepted or specifically determined. The fourth quadrant is People & Places, where there is not a fixed concept or approach; rather, a number of concepts and approaches must be considered. We know from professional problem-solving literature drawing on this plane [9] that effective problem solvers move between fixed and open-ended approaches to concepts ranging from accepted (or standardised) to ambiguous. In other words, they need to think differently at different stages of tackling a particular problem. Supporting cumulative learning [8] means designing opportunities for students to shift between these different epistemic codes or ways of thinking using different mediating artefacts.

Using the epistemic plane, we describe the design and implementation of an initiative to teach engineering students about control using holistically integrated virtual and physical laboratory experiences.

III. IMPLEMENTATION

This section presents a case study of the integration of a VP and LP within an undergraduate control systems module. The rationale behind the integration of the initiatives, the content of the two initiatives and the nature of the integration are discussed.

A. Rationale

The introduction to feedback control module traditionally comprised a theoretical and LP component. With LPs not possible during the pandemic, a VP that replicates the LP setup was developed in an attempt to maintain the practical component of the module [15]. The two initiatives each have advantages and disadvantages. The LP offers exposure to a real world application, but also introduces complexity such as understanding the workings of equipment, discovering limitations to the theory, and the introduction of external effects. The VP, on the other hand, has low specialised equipment cost, is highly accessible, and presents a more controlled environment. However, it lacks the tangible experience of real world applications.

Considering the above-mentioned characteristics, the two initiatives were integrated to offer a scaffolded learning experience. The VP serves as a precursor for the LP, where the theoretical analysis of the problem can be applied in a simplified, simulated environment. Students can then engage with the LP with a better understanding of the problem and appreciation for the implications of real world control applications. To support the intended holistic and integrated learning experience, it is imperative that the integration of two practical initiatives is designed to support the scaffolded linking of theory and practice, and guides the students through the transitions between the abstract and concrete phenomena.

B. Description of initiatives

The initiatives have a two-fold objective: to provide an immersive learning experience that supports students' understanding of control theory, while simultaneously offering exposure to the real world application of the control theory introduced in the module. Specifically, the presented initiatives focus on the position control of a brushless DC motor using Proportional-Integral-Derivative (PID) and compensator based control strategies.

The two control strategies have different requirements that must be supported by the initiatives. PID control implementation is often based on intuition, trial-and-error and experimentation. Compensator controllers require a more analytical approach for describing the system and designing the controller. It is thus important that the initiatives facilitate both the experimental and analytical approaches.

Both initiatives focus on the position control of a DC motor that rotates a steel disc, as shown in Figure 1. The DC motor is powered by means of an H-bridge motor driver and is equipped with a magnetic encoder to provide feedback of the motor's rotation. The system is controlled by a Programmable Logic Controller (PLC), which generates a pulse-width modulated control signal to drive the motor and reads the motor encoder's output through digital inputs.

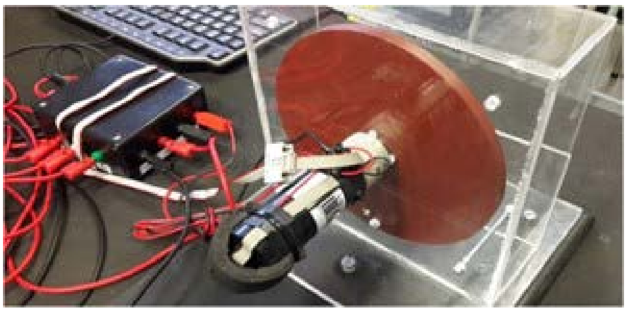

FIGURE 1: DC motor system used in the LP.

The LP was traditionally completed in three phases: system identification (modelling), PID controller implementation and lead compensator controller implementation. Students are guided through the LP by an instruction document for each practical phase and supporting videos, which give background on the system and offer guidance for the setup of practical equipment.

The VP replicates the LP. The VP was developed in MATLAB, using the Simscape library to implement the modelling and visualisation of the motor system and the Simulink library to implement the control of the motor. The Simulink block diagram and the visualisation of the motor's response are shown in Figure 2 and Figure 3, respectively.

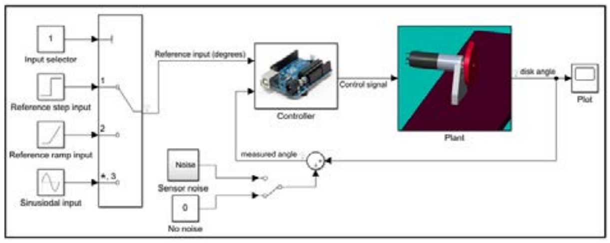

FIGURE 2: Simulink block diagram for the VP.

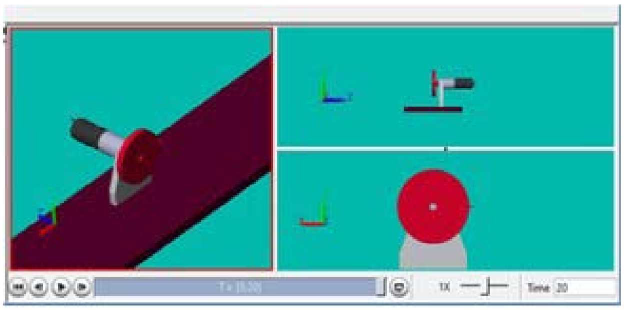

FIGURE 3: VP visualisation of the motor's response.

C. Integration of virtual and laboratory practicals

As mentioned, the aim of integrating the initiatives is to support a scaffolded, holistic learning experience. As such, the discussion of the integration is supported by a visualisation of the integrated initiative's activities on an interpretation of the epistemic plane (as described in section II).

The epistemic plane, which considers the two dimensions of phenomena (ranging from accepted to ambiguous) and procedure (ranging from standardised to open-ended), is visualised in Figure 4, with the four quadrants representing the intended learning objectives: Principles as "Understanding principles"; Procedures as "Applying procedures"; Possibilities as "Identifying opportunities"; and People & Places as "Considering context".

A complexity dimension is added to the visualisation, such that the complexity of a learning activity is indicated by the distance it is located from the origin of the plane (i.e. the further from the origin, the more complex the activity).

The integrated initiative entailed nine activities, which start with VP engagement and progress to LP engagement. The nine activities, which are mapped to the quadrants of the epistemic plane in Figure 4, are summarised as follows:

1. **Students are presented with a real world control problem.** The integrated initiative commences with the introduction of a real world control problem, as detailed in a brief document and supported by pictures and videos of real world examples. The problem is selected to be both familiar and interesting to the students (e.g. a position controller for a camera tracking system or a position controller for a fireboat water cannon).

2. **Students identify the opportunities for implementing feedback control to solve the problem.** The brief further details the requirements that must be satisfied by the developed controller and highlights the theoretical content which the students will have to draw from. Students must thus consider what they have learned from the theory and how that can be applied to the problem.
3. **Students derive a mathematical model representing the physical system.** To support the analysis involved in theoretically designing the control system for the application, a mathematical model of the physical system is derived using well-established modelling principles. However, the derivation entails some simplifications at this stage.
4. **Students design and implement a control system in the VP.** A controller is designed according to theoretical procedures and then implemented in Simulink.
5. **Students visualise and analyse the response of the system in the VP.** The implemented controller is tested in MATLAB (using the Simulink and Simscape tools). The students observe the animated system response and plots of various signals, and tune their controllers to obtain a response that satisfies the application requirements.
6. **Students identify the shortcomings of the VP according to the implications for practical implementation.** At this stage, the students are asked to consider the limitations of the virtual environment, such as the assumption of an ideal actuator and the absence of sensor noise, and the implications thereof for the real world application.
7. **Students perform the system identification in the LP to obtain an accurate mathematical model.** The response of the physical system is captured in experiments and compared to the simulated response of the mathematical model. The parameters of the mathematical model are then adjusted so that the model's response matches that of the real system.
8. **Students redesign and implement the control system in the LP.** Using the tuned mathematical model for analysis, the controller is redesigned and implemented by writing the control code for the PLC digital controller.
9. **Students relate the system's response observed in the LP to the real world context.** At this stage, students must identify the assumptions and limitations of the LP considering the real world application.

Considering the complexity dimension added to the epistemic plane and the plotted learning activities in Figure 4, the scaffolded approach to the integrated initiative is visualised. The intention is to increase the level of complexity with each activity, which results in the spiral mapping of the activities in the epistemic plane. Furthermore, Figure 4 also shows how the initiative transitions between the quadrants of the plane – indicating the different perspectives by which students engage with the problem and the intention to facilitate a holistic learning experience.

The mapping of the activities in Figure 4 provides insight into the characteristics of the two initiatives. The activities related to the VP are mapped closer to the origin, which represents lower levels of complexity. The complexity in the VP is reduced by the controlled simulation environment and the mechanisms to hide complexity from students (e.g. an entire network of function blocks in Simulink can be masked to appear as a single block). In contrast, the activities related to the LP are located further from the origin – representing the complexity of the real world through the presence of external factors (e.g. sensor noise) and the use of equipment (e.g. interfacing with a PLC).

The limitations of the two initiatives, when presented individually, are thus also evident. The VP is limited to simulation and thus in the complexity that can be achieved.

The LP represents an initial complexity barrier for students to overcome in order to effectively engage. As such, the integration of the initiatives can be supplementary and thus result in the scaffolded, holistic learning experience that is desired - a 'spiral pedagogy' [16].

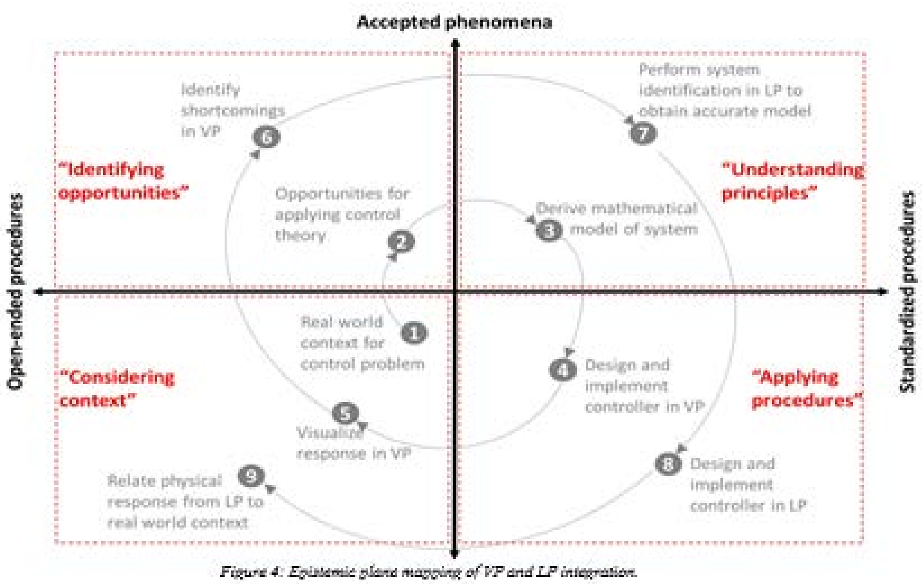

FIGURE 4: Epistemic plane mapping of VP and LP integration.

IV. DISCUSSION

The discussion of the integrated initiative is supported by a consideration of both student and lecturer feedback, and an analysis of the initiative towards refinement and adoption.

A. Student feedback

The integrated initiative was presented as part of the Control Systems module in 2021. The students provided feedback on their experience of the initiative by means of a set of yes/no questions and a field for general text input. Table 1 shows seven yes/no questions and the response from the group of 208 students who provided feedback. An analysis of the feedback – both from the set of questions and the general feedback – provides the following insights:

- Both the VP and LP increased the interest and understanding of the students and the initiatives are considered to be valuable to their learning experience.
- The integration of the VP and LP is considered effective.
- The software used has a significant impact on the effectiveness of the learning activity. While students found the MATLAB tools easy to use (though not without initial facilitator guidance), the majority encountered issues with the software at some point that were not directly related to the VP (e.g. installation, configuration, etc.).
- Students did not always see the "big picture" – i.e. the integration of the two initiatives and the flow of the learning activities, and their relation to the theory.
- Students indicated that time constraints often hindered their engagement, which left them feeling that they could not make the most of the learning opportunities.

B. Lecturer feedback

The lecturer feedback can be summarised as follows:

- It was evident that the students were interested and challenged by the initiative, which led to better understanding of the practical application of control systems in general.
- To enable students to effectively engage with the integrated initiative, very clear communication and guidance is required throughout. The brief and assignment/instruction documents must be clear and concise, must facilitate the transitions between learning activities and between the VP and LP, and must continuously link the practical initiatives to the theory.
- The design and integration of the initiatives requires notable thought, planning and time.
- The presentation of the initiative requires communication and engagement with the students and learning assistants at every step.

C. Analysis

The analysis of the student feedback showed that the integrated initiative was mostly successful in its objective of providing a scaffolded, holistic learning experience. However, there are issues concerning the use of software and the continuous interaction with and support of students throughout the initiative that require refinement. The lecturer feedback confirms that the initiative achieved the objective, but highlighted the challenges of presenting the initiative in terms of the time and attention that is required.

From the feedback, it is evident that the integration of the VP and LP initiatives has merit. While some aspects require refinement, the value of scaffolding complexity and the different perspectives of engagement as facilitated by the integrated initiative is notable.

Further work will focus on the refinement of the initiative and the design of new initiatives of this kind for other topics in the module. The educational perspective, such as the use of Legitimation Code Theory and visualisation of the epistemic plane, will be further explored.

V. CONCLUSION

The paper discusses the opportunities for the integration of VPs and LPs to support epistemic transitions. The paper draws from Legitimation Code Theory and uses the epistemic plane to visualise the integrated practical initiatives from an educational perspective. The integrated initiative consisted of nine sequential learning activities, which transition between the quadrants of the epistemic plane and at incremental levels of complexity. The impact of the integrated initiative is discussed in terms of lecturer and student feedback. The paper concludes that the integrated approach shows promise for effective teaching and learning in the post-pandemic era, but that it requires critical consideration and careful planning in the design and presentation of such initiatives, and continuous monitoring of student progress and understanding, to be successful.

TABLE 1: *Student feedback.*

Question	YES	NO
1. The LP made the module more interesting.	96%	4%
2. The test procedures of the LP improved my understanding of control theory and application.	86%	14%
3. Being able to interact with the virtual system in the VP made the module more interesting.	76%	24%
4. Being able to view the animated response of the VP was very valuable.	78%	22%
5. The VP supports the LP by giving more exposure to practical control application.	79%	21%
6. With the VP, I encountered serious issues with MATLAB.	65%	35%
7. The MATLAB (Simulink) tools are easy to use and improve my interest and understanding.	77%	23%

REFERENCES

[1] Slaper, T. F. & Hall, T. J., "The triple bottom line: What is it and how does it work", Indiana business review, 86(1), 4-8, 2011.

[2] Pott, R. W., & Wolff, K., "Using Legitimation Code Theory to conceptualize learning opportunities in fluid mechanics", Fluids, 4(4), 203, 2019.

[3] Jackson, D., "An international profile of industry-relevant competencies and skill gaps in modern graduates", International Journal of Management Education, 8(3), 29-58, 2010.

[4] WEF, "The future of jobs", World Economic Forum report, 2020.

[5] WEF, "South Africa has a skills shortage. How do we fix it?", World Economic Forum on Africa, May 2016, [Online] Available: https://www.weforum.org/agenda/2016/05/south-africa-skills- shortage-how-do-we-fix-it/

[6] Uyanik, I., & Catalbas, B., "A low‐cost feedback control systems laboratory setup via Arduino – Simulink interface", Computer Applications in Engineering Education, 26(3), 718-726, 2018.

[7] Hodges, C. B., Moore, S., Lockee, B. B., Trust, T., & Bond, M. A., "The difference between emergency remote teaching and online learning", 2020 [Online] Available: https://er.educause.edu/articles/2020/3/

[8] Maton, K., Knowledge and knowers: Towards a realist sociology of education, Routledge, 2014.

[9] Wolff, K., "Insights into conceptual and contextual engineering problem-solving practices in the 21st century: some implications for curriculum redesign", In Proceedings of the 3rd Biennial Conference of the South African Society for Engineering Education, pp. 189-198, Durban: SASEE, 2015.

[10] Wolff, K., Blaine, D., & Lewis, C., "A cumulative learning approach to developing scholarship of teaching and learning in an engineering community of practice", In 2021 World Engineering Education Forum/Global Engineering Deans Council (WEEF/GEDC), IEEE, Nov. 2021, pp. 310-318.

[11] Pott, R. W. M., Wolff, K. E., & Goosen, N. J., "Using an informal competitive practical to stimulate links between the theoretical and practical in fluid mechanics: A case study in non-assessment driven learning approaches", Education for Chemical Engineers, 21, 1-10, 2017.

[12] Dorfling, C., Wolff, K., & Akdogan, G., "Expanding the semantic range to enable meaningful real-world application in chemical engineering", South African Journal of Higher Education, 33(1), 42- 58, 2019.

[13] Shay, S., Wolff, K., & Clarence-Fincham, J., "Curriculum reform in South Africa: more time for what?", Critical Studies in Teaching and Learning (CriSTaL), 4(1), 74-88, 2016.

[14] Kozulin, A., "Sociocultural theory and the mediated learning experience", School psychology international, 23(1), 7-35, 2002.

[15] Kruger, K., Wolff, K., & Cairncross, K., "Real, virtual, or simulated: Approaches to emergency remote learning in engineering", Computer Applications in Engineering Education, 2022.

[16] Han, H. C., "Gamified pedagogy: From gaming theory to creating a self-motivated learning environment in studio art", Studies in Art Education, 56(3), 257-267, 2015.

Technical papers

Integrating game-based learning in an industrial engineering module at a South African university

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***Abstract* — The development of non-technical skills prepares engineering students to adapt to the volatile, uncertain, complex, and ambiguous world we are currently experiencing. Learning strategies that involve learning by doing could enhance the development of such skills. This study explores the impact of game-based learning on improving a deep understanding of technical knowledge and acquiring non-technical skills in a third-year industrial engineering module at a South African University. The paper employs a qualitative research approach using self-reflective inquiry that describes the practical application of game-based learning and the perceived impact on student learning. The study revealed that game-based learning enhances higher-order thinking skills and strengthens teamwork, providing a platform for the social construction of knowledge. This study highlights the value of integrating game- based learning into engineering education. Future studies include conducting a scholarship of teaching and learning project to investigate students' views on game-based learning's impact on their overall experience.**

Keywords — Game-based learning, non-technical skills, industrial engineering, engineering education, action research

I. INTRODUCTION

A. Introduction

The volatile, uncertain, complex and ambiguous (VUCA) world [1] is challenging the status quo in engineering education. Technological disruptions in the industry continuously demand a deep understanding of technical content and developing creativity, critical thinking, problem-solving, and collaboration skills. Furthermore, engineering education should consider shaping how students will behave and engage in the world of work which includes developing mindful, curious, courageous, resilient, and ethical engineers. According to Callaghan et al. [2], game-based learning is increasingly becoming part of engineering education's mainstream teaching and learning pedagogies. Therefore, exploring how game-based learning can enhance students' understanding of technical content and foster the development of non-technical skills is necessary.

B. Context

This study focuses on integrating a web-based business simulation game into Supply Chain Management (SCM), a third-year module in the industrial engineering program at a South African university. One of the roles of industrial engineers is to design, analyze, integrate, and optimize supply chain logistics. In addition, SCM plays a pivotal role in driving organizational competitiveness. Students should have passed operations management, a second-year module in the same program to participate in this module. The module is pegged at National Qualification Framework (NQF) level 7 and is a 12 credits (120 hours) module. Enrolment in the module is averaged at 60 students per year.

The Supply Chain Management module introduces terminology, approaches and techniques in supply chain design and optimization. Furthermore, the module seeks to develop students' competence in applying the acquired knowledge and skills to solve practical and simulated real-world problems. To complete the module, students are expected to: understand core SCM principles concerning practical scenarios and contexts; apply various supply chain problem-solving approaches, methodologies, and tools to solve simple and complex problems; interpret and analyze supply chain scenarios in various contexts; and communicate effectively. The technical content includes an introduction to supply chains, supply chain network design, demand management, inventory management, sales and operations planning and supply chain performance measurement. Traditionally the module has been assessed using tests, assignments, and exams.

To assist students in gaining a deep understanding of important SCM concepts and improve their non-technical skills, the lecturers implemented experiential learning through game-based learning. The Fresh Connection [3], an Inchainge innovative, web-based business simulation game, was integrated into the SCM module from 2019 to date. The Fresh Connection allows students to operate and improve a virtual juice manufacturer to improve profitability [3].

In the game, students are placed into groups of four and assume one of four vice-president roles: supply chain, operations, purchasing, or sales. The students operate the virtual company for six rounds, equivalent to three years of operation, with each round representing six months.

C. Motivation for the Study

Experiential learning enhances a deep understanding of technical subject content and develops students' creativity, critical thinking, problem-solving, and collaboration skills.

However, access to companies for work-integrated learning is limited, especially in developing countries. The COVID-19 pandemic has exacerbated the challenge of in-person learning in companies [4]. Game-based learning [5] has the potential to contribute to mitigating this challenge. Therefore, the exploration of the use of game-based in engineering education becomes significant.

The use of the Fresh Connection game in undergraduate and postgraduate modules is not unique. The integration of the game in the module for this study mimics the typical approach recommended by Inchainge when using the game for teaching and learning. However, the purpose and context of each application in a practical setting provide an opportunity for reflection and investigation. Studies on game-based learning lack empirical reflection on activities such as facilitation, coaching, design, and debriefing [4]. This study could contribute to closing the gap by presenting the lecturers' self- reflective inquiry from their practical experience with game- based learning. Furthermore, our exploration could increase interest in game-based learning by providing lecturers' personal experiences of integrating the game into this module.

D. Study Purpose

This study explores the impact of game-based learning on improving a deep understanding of technical knowledge and acquiring non-technical skills in a third-year industrial engineering module at a South African University. Three research questions guide the study:

1) *How does game-based learning support experiential learning in engineering studies?*
2) *How was the Fresh Connection incorporated into the course design?*
3) *To what extent did the Fresh Connection contribute to the student experience and development of technical and non-technical skills?*

II. LITERATURE OVERVIEW

A. Experiential Learning

Engineering education should provide students with learning environments that encourage a deep understanding of technical content combined with developing non-technical skills such as collaboration, critical thinking, and problem-solving as individuals and in teams [6]. Experiential learning provides students with active learning opportunities through "exploring and experiencing authentic contexts" that allow them to discover through personal experience [7]. Experiential learning can be accomplished in educational, workplace and practice environments. The design of effective experiential learning needs to consider key elements. These include a simulated workplace; exposure to authentic requirements that enhance student employability, interpersonal skills and transition to the workplace; purposeful and meaningful activities; the application of abstract knowledge and skills; self-assessment of performance concerning learning outcomes and reflection and evaluation of the student learning experience [8].

Effective experiential learning enables students to move through all phases of Kolb's experiential learning process, as shown in Figure1 [4, 7, 9].

Learning begins with substantial experience followed by reflective observation, abstract conceptualization, and active experimentation [4, 7, 10, 11]. Experiential learning fosters an iterative learning process and appropriate feedback, which provides students with a "continuous process of goal-directed action" [11]. Ross et al. [5] pointed out that work-integrated learning has been the most common way for students to acquire experience in understanding and applying abstract concepts.

Although game-based learning cannot replace the value of work-integrated learning, it can complement and provide a valuable tool for effective teaching and learning in engineering education. Game-based learning can provide an effective experiential learning environment [4, 7] that enables students to move through all phases of Kolb's experiential learning process [4].

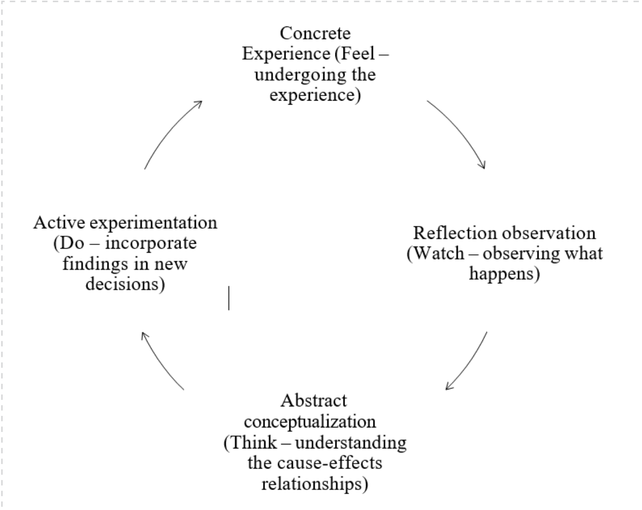

FIGURE 1: *Experiential Learning Cycle [4, 7, 9]*

B. Game-based Learning

Game-based learning allows real-life targeted experiences twinned with pedagogical constructs [5, 10]. Simulations such as business simulation games are designed based on experiential learning, providing an opportunity to integrate gameplay and pedagogy.

Game-based learning provides a learning environment that subjects students to multiple skills [4, 6, 7, 12] and has the potential to enhance student experiences and performance, which could attract more students to enroll in engineering programs [5, 7, 13]. Examples of game-based learning research in engineering education include the use of games to facilitate civil engineering learning and practice [12], support creativity and inspiration for problem-solving [14], enhance students' reasoning, critical thinking and problem-solving skills [6], illustrate systems engineering concepts [5] and incorporate virtual worlds to teach electronic and electrical engineering [2].

According to de Carvalho [10], game-based learning in engineering education can take two forms: addressing specific content related to a knowledge area or developing generic, relevant engineering skills. Game-based learning can present similar characteristics to problem-based learning [12] by requiring students to face novel situations that trigger problem-solving capabilities [11]. Since games can make knowledge accessible, they can be employed to support overall pedagogical aims [5]. In essence, game-based learning supports major learning theories in higher education, such as constructivism, collaborative, experiential, and problem-based learning [7].

Nordstrom and Korpelaine [14] list three conditions for effective learning: active learning by doing, cooperation and teamwork in learning, and learning through problem-solving. Learning by doing, in particular, has been shown to foster creative thinking, reasoning and problem-solving skills [6]. Therefore, game-based learning could provide students with an engaging learning experience through active participation [2, 6, 7, 10, 11] and enhance motivation [5, 7, 10, 12].

De Carvalho [10] argues that game-based learning can also mould personal characteristics that help students to become sound engineers. Non-technical skills such as decision-making, prioritization, negotiation, teamwork, planning and strategic thinking can be developed through game-based learning [10].

A study by Dantas et al. [15] showed that a lack of the ability to apply in theoretical courses such as project management could be due to a lack of teaching and learning strategies that provide an opportunity for learning by experience. Assuming real-life roles and executing duties is regarded as the best motivation strategy for students [15]. Learning and teaching strategies that are content-centric and focus on what to learn can lead to students having challenges in applying the acquired knowledge.

Discussing the failure of Overall Equipment Effectiveness implementation in companies, Bengtsson [16] pointed out that a significant contributor is inadequate competency development caused by abstract knowledge and theoretical based learning, which can make it challenging for learners to apply knowledge in real-world work environments. Game-based learning was suggested as a driver to mitigate these challenges [16].

Therefore, game-based learning enables students to acquire knowledge through applying and consolidating theoretical concepts in real or quasi-real contexts [10]. It also offers a safe learning environment where students can make real-life decisions in a simulated environment without fearing making mistakes with real consequences [5, 13]. Accordingly, game-based learning allows students to experiment and learn through failure and develop management and decision-making skills [15].

C. Game-based Learning in Supply Chain Management

Supply Chain Management (SCM) is a popular module offered in top business schools and engineering programs, such as Industrial Engineering [17]. SCM is a complex subject area that integrates many disciplines and uses qualitative and quantitative tools [17, 18]. Chuang [18] highlighted that the complexity of SCM makes it challenging to facilitate learning in both undergraduate and postgraduate modules.

Johnson and Pyke [17] pointed out that a combination of lectures, case studies and projects facilitates teaching and learning in SCM. However, these approaches can lack practical application due to the complex and abstract nature of the learning content. Chuang [18] noted that web-based computer simulation games noticeably increase students' ability to grasp these abstract and complex concepts in SCM. Examples of games used in the teaching of SCM include responsive learning technologies supply chain [18], the beer game, the Siemens briefcase game and the Llenroc plastics game [17].

III. METHODOLOGY

This study follows a qualitative research approach using a self-reflective inquiry method known as first-person action research [19, 20] to reflect on the practical application of game-based learning and preserved impact on the overall student learning experience. This method is chosen over second-person and third-person action research as it allows the researchers to reflect intentionally and consciously on their intentions and actions and their impact in their context [19]. Self-reflective inquiry allows practitioners to solve problems, improve practices and enhance their understanding of their context [20]. Furthermore, first-person action research provides an opportunity to articulate and critique actions to develop awareness and competence in practice and improve thereon [19, 20].

In first-person action research, the researcher is both the subject and the research participant [19]. Therefore, this study involves the reflective inquiry of two lecturers involved in lecturing Supply Chain Management and integrating the Fresh Connection into the course design between 2019 and 2022. The self-reflective inquiry process required both lecturers to reflect on the integration of the Fresh Connection into Supply Chain Management module using a set of five reflective questions. The lecturers completed the reflective inquiry independently. An analysis of the responses followed this.

IV. STUDY FINDINGS AND DISCUSSION

Table 1 presents an overview of the reflective questions and summarized responses derived from the self-reflective inquiry process. Sections A to E elaborates on the responses to these self-inquiry questions.

***TABLE 1:** Self-inquiry reflection summarized response*

Self-inquiry questions	Summarized responses
What did you want to achieve using game- based learning (the Fresh Connection)?	• Make the learning experience fun and exciting • Improve student learning experience through playing, exploring, and teamwork • Improved student engagement and learning by doing • Apply tools leant (theory) in class to solve real-world problems • See the value of the module in real-world • Development of non-technical skills • Improve student preparedness for the world of work
How did you integrate the Fresh Connection into the course design?	• Students play the game over a period of 6 weeks • Weekly lectures to supplement the game as the rounds increased in complexity • Students to submit a poster after 6 weeks • Lecturer-student debriefing sessions after every round played • Students to formulate a management performance report • Run the study units content and game rounds concurrently • Lecturer and students reflect on the process through feedback sessions, evaluations, discussions and presentations
How did the Fresh Connection contribute to the student learning experience and understanding of Supply Chain Management concepts?	• Increased student engagement and motivation • Application of concepts to a multi-dimensional and rapidly changing scenario • Use of higher-order thinking skills • Social construction of knowledge through teamwork • Interaction, reflection and discussion and direct application of knowledge acquired • Practical and real decision-making opportunity and to see the consequence of their decision
How did you measure the impact of the Fresh Connection on student learning experience and development of non- technical skills?	• Student reflection activities, group assignment • Student informal feedback
What is your personal experience on the Fresh Connection impact on developing non- technical skills and improving the student learning experience?	• Provides student opportunity to interact with non-linear and complex problems which could foster non-technical skills • Students interact and communicate using SCM technical langauge • Student motivation and engagement increased

A. Purpose

The self-reflective inquiry revealed that the Fresh Connection game was integrated into the SCM module to enhance the student learning experience through improved engagement, active learning, and allowing the students to have fun. The lecturers wanted to provide a learning environment where students could apply theoretical tools learnt in class to solve real-world problems and see the module's value concerning the world of work.

B. Integration into the Course Design

The Fresh Connection game was integrated into the module using the model presented in Fig 2. The students played the game for six weeks, and weekly lectures were used to supplement the game as the rounds increased in complexity. Each student group was then required to prepare a poster or management performance report at the end of the module to show evidence of a solid understanding of core supply chain concepts, creativity and effective communication. The assessments linked to the game contributed 45% to the module mark. The authors acknowledge that using assessment can influence student engagement and motivation. Therefore, the game activities contributed significantly to the module mark.

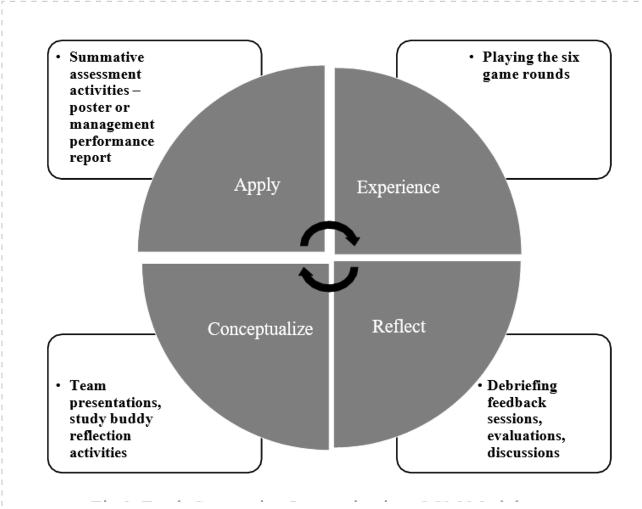

***FIGURE 2:** Fresh Connection Integration into SCM Module*

C. Contribution to the Student Learning Experience and Understanding of Concepts

The Fresh Connection is a business simulation game that links to important Supply Chain Management topics such as supply chain strategy, sales and operations planning, demand management, inventory management, operations management, and supplier management.

Though this was not directly measured, the lecturers' opinion is that the game significantly contributed to students' engagement and motivation, allowing them to grapple with SCM concepts deeper. The game facilitated interaction, reflection and discussion and direct application of knowledge acquired. The game required the application of concepts to a multi-dimensional and rapidly changing scenario in each round of play which also required higher-order thinking skills. Students had the opportunity to make authentic SCM decisions and observe the consequence of their choices.

In addition to providing a fun learning experience, the game required students to work together in teams, which could provide a platform for the social construction of knowledge.

Furthermore, this could allow students to develop non-technical skills such as cross-functional collaboration, negotiation, communication, team development strategies and conflict management.

D. Measuring Fresh Connection on Student Learning Expereince

Though there was no formal study to evaluate students' views on the Fresh Connection's impact on their learning experience, the lecturers observed the game's impact from student reflection activities, group assignments and informal student feedback on their personal experience.

The assessments included questions that prompted students to reflect on their experience with the game. After every round, the students completed a self-reflection activity that allowed them to provide feedback and a personal evaluation of the game. The students also conducted a study- buddy activity where they had the opportunity to discuss the game's impact on developing non-technical skills. Students provided informal feedback on how the game assisted in understanding the application of SCM theory into practice, developing non-technical skills and improving their learning. They further provide insights on personal views on the game and experience and provide suggestions.

There was low student participation in class before deploying the game. However, class attendance significantly improved after the first round and debriefing sessions. Though there was no formal study to ascertain the game's contribution to this, students pointed out how the game motivated them and made them love the module through informal discussions.

E. Development of Non-technical Skills

The game is designed to show students the importance of teamwork and communication skills and a clear strategic vision, processes and procedures that align measures and activities across the game. The lecturers believe that by playing this game, the students developed an appreciation of these skills.

Through participation in the global educator challenge, the lecturers get the opportunity to play the game. The lecturers' experience when playing the game revealed that the game provides an opportunity to interact with non-linear and complex problems that foster the development of non- technical skills such as teamwork, collaboration, agile decision making, and negotiating skills (trade-offs).

Furthermore, through informal feedback sessions and discussions, it was observed that students' SCM technical language improved, and students could apply themselves to real-life problems.

V. CONCLUSION

A. Contribution of the Study

This self-reflective inquiry revealed the importance of game-based learning in engineering education in developing graduates who can practice engineering with competent technical know-how and non-technical or professional skills. Although there was no formal assessment of non-technical skills, the lecturers observed that students' engagement, critical reasoning, collaboration and problem-solving skills improved as the students progressed through six rounds of the Fresh Connection game. The uncertainty in the virtual company performance and increased complexity after each review period fostered students' curiosity, courage and resilience.

Furthermore, the game improved the module design by offering students practical experience in developing their supply chain management knowledge. At the end of the module, students could connect the dots between abstract knowledge and practice. The study confirmed findings in the literature [5, 13] that game-based learning enhances student learning experiences and performance in engineering studies.

Although this self-reflective inquiry study was conducted for a single module in industrial engineering, the findings could be helpful to other engineering education lecturers' contemplating integrating game-based learning in their modules.

The integration of game-based learning aligned the SCM module outcome requirement of developing students' competence in applying the acquired knowledge and skills to solve practical and simulated real-world problems. The study revealed the importance of game-based learning in engineering education. First-person action research inquiry provides a foundation for second-person action research. Therefore, the paper paves the way for empirical inquiry on students' perspectives on Fresh Connection's contribution to their learning experience.

B. Recommendations for Further Work

De Carvalho [10] pointed out that evaluating game-based learning efficiency is difficult. The current study did not consider the formal assessment of non-technical skills developed due to integrating the game. Therefore, further studies could include formulating strategies to measure and assess non-technical skills in the game.

An empirical study on students' views on the game's impact on their overall experience and development of non-technical skills could add value in evaluating the contribution of games in engineering education. The study, therefore, lays a foundation for further exploration of the impact of game-based learning on engineering students. The recommended next step is to conduct a scholarship of teaching and learning (SoTL) project to investigate students' views on the impact of the Fresh Connection game on their overall experience and development of technical and non-technical skills.

REFERENCES

[1] E. Weenk, "Mastering the Supply Chain: Principles, Practice and Real- life Applications," 1st ed., Kogan Page Publishers: London, 2019.

[2] M. J. Callaghan, K. McCusker, J. L. Losada, J. Harkin and S. Wilson, "Using game-based learning in virtual worlds to teach electronic and electrical engineering," IEEE Transactions on Industrial Informatics, vol. 9, no. 10, pp. 575-584, 2012.

[3] Inchainge, The ultimate learning expereince for students in higher education. 2022. [Online]. Available: https://inchainge.com/. [Accessed March 5, 2022].

[4] S.-J. Ho, Y.-S. Hsu, C.-H. Lai, F.-H. Chen and M.-H. Yang , "Applying Game-Based Experiential Learning to Comprehensive Sustainable Development-Based Education," Sustainability, vol. 14, no. 3, pp. 1171, 2022.

[5] A. M. Ross, M.E. Fitzgerald, and D.H. Rhodes, "Game-based learning for systems engineering concepts," Procedia Computer Science, vol. 28, pp. 430-440, 2014.

[6] C. A. Talib, F. Aliyu, A. M. B. A. Malik and K. H. Siang, "Enhancing students' reasoning skills in engineering and technology through game- based learning," International Journal of Emerging Technologies in Learning, vol. 14, no. 24, pp. 69-80, 2019.

[7] N. J. Whitton, "An investigation into the potential of collaborative computer gamebased learning in higher education," Ph.D. thesis, Edinburgh Napier University, Edinburgh, 2007.

[8] George Brown College, Experiential learning and work integrated learning. 2022. [Online]. A v a i l a b l e : https://www.georgebrown.ca/faculty/teaching-and-learning-exchange/academic-support/experiential-learning [Accessed May 10, 2022 10].

[9] J. H. Klabbers, The magic circle: Principles of gaming & simulation, in The Magic Circle: Principles of Gaming & Simulation. 2009. [ebook]. Available: https://www.researchgate.net/profile/Jan- Klabbers/publication/273947293_The_magic_circle_Principles_of_ga ming_simulation/links/574c3d5f08ae8d6e6a7b58e5/The-magic- circle-Principles-of-gaming-simulation.pdf [Accessed April 10, 2022].

[10] C. V. de Carvalho, "Is game-based learning suitable for engineering education?," IEEE Global Engineering Education Conference (EDUCON) Proceedings. 2012. [Online]. doi: https://doi.org/10.1109/EDUCON.2012.6201140 IEEE [Accessed March 23, 2022]

[11] K. Kiili, "Digital game-based learning: Towards an experiential gaming model," The Internet and higher education, vol. 8, no. 1, pp. 13-24, 2005.

[12] M. Ebner, and A. Holzinger, "Successful implementation of user- centered game based learning in higher education: An example from civil engineering," Computers & education, vol. 49, no. 3, pp. 873-890, 2007.

[13] M.T. Soo and H. Aris, "Game-based learning in requirements engineering: An overview," IEEE Conference on e-Learning, e-Management and e-Services (IC3e) Proceedings. 2018. [Online]. Available: https://doi.org/10.1109/IC3e.2018.8632650 [Accessed March 23, 2022]

[14] K. Nordstrom, and P. Korpelainen, "Creativity and inspiration for problem solving in engineering education," Teaching in Higher Education, vol. 16, no. 4, pp 439-450, 2011.

[15] A. R. Dantas, M. de Oliveira Barros, and C.M.L. Werner, "A Simulation-Based Game for Project Management Experiential Learning," Software Engineering & Knowledge Engineering (SEKE) Proceedings. 2004. [Online]. Available: https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.477.2799&rep=rep1&type=pdf [Accessed March 20, 2022].

[16] M. Bengtsson, "Using a game-based learning approach in teaching overall equipment effectiveness," Journal of Quality in Maintenance Engineering, vol. 26, no. 3, pp. 489-507, 2020.

[17] M.E. Johnson, and D.F. Pyke, "A framework for teaching supply chain management," Production and Operations Management, vol. 9, no. 1, pp. 2-18, 2000.

[18] M.-L. Chuang, "A web-based simulation game for teaching supply chain management," Management Teaching Review, vol. 5, no. 3, pp. 265-274, 2020.

[19] D. Coghlan, and M. Brydon-Miller, The SAGE Encyclopedia of Action Research. 2014. [Online]. Avialable: https://methods.sagepub.com/reference/encyclopedia-of-action- research [Accessed March 5, 2022].

[20] J. Marshall, "Living systemic thinking: Exploring quality in first-person action research," Action research, vol. 2. no. 3, pp. 305-325, 2004.

Technical papers

Simulation-supported engineering curriculum

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***Abstract* — This study outlines a systematic approach to simulation-supported teaching and learning across the undergraduate engineering curriculum. Simultaneous use of finite element analysis and computational fluid dynamics tools to visualize and teach mechanical engineering topics and simulation assignments to facilitate learning has been examined in five thermo-fluids courses in the past seven years. The outcomes of the same pedagogical and assessment approaches applied in different courses, using different simulation software, and led by different instructors, demonstrated increased engagement, study time, and ultimately, confidence.**

The significance of this educational method is in bringing the digital engineering process into the curriculum, increasing the time students invest in studying, ensuring access to real-world experiences for all learners, and creating a roadmap for curricular design and assessment easily transportable across science and engineering disciplines. Furthermore, a simulation-based approach to learning does not depend on access to laboratory facilities and funding that can reach a limited number of students. It encourages students' spirit of inquiry and ultimately leads to professional development opportunities beyond the classroom setting.

Keywords — simulation- and inquiry-based learning, FEA, CFD, COMSOL, Ansys Fluent, Assessment

I. INTRODUCTION

Over the last three decades, undergraduate education shifted from teaching to learning and discovery [1-3] with a research-based learning standard, an inquiry-based curriculum, and a culminating capstone experience. In an ongoing effort to couple theory and practice before the senior year, the Carnegie Foundation for the Advancement of Teaching [4] called for moving students from passive viewers to active participants or creators within the engineering field. Experiences that link theory and practice throughout the curriculum, and integration of engineering identity, knowledge, and skills through approximations to practice were identified as two important strategies that help support the goal.

The past thirty years have also been characterized by the explosive growth and democratization of digital engineering tools and devices. Technology has allowed the implementation of new strategies that facilitate student-centric instruction and learning such as simulations, simulation-based games, apps, mobile devices, and virtual environments [5-10]. In the process, for example, the undergraduate mechanical engineering (ME) thermo-fluids curriculum has gone from a lack of support for the use of industrial software [11] to an ABET-recognized requirement that students need to employ modern engineering tools.

Finite element analysis (FEA) and computational fluid dynamics (CFD) have been utilized first for teaching fundamentals and in graduate courses. Subsequently, simulations performed with commercial packages spread from technical electives to senior design projects and lab-based courses. Bhaskaran [12] established an online repository of learning modules for FEA and CFD with Ansys and Fluent, respectively, and reported its use in elective and required lab- based ME courses. Lecture-based courses in the area of thermo-fluids featuring simulations with industrial software started appearing in the 2010s [13-15].

A review of the literature reveals a dearth of studies on early and continued exposure to FEA and CFD. The first to articulate a philosophy of integrating FEA practice throughout the engineering curriculum appears to be Papadopoulos et al. [16]. They advocated for the FEA as a tool in the civil engineering (CE) and ME curriculum. SolidWorks simulation platform was used on a trial basis from Introduction to Engineering to the subsequent mechanics courses. Bruhl et al. [17] integrated SolidWorks into CE sophomore mechanics courses and reported assessment data focused on student opinions about using the software and how they believe it has influenced their learning. Milanovic and Eppes [14] embedded inquiry-based learning (IBL) within COMSOL simulation assignments in the junior year Fluid Mechanics and Heat Transfer course sequence. This work was expanded to include sophomore Thermodynamics I and elective courses [18-19]. Additionally, Milanovic et al. [20- 21] incorporated Ansys Fluent simulation assignments in Thermodynamics I and II [20], and Gas Dynamics [21]. All courses were assessed with surveys that contained both student opinions and time use estimates.

It is apparent that the engineering curriculum has undergone significant changes in the past three decades. However, simulations are yet to be considered its integral part. The resulting issues were effectively summarized by Reffeor [22]: the state-of-the-art is beyond the information being conveyed to students, and students are not learning to explore modern topics with modern tools. This is a decade after the Carnegie Foundation for the Advancement of Teaching [4] called for more opportunities to apply the knowledge to real-life scenarios. Perceived limitations of industrial software as documented in the 90s [11] persist even today: packages require many hours of familiarization and they are not tailored to individual courses.

The state of academic affairs is now juxtaposed with the two recent developments in the military. The Air Force and Space Force announced in 2020 an e-designation for the names of aircraft, weapons, and satellites designed and tested using digital engineering. The new classification is meant to spur the defense industry to adopt advanced computer modeling and simulation, and technologies like virtual and augmented reality [23-25]. In addition, the Space Force vision 2021 is to become the world's first fully digital service. It is now apparent that the new digital engineering process demands a different approach to the curriculum.

Our study outlines the systematic approach to simulation-supported teaching and learning across the curriculum, illustrates its findings with the quantitative and qualitative data obtained in the past two years, and, for the first time, summarizes results obtained over the seven years. Simultaneous use of FEA and CFD tools to visualize and teach engineering topics and simulation assignments to facilitate learning and inquiry were examined in five lecture-based thermo-fluids courses. To the best of the author's knowledge, this is the only study providing time-use data in support of early and continued exposure to FEA and CFD.

The outcomes of the same pedagogical and assessment approaches applied in different courses, using different simulation software, and led by different instructors, demonstrated increased engagement (through the process of creation/simulation), study time (higher than the national average), and ultimately, confidence (while dealing with an open-end design project and research). The significance of our educational method is in bringing the digital engineering process into the curriculum, ensuring access to real-world experiences for all learners, and creating a roadmap for curricular design and assessment easily transportable across science and engineering disciplines.

II. COURSE DESIGN

The most important indicator of student success in any course is time spent studying [26]. Although a general rule of thumb holds that students should study 2-3 hours per week for each unit of credit, pre-pandemic data from the National Surveys of Student Engagement (NSEE) show the average study time of about one hour per week per credit [27]. The NSEE findings also track closely with time-use studies from the late 80s and early 90s [26] and the Bureau of Labor Statistics' American Time Use Survey [28]. Time spent in academic preparation featured slight gains that eventually plateaued (2004-2019), and were probably erased in the years of living with COVID-19. Their cause is still unclear, and educational research can only stipulate that higher expectations, more emphasis on collaborative learning, or wider adoption of new instructional methods were likely contributors [27].

In order to significantly increase time spent studying in lecture-based courses and provide students with opportunities to explore modern thermo-fluids topics with modern tools, Milanovic and Eppes [14] added simulation assignments with the IBL component to the list of student deliverables. The mastery of theory and problem solving continued to be accomplished with in-class activities and self-study, i.e. class time did not support the simulations. Assessment of theoretical knowledge and analytical skills continued to be based on the same number of homework assignments and major exams over the semesters. Simulations were delivered, supported, and graded online with the assistance of Blackboard as a Learning Management System (LMS). While [14] did not provide time use data, students' evaluations of teaching showed that increased assignment load did not adversely affect learners' satisfaction.

We will now compare homework and simulation assignments dealing with a printed circuit board (PCB) thermal management. Problems concerning efficient dissipation of heat within the electronic systems are frequently encountered in the context of the Heat Transfer course. Pen & paper analysis of a PCB produces an electric power dissipation, i.e. a singular number. This analytical approach typically results in students having a hard time connecting abstract formulae and mathematical equations to the real world. Consequently, they may not be able to place a value on the covered material and have an adequate appreciation for its application.

Two simulation assignments related to PCB thermal management are illustrated in Figs. 1-3. Electronic chip cooling is analyzed with different heat sink models and computational approaches, a disk-stack heat sink with an assumed constant convective heat transfer coefficient and air temperature (Figure 2), and a pin-fin heat sink in an air channel (Figure 3).

First, students simulate a board with integrated circuits and a convective boundary condition on the surfaces (Figure 1). The heat diffusion through the board and natural convection are not sufficient to cool the central region which exceeded the maximum operating temperature. When the disk-stack heat sink is added above the central chip the maximum PCB temperature drops significantly (Figure 2). The adoption of a constant convection heat transfer coefficient enables a quick computational solution. However, its accuracy depends on the reliability of the assumption [29-30]. The second simulation assignment features a pin-fin heat sink and an air domain that allows the calculation of the fluid temperature and velocity while assuming nonisothermal flow in the channel (Figure 3). The convection heat transfer coefficient is not approximated; consequently, this is a more accurate approach that will require increased computational time [30]. Simulations like these can easily be tailored to go hand in hand with the theory by showing relevant applications of abstract concepts and enabling a deeper understanding of the course material.

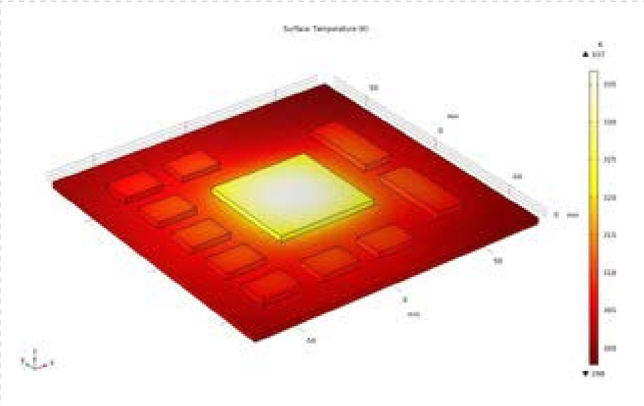

FIGURE 1. Temperature distribution of the PCB without the heat sink.

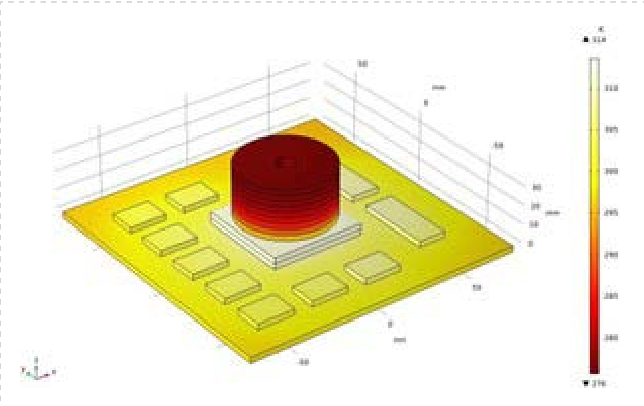

FIGURE 2. Temperature distribution of the PCB after adding the disc-stack heat sink.

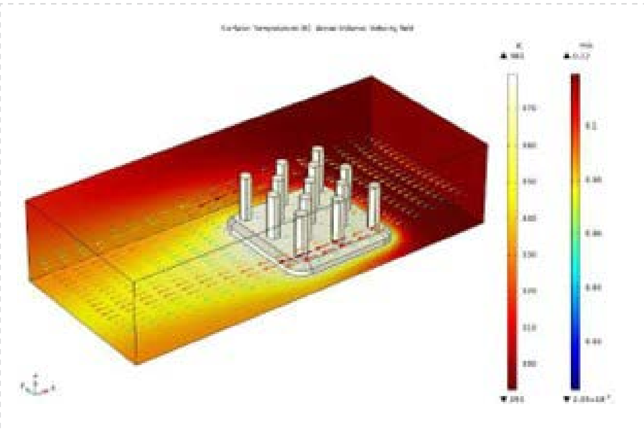

FIGURE 3. The velocity and temperature fields for the case of pin-fin heat sink.

Simulation assignments are designed in the form of project-based learning (PjBL) with an IBL component, thus moving students from structured tasks with step-by-step instructions to unstructured tasks with a research component. The dynamic autonomous learning and development of simulation skills are facilitated with supplementary materials:

- Fluid Mechanics and Heat Transfer simulation assignments feature (1) step-by-step written instructions for structured tasks available from the COMSOL application gallery [31], (2) COMSOL Blogs and relevant industry articles, (3) Discussion Board forums, (4) rubric that looks into the technical content of deliverables and the capacity for IBL (grading criteria), and (5) simulation assignment survey (SAS).
- Thermo I and II, and Gas Dynamics simulation assignments are accompanied by (1) step-by-step video instructions available from Ansys Innovation Courses [32] and Ansys Learning YouTube channel [33], (2) handout with additional information such as theory and some illustrations of the results, (3) mesh file, (4) Ansys Blog and relevant industry articles, (5) Discussion Board forums, (6) grading criteria, and (7) SAS.

The deliverable is the report only, i.e. simulation products are not required. Students are allowed an unlimited number of assignment uploads within the one-week time frame. This provides the learner an opportunity to ask for guidance and improve the report. A strictly observed time limit ensures that all students learn and develop skills at a similar pace.

Students' achievement of course outcomes and their final grades were determined by performance on simulation and homework assignments and three exams. The percentage of the final grade allocated for simulation assignments varies. For a sophomore course such as Thermo I, it was 10%, for junior courses it may be 15-20% pending on the number of simulation assignments and the level of IBL. The SAS submittal was incentivized with 5% of the assignment grade.

It is apparent that the successful design and implementation of simulation-supported courses require four elements: learning method, supporting materials, learning technology, and evaluation method. More details on the course design taxonomy and specific assignments in each of the five courses are provided in [14] and [18-21]. Now we turn our attention to the first comprehensive summary of the outcomes that are illustrated with both quantitative and qualitative data.

III. RESULTS

The focal population of the study were students in the Mechanical, Aerospace, and Acoustical Engineering department at the University of Hartford in the period 2015 to 2022. Simulations assignments were implemented in five undergraduate courses: Fluid Mechanics (2015), Heat Transfer (2016), Thermodynamics I and II (2021), and Gas Dynamics (2022). This sophomore-junior ME (or sophomore-senior Aerospace) sequence is supported by a first-year graphics communication course. The acquired knowledge and skills are further reinforced by senior design and elective courses.

We did not have a control group to compare the quantitative outcomes obtained with and without simulation assignments. The instructors typically teach just one section of the course, and our objective was to provide the same learning experience within the section. Hence, all students performed simulation assignments. The data presented here is sourced from course grades, SAS administered with each assignment and student evaluations of teaching. In addition, the instructor's observations and interviews with students throughout the semester and after the course were used to plan for future assignments and their line-up.

Average final grades on simulations performed with COMSOL and Ansys Fluent are shown in Tables I-II, and III, respectively.

They are all excellent (As) and satisfactory (Bs and Cs). The high success rate is attributed to the detailed grading criteria where most report requirements were accompanied by sample figures, and supported with online materials and mentoring. The typical score on the first simulation is in the 70- 80 range, while the final assignment scores are in the 90s.

All sections were graded by the same instructor, with an exception of Fluid Mechanics in fall 2019 which had a dedicated teaching assistant (TA). The lowest averages are observed for Fluid Mechanics cohorts of 2019 and 2021 signaling that something else other than pandemic or TA influenced the grades.

TABLE 1: *Simulation grades: Fluid mechanics, COMSOL*

YEAR	F21	F20	F19	F18	F17	F16	F15a	F15b
SIM. NO.	7	8	10	10	9	8	6	6
GRADE	75	89	75	86	84	90	84	93

TABLE 2: *Simulation grades: Heat transfer, COMSOL*

YEAR	S22a	S22 b	S19	S18	S17	S16
SIM. NO.	5	5	9	9	9	10
GRADE	92	85	80	90	85	92

TABLE 3: *Simulation grades: Ansys fluent*

COURSE	THERMO I	THERMO I	THERMO II	GAS DYNAMICS
YEAR	F21a	F21b	F20	F21
SIM. NO.	4	4	5	6
GRADE	87	94	90	92

Since the lower scores are always associated with the first simulation, the absence of students attending office hours and the lack of activity on the Discussion Board triggered tutor hires early in the semester. Both tutors were senior students with at least one course with the simulation requirement. However, the same lack of motivation and reluctance to seek help continued to play a role until the end of the semester. Subsequent SAS and student evaluations of teaching showed that students greatly enjoyed simulations that came with step-by-step instructions, but were frustrated with the IBL portion.

The search for the optimal number of simulations and the impact of the pandemic is evident in Tables I-III. Fluid Mechanics assignments went from 6 to 10 in three successive pre-pandemic years. Projects given at the beginning of the semester are not in sync with the material since the properties, fluid statics, conservation laws, and dimensional similarity are covered first. However, visually exciting and relevant simulations keep students' interest throughout the long stretch of the necessary fundamentals. For example, in the first week, students reveal a vortical pattern in the flow that cannot be initially observed. The concept of vortical flows is later on tied with energy losses and drag, both in the class and follow-on assignments.

A Heat Transfer course starts with the definitions of heat transfer modes and introduces the concept of boundary conditions that are immediately used in the simulation assignments. Hence, the number of simulations did not change significantly in the pre-pandemic period.

The pandemic necessitated an adjustment in the students' workload. The authors remained committed to the delivery of the same theoretical material and homework assignments which reduced the number of simulations. In the process, application building that used to be a standard component in Fluid Mechanics and Heat Transfer was removed from the list of requirements.

As indicated before, the [14] offered a proof of concept without the information on the time use. Simulation Assignment Surveys had been administered in all five courses for the past two years to collect the following quantitative and qualitative data on student engagement:

- Students' experiences with developing simulation skills, clarity of the grading criteria, and access to informative supporting materials. The same survey questions and Likert scale (-2 to 2) enable the systematic pedagogical approach and comparison of results;
- The time spent in academic preparation, specifically on simulation and homework assignments;
- Students' comments to further explain and contextualize quantitative data.

Sample survey results are presented in Tables IV-V. The SAS components are mapped to the tables as follows:

1. The assignment was useful in developing my simulation skills (Q1 for brevity)
2. The assignment had clear & detailed grading criteria (Q2)
3. The assignment had informative supporting materials such as Discussion Board, [COMSOL/Ansys Fluent] Materials, YouTube, and Other (Q3)
4. Your comments & suggestions
5. How much time did you spend working on this simulation assignment (Sim-A, hrs)?
6. How much time did you spend working on homework (HW, hrs)?

For engagement analysis (Questions 1-3), a positive average would indicate agreement with survey key constructs, thus enhanced engagement. Students' aggregate levels of agreement reveal that the simulation assignments were useful in developing simulation skills (Q1= +1.5), the simulation had clear and detailed grading criteria (Q2 = +1.3), and supporting materials were informative (Q3 = +1.2). The overall average of all quantitative responses (Q1-Q3) to the SAS in Fluid Mechanics was on par with the results of Wright et al. [34]. Thus, the same pedagogical and assessment approach in different sections of the same course using the same software and led by different instructors yielded similar results.

TABLE 4: *Fluid mechanics F21, COMSOL*

SIM-A	Q1	Q2	Q3	SIM-A (hrs)	HW (hrs)
1	1.2	0.7	0.3	5	1.0
2	1.2	1.3	1.0	3	1.2
3	1.7	1.9	1.6	3.1	1.5
4	1.8	1.5	1.2	2.8	1.6
5	1.6	1.4	1.4	2.2	2.4
6	1.6	1.1	1.4	2.2	2.7
7	1.5	1.2	1.2	2.3	2.4

TABLE 5: *Heat transfer S22, COMSOL*

SIM-A	Q1	Q2	Q3	SIM-A (hrs)	HW (hrs)
1	1.6	1.3	1.1	2.6	1.9
2	1.6	1.4	1.3	2.7	2.4
3	1.4	1.2	1.1	2.1	2.9
4	1.5	0.8	1.2	3.3	3.0
5	1.3	1.0	1.3	2.8	3.0

Time use data (Questions 5-6) enables comparison of study times by the assessment type, course, and finally, with the national average. Students typically spent slightly more time on simulations than on the homework. It appears that the choice of software did not influence time use data. The average number of hours spent on simulation and homework assignments was 2.8 and 2.7, respectively. This corresponds to 1.8 hours per week for each unit of credit and can be as high as 2.1 hours per week per credit (Gas Dynamics). These results obtained during the pandemic are well above the pre-pandemic national average.

Students' evaluations of teaching enabled comparison between the course and the department mean (4.3 in F21 and S22). Course means for Fluid Mechanics, Heat Transfer, and Gas Dynamics sections shown here were 4.7, 4.8, and 5.0, respectively. Students' evaluations of teaching provided insight into students' opinions of the course, especially in the areas of useful information and skills, presentation of the subject, and clarity of the expectations.

Some qualitative comments (Fluid Mechanics, F21) were as follows: *The simulations are a great tool to learn and utilize. It just need some practice and getting used to. It was overwhelming to try to get stuff done; I enjoyed the simulations and the course content; Lots of interactive material, presented in a variety of different ways; The sims were looks into real world applications that kept students engaged and excited for the work in the field; The material was presented in a few different ways, including practical applications through simulation assignments. Knowledgeable professor with added preparation for future courses in the form of simulations.*

It is interesting to observe that the section with the lowest average grade on simulation assignments had such positive and thoughtful opinions. Students understood the importance of simulations for their professional preparation even when the process of obtaining the skill was 'overwhelming,' and the grades were not the best. It is now apparent that our students are learning to explore modern topics with modern tools. They are also able to place a value on the covered material and have a significant appreciation for its application.

The impact of simulations incorporated early and consistently throughout the curriculum is also seen in capstone design and extracurricular accomplishments such as awards, grants, and publications. For example, Robert Galvez (BSME '19, MSME'20) is the first student to be recognized on a national level with ASME Fluid Engineering Division 2020 Graduate Student Scholar Award for a simulation-based technical paper [35]. Jeffrey Severino (BSME'19) presented a simulation app on engineering.com webinar and obtained a NASA GRC summer internship which led to the NASA Pathways Intern Program.

IV. CONCLUSIONS

This study outlines the systematic approach to simulation-supported teaching and learning across the curriculum, and summarizes the quantitative and qualitative data obtained in the past seven years. Engineering theory and practice were successfully linked with simulation assignments in lecture-based courses with students exploring modern topics with modern computational tools. The most important findings from engagement analysis conducted in five courses during the last two years are as follows:

1. The average study time during the pandemic was consistently above the pre-pandemic national average. The SAS did not track the time allocated for assigned readings, review, and test preparation which would further increase the overall average study time.
2. Simulation Assignment Surveys confirm the usefulness of simulation assignments in developing simulation skills with consistently positive aggregate levels of agreement.
3. The student evaluations of teaching had course means above the department mean. Hence, the additional workload did not negatively impact students' perceptions of the course. Students' qualitative comments had a considerable appreciation for the material and its application.
4. The same pedagogical and assessment approach produced similar results in different courses, thus giving other instructors confidence in the use of our educational method.

These results demonstrate that student engagement is improved by introducing simulation assignments and support our advocacy for learning through the process of creation (simulation). Making connections between theory and engineering practice as well as acquiring simulation skills are complex processes. Some posit that students first need to learn how to work with the tool [36]. However, learning through creation is supported by the findings of brain science: thinking does not operate within hierarchies, it happens simultaneously in a variety of places in the brain [37-38]. Our educational approach is the only credible response to the new digital engineering process ushered in the time of information explosion and accelerating rates of technological change.

The significance of our method is in bringing the digital engineering process into the curriculum, ensuring access to real- world experiences for all learners, and creating a roadmap for curricular design and assessment easily transportable across science and engineering disciplines. Furthermore, a simulation- based approach to learning does not depend on access to laboratory facilities and funding that can reach a limited number of students. It encourages students' spirit of inquiry and ultimately leads to professional development opportunities beyond the classroom setting.

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REFERENCES

[1] Boyer Commission on Educating Undergraduates in the Research University, S. S. Kenny (chair), "Reinventing Undergraduate Education: A Blueprint for America's Research Universities," State University of New York – Stony Brook, 1998.

[2] J. E. Froyd, P. C. Wankat and K. A. Smith, "Five Major Shifts in 100 Years of Engineering Education," in Proc. IEEE, vol. 100, no. Special Centennial Issue, pp. 1344-1360, 13 May 2012, doi: 10.1109/JPROC.2012.2190167.

[3] C. Tanenbaum, "STEM 2026: A Vision for Innovation in STEM Education," Office of Innovation and Improvement, US Department of Education, Washington, DC, 2016.

[4] S. D. Sheppard, K. Macatangay, A. Colby, and W. M. Sullivan, "Educating Engineers: Designing for the Future of the Field," Carnegie Foundation for Advancement of Teaching, Jossey-Bass, USA, 2009.

[5] T. J. Benson, "Using Computers in Fluids Engineering Education, ASME Fluids Engineering Summer Meeting Conference," in Proc. 1998 FEDSM, Paper FEDSM98-5135.

[6] T. Sitzmann, "A meta-analytic examination of the instructional effectiveness of computer-based simulation games," Personnel Psychology, vol. 64, no. 2, pp. 489-528, 2011, doi:10.1111/j.1744- 6570.2011.01190.x.

[7] J. A. Chen, S. J. Metcalf, S. J., and M. S. Tutwiler, "Motivation and beliefs about the nature of scientific knowledge within an immersive virtual ecosystems environment," Contemporary Educational Psychology, vol. 39, no. 2, 112-123, 2014, doi:10.1016/j.cedpsych.2014.02.004.

[8] T. A. Grotzer, M. M. Powell, K. M. Derbiszewska, C. J. Courter, A. M. Kamarainen, S. J. Metcalf, and C. J. Dede, "Turning transfer inside out: The affordances of virtual worlds and mobile devices in real world contexts for teaching about causality across time and distance in ecosystems," Tech. Know. Learn., vol. 20, no. 1, pp. 43-69, 2015, doi:10.1007/s10758-014-9241-5.

[9] N. Campos, M. Nogal, C. Caliz, and A. A. Juan, "Simulation-based education involving online and on-campus models in different European universities", Int. J. Educ. Technol. High. Educ., vol. 17, no. 8, 2020, doi:10.1186/s41239-020-0181-y.

[10] O. Chernikova, N. Heitzmann, and M. Stadler, "Simulation-Based Learning in Higher Education: A Meta-Analysis," Review of Educational Research, vol. 90, no. 4, pp. 499-541, 2020, doi:10.3102/0034654320933544.

[11] R. D. Allwright and K. A. Tubman, "The use of computer-assisted learning within undergraduate thermofluids courses," International Journal of Mechanical Engineering Education, vol. 22, no. 1, pp. 69-73, 1994, doi:10.1177/030641909402200109.

[12] R. Bhaskaran, "SimCafe: A Wiki-Based Repository of Learning Modules for Deploying Simulation Technology in Mechanical Engineering Education." in Proc. 2010 ASEE, Louisville, Kentucky, USA, doi:10.18260/1-2—16241.

[13] W. Mokhtar, "Using Computational Fluid Dynamics to Introduce Critical Thinking and Creativity in an Undergraduate Engineering Course," Int. J. Learn.: Annual Review, vol. 17, no. 9, pp. 441-458, 2010, doi:10.18848/1447-9494/CGP/v17i09/47257.

[14] I. Milanovic and T. A. Eppes, "Application Building in Undergraduate Courses with a Simulation Component," in 2016 Proc. ASME HT/FE/ICNMM Conf., vol. 2, Paper AJK2016-7844, Washington, DC, USA, 2016, doi:10.1115/FEDSM2016-7844.

[15] J. Weber, G. N. Facas, M. Horst, and M. Sharobeam, "Using FLUENT to Supplement Theory in an Introductory Fluid Mechanics Course, " Int. J. Hydraul. Eng., vol. 8, no. 1, pp. 11-21, 2019, doi:10.5923/j.ijhe.20190801.03.

[16] J. M. Papadopoulos, C. Papadopoulos, and V. C. Prantil, "A Philosophy of Integrating FEA Practice Throughout the Undergraduate CE/ME Curriculum," in Proc. 2011 ASEE Conf., Vancouver, BC, doi:10.18260/1- 2—17365.

[17] J. C. Bruhl, R. J. Gash, A. Freidenberg, C. H. Conley, and P. M. Moody, "Helping Students Learn Engineering Mechanics Concepts through Integration of Simulation Software in Undergraduate Courses," Proc. 2018 ASEE Conf., Salt Lake City, Utah, USA, doi: 10.18260/1-2—30573.

[18] I. Milanovic, T. A. Eppes, and K. Wright, "Simulation-Based Approach to Science, Technology, Engineering, and Math Challenges," in Proc. 2019 ASME-JSME-KSME Joint Fluids Engineering Conf., vol. 1, San Francisco, California, USA, doi:10.1115/AJKFluids2019-4864.

[19] I. Milanovic, T. A. Eppes, and K. Wright, "Unified Assessment Approach for Courses With Simulation Component [And Professors in Hurry]," in Proc. 2020 ASME FEDSM Conf., vol. 2, doi.org/10.1115/FEDSM2020- 20161.

[20] I. Milanovic, Eppes, T. A., and K. Goparaju, "Digital Assignments for Thermo-Fluids Courses," in Proc. 2021 ASME FEDSM Conf., vol. 3. doi.org/10.1115/FEDSM2021-65613.

[21] I. Milanovic, T. A. Eppes, and K. Goparaju, "e-Designation for Compressible Aerodynamics Course," in 2022 ASME FEDSM Conf., Paper FEDSM2022-86317, In press.

[22] W. S. Reffeor, " Using FEA as a Pedagogical Tool for Teaching Machine Component Design, " in Proc. 2018 ASEE Conf., Salt Lake City, Utah, USA, doi: 10.18260/1-2—31205.

[23] R. S. Cohen. "Air-Force Introduces e-Planes for the Digital Era," Air Force Magazine, 2020. https://www.airforcemag.com/air-force- introduces-e-planes-for-the-digital-era/

[24] W. Roper. "There is No Spoon: The New Digital Acquisition Reality." Defence AR J., Fort Belvoir, vol. 28, no. 4, 488, 2020. https://software.af.mil/wp-content/uploads/2020/10/There-Is-No-Spoon-Digital-Acquisition-7-Oct-2020-digital-version.pdf

[25] N. Strout. "From sci-fi to reality: How the US Space force launched a digital revolution." C4ISRNet, 2021. https://www.c4isrnet.com/battlefield-tech/space/2021/10/11/from-sci-fi-to-reality-how-the-us-space-force-launched-a-digital-revolution/

[26] A. C. McCormick, "It's about Time: What to Make of Reported Declines in How Much College Students Study," Liberal Education, vol. 97, no. 1, pp. 30-39, 2011.

[27] NSEE. "How has Engagement Changed Over Time? Longitudinal Trends: 2004-2019, " 2021, https://nsse.indiana.edu/research/annual- results/past-annual-results/nsse-annual-results-2019/selected- results/longitudinal-trends.html

[28] Bureau of Labor Statistics, American Time Use Survey, 2016.

[29] B. Cunningham, Designing a More Efficient Disk-Stack Heat Sink with Simulation, 2015, https://www.comsol.com/blogs/designing-a-more- efficient-disk-stack-heat-sink-with-simulation/

[30] C. Fairclough, Comparing 2 Approaches for Modeling Electronic Chip Cooling, 2017, https://www.comsol.com/blogs/comparing-2-approaches- for-modeling-electronic-chip-cooling/

[31] COMSOL Application Gallery, https://www.comsol.com/models

[32] Ansys Innovation Courses, https://courses.ansys.com/

[33] Ansys Learning YouTube channel, https://www.youtube.com/c/AnsysLearning

[34] K. Wright, I. Milanovic, and A. Eppes, "The Rise of Simulations in a Junior-level Fluid Mechanics Course," in Proc. 2020 ASEE Conf., doi:10.18260/1-2—35362.

[35] R. Galvez, K. Wright, and I. Milanovic, Using Computational Fluid Dynamics to Analyze Convection in Plasma Pin-to-Plane Discharge. in Proc. 2020 ASME FEDSM Conf., doi:10.1115/FEDSM2020-20244.

[36] M. D. Koretsky and A. J. Magana, "Using Technology to Enhance Learning and Engagement in Engineering," Adv. Eng. Educ., vol. 7, pp. 1-53, 2019.

[37] S. Kagan. "Rethinking Thinking – Does Bloom's Taxonomy Align with Brain Science?" 2005, https://www.kaganonline.com/free_articles/dr_spencer_kagan/289/Rethi nking-Thinking-Does-Bloom-s-Taxonomy-Align-with-Brain-Science

[38] L. Gracey. "Why it may be time to dump Bloom's taxonomy," Technotes: Educational Research, 2021, https://blog.tcea.org/why-it-may-be-time- to-dump-blooms-taxonomy

Technical papers

Engineering education in the Global North and South: A comparative thematic analysis

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Abstract — **A challenge noted by engineering education (EE) researchers in the Global South (GS) is that literature addressing their context specific needs is primarily produced in the Global North (GN). In seeking to gain a better understanding of the literature resources available to support EE in a GS context, this study aimed to: (a) provide a broad-based quantitative overview of differences in representation between the GN and GS in education literature, and (b) to investigate the thematic differences between GN and GS publications in EE literature. A scientometric analysis of education-themed publications was firstly conducted in terms of publication volume and citations with a focus on the GN/GS divide. Secondly, a body of EE literature (consisting of >500 studies selected over a 7- year period for their relevance to the EE context in South Africa) was analysed using the Legitimation Code Theory (LCT) dimension of Specialisation to interrogate the thematic differences between GN & GS. The GS was found to be underrepresented in terms of the volume of education research and research impact. A level of relative parity between GN and GS was revealed in terms of themes studied and a general orientation towards the elite code on the LCT specialization plane. Distinct thematic differences were also observed, such as the GS focussing more explicitly on understanding the challenges at statistical and curricular levels, in contrast to the well-developed GN showcasing innovative learning practices in better-resourced contexts. The thematic comparison may be useful to educators in both the GN and GS. Identifying 'what matters to whom' offers the opportunity for more efficient collaboration based on strengths, so that we as a global community of practice can tackle the challenges of our time.**

Keywords — professional development, engineering education literature, community-of-practice, Global North and South

I. INTRODUCTION

The complexity of engineering practice in the 21st century and well-reported disjunctures between the curriculum and the profession has seen an increase in initiatives to support the development of pedagogical competence [1] in engineering educators. Strategies to aid engineering academic staff range from generic, practical classroom tips and broad theories of teaching and learning (ibid.) to more discipline-specific

This research project was supported by the South African Department of Higher Education & Training – University Capacity Development Grant design-thinking curriculum approaches [2]. The focus of such capacity-building initiatives is to empower engineering academics to adapt to increasingly diverse Higher Education (HE) contexts, larger undergraduate classes, industry demands for improved employability [1] and the rapidly evolving technological landscape [3].

In a marked shift from the focus on academic literacies and practical classroom strategies to support increasing numbers of differentially equipped school leavers entering the HE space [4], academic staff development in the Global South (GS) has become increasingly scholarly [5], drawing on theorised empirical studies to enable a more informed understanding of teaching and learning. However, two challenges face engineering educators in the GS. Firstly, most of the literature addressing their particular curricular, teaching, learning and assessment needs is produced in the Global North (GN), which has not only more resources and published experience, but significantly different contexts. Secondly, engineering educators report finding scholarly discourses and approaches inaccessible [6–8]. It has, for example, been noted that Engineering Education Research (EER) publications originating within the GN, particularly the US, tend to be internally focused rather than global in terms of literature cited [9] suggesting such research may not address context specific requirements of EER in the GS. It is also been found in a review by Matemba and Inglis [10] that the number of studies focused on student success in STEM- based higher education (HE) originating in sub-

Saharan Africa is very limited - especially compared to a vast body of global literature, mostly originating in the GN. [10] They further found that the majority of such sub-Saharan literature originated in South Africa.

To address these challenges, this paper firstly provides a scientometric analysis of education themed publications in terms of volume and citations with a focus on the GN/ GS divide. The aim of this analysis is to provide the reader with a broad-based quantitative overview of differences in representation between the GN and GS in education literature. This paper secondly conducts a more detailed comparative analysis between EER publications from the GN and GS, drawing from over 500 publications (published between 1990- 2020) to investigate the nature of thematic differences in research focus between GS & GN in EER literature. While making no claims for generalisability and acknowledging the GS – and in particular, the South African - context-specific bias behind the purposive selection of literature, we believe a comparative thematic review can contribute to understanding how to *enable scholarly-informed and holistic engineering education in a GS context.* It is hoped that the thematic analysis of these papers can help us to better understand the challenges facing the GS, learn from strategies employed in the GN, and possibly pre-empt trends in EE research.

The rest of this paper progresses as follows: Section II provides background and context to this study with specific reference to the larger project within which this study is located; Section III provides some theoretical background on Legitimation Code Theory, relevant to the classification methodology used in this paper; Section IV discusses the methodology; Section V provides results and Section VI concludes the paper.

II. BACKGROUND & CONTEXT

Based on recent population statistics [11], and using the Brandt-line classification (Fig 1), the GS accounts for approximately 83% of the world's population as of 2021. Despite the majority of the global population residing in the GS and its contribution of key natural and human resources to the wealth and progress of the GN, the GS remains significantly underrepresented in pedagogical research both in terms of research output, i.e., number of publications, and in terms of research impact, i.e., number of citations. The North- South divide represents our first contextual level.

The Brandt-line [12] (Fig 1) was used to make the Global North-South distinction. Despite the various valid criticisms levelled at it as being overly simplistic and possibly outdated, the Brandt-line remains commonly used in social studies literature to illuminate differences between the North and South and has been found to remain valid in terms of certain metrics such as inequality and political dissatisfaction [13].
The study presented in this paper is located at a research-intensive institution in South Africa. The country has been tackling significant post-Apartheid education challenges, withv student success still determined by pre-1994 racial and socio- economic patterns. We have seen the emergence of increasing calls for a decolonial approach to education [14]. In other words, contextually, the institution is located in a national context of calls for the recognition of alternative approaches to the production, recontextualisation and reproduction of knowledge practices. A further contextual factor is the recent global experience of Covid-19 era teaching, which served to highlight the vast disparities between the haves and have-nots [15], particularly with respect to digital and infrastructural resources.

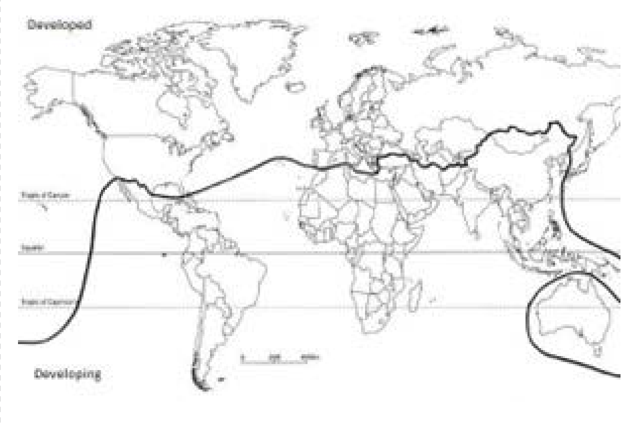

FIGURE 1: *Brandt-line [25]*

The faculty of engineering at the institution in question benefits from University Capacity Development Grant (UCDG) funds to support its Recommended Engineering Education Practices (REEP) project. The project is aligned to institutional strategic professional development goals, and offers a space to build on the formal institutional academic development opportunities, by way of EER projects, community-of-practice development and practice-sharing via case study presentations and publications. The REEP academics have grappled with the key questions of enabling a more resource-efficient approach to engaging students in opportunities for deeper learning, and developing assessment strategies that can meaningfully support such learning. These concerns, together with emerging national questions, have culminated in a more holistic approach to curriculum design and pedagogic practices under the banner of a cognitive, affective and systemic (CAS) educational support strategy [16]. In line with the institutional commitment to enabling more scholarly approaches to pedagogy, the faculty teaching and learning (T&L) advisor had begun to source context- specific literature (reflecting the CAS dimensions) for use in the various continuous professional development opportunities as of 2015. This literature forms the basis of the thematic assessment presented in this paper.

The original purpose of selecting appropriate EE literature for the REEP project was to ensure the provision of accessible and relevant material to support engineering educators in their innovation or research T&L projects, without alienating them or presenting them with typical victory narratives from well- resourced contexts in the GN. The collaborative and theoretically-informed analysis of the South African Society for Engineering Education [SASEE] conference papers in

2019 [17] proved insightful for the increasing numbers of academics engaging in REEP initiatives. A group of REEP researchers subsequently set about reviewing, classifying and analysing the selection of literature from both the GN and GS as a means to expand our field of reference. This body of literature forms the basis of the review presented here.

III. THEORY

Legitimation Code Theory (LCT) [17] extends and integrates certain concepts from Basil Bernstein (particularly his code theory) and Pierre Bourdieu (particularly his field theory). LCT is concerned with the organizing principles that underpin practice and may be applied to a range of fields. *Legitimation codes* refer to the distinct languages – or modes of communication - associated with *'social fields of practice'*[18], which within the pedagogical and research contexts of higher education may be considered as practices associated with certain disciplines. The LCT model has five dimensions: Specialization, Semantics, Density, Autonomy and Temporality – for details of these the reader is referred to [17]. This study's analysis of research literature produced by the GN and GS is focused on the LCT dimension of Specialization which is illustrated in Fig 2., and has been used extensively to analyse different curricula [19], programme types [20], and in the interpretation of Graduate Attributes (formerly called Exit Level Outcomes (ELO) in South Africa).

In any socio-cultural/technical knowledge practice terms, the Specialization plane is useful for differentiating between a knowledge practice which foregrounds either 'knowledge' as the basis of legitimacy or 'knower' attributes/ dispositions, or relations between these. The vertical axis represents epistemic relations (ER), focused on knowledge, and the horizontal axis represents social relations (SR), focused on the knowers [17]. Simply put, any practice is underpinned by a particular kind of knowledge and/or knower disposition. The writing of this paper, for example, demonstrates knowledge of appropriate publication practice (format, argument, references, and so on) as well as the 'knowers' who might read this (the audience in the context of an international conference). This means the writing (a knowledge practice) is strongly orientated towards both epistemic relations (ER+) and social relations (SR+) thereby attempting to demonstrate an *elite code*, as illustrated in Fig 2. In contrast, engineering curricula are ostensibly dominated by 'a *knowledge code*' (disciplinary knowledge areas), while statistical studies on throughput and performance could be viewed as demonstrating a *relativist code*, foregrounding neither specific forms of knowledge nor knower dispositions. It is in the different classroom contexts that we may observe all the codes at work, with the more student-centered and professional skills pedagogies revealing a greater *knower code*.

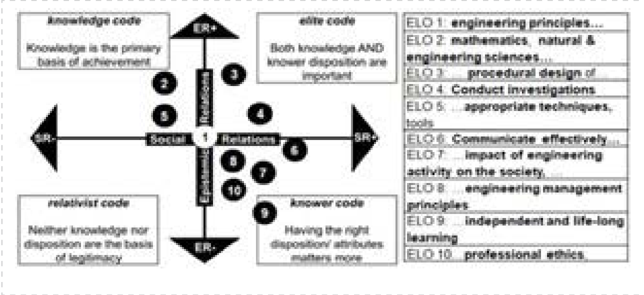

FIGURE 2: *LCT Specialization Plane*

The Specialisation dimension has been used to quantify (and qualitatively discuss) the primary orientation of the different SASEE papers [17] according to whether the focus was predominantly knowledge, knower, both or neither. Similarly, it has been used to map the International Engineering Alliance graduate competencies [21] to the four different quadrants on the plane, as part of a curriculum development initiative. Using this plane, the SASEE publication study revealed i) a predominant focus on 'knowers', ii) increasingly rigorous, scholarly approaches to understanding engineering education (EE), and iii) limited focus on the nature of engineering disciplinary knowledge and implications for curriculum. The study also highlighted significant shifts in the South African EE community focus over the decade from quantitative statistical studies to the integration of technologies and increasing interest in broader professional development.

While the SASEE paper marked an important step in a more context-specific approach to capacity building, globalisation demands that educators take a bigger picture view of developments in their disciplinary and pedagogical fields. Accordingly, publications sourced by the REEP group represent literature that enables insights into engineering education themes such as large classroom contexts, foundational support strategies and the resource-efficient integration of technologies.

IV. METHODS

The classification of studies used in this paper was based on the geographic location of the lead author's affiliated research institute. A scientometric analysis of education themed publications between the GN and GS was firstly conducted to gain a broad overview of how the North-South divide is expressed within this context. Our analysis was based on Scopus publication data gathered by and available from SCImago Journal & Country Rank [22]. From the SCImago Journal & Country Rank website, the annual statistics for academic publications dealing with 'education' (i.e., number of publications, citations, etc.) were downloaded for each country for the period 1996-2021. The category 'engineering education' was not available on the SCImago platform, however the use of general 'education' publications in this analysis is deemed acceptable for the purposes of gaining a broad overview of the GN/GS divide, as intended. We further acknowledge that bibliometric indicators – i.e. number of citations - are viewed as inadequate indicators in different socio-economic contexts [23], but they remain widely used as indicators of research impact and, as such, were deemed acceptable for our purposes.

TABLE 1: Classification of themes, LCY specialization codes and search terms

Theme/ Sub- theme	LCT Specialisation	Search Terms
Curriculum	Knowledge	Curriculum design; Extended degree; Course/curriculum review
Teaching	Elite	Large class; Flipped classroom; Connecting theory & practice; Contact time; Framing; Teaching strategy; Staff development;
Learning	Elite	Peer learning/teamwork; Online learning; Deep vs. surface; Project-based; Experiential; Mastering practice/assessment preparation; Learning styles; Learning spaces; Sample answers; Self-regulated learning; Active learning
Assessment	Knowledge/ Relativist	Formative; Continuous and flexible; Computer- based assessment; Teamwork/Peer assessment; ECSA ELO; Crib notes; Programme admission/predicting performance; Plagiarism; Learning taxonomies; Summative
Engagement	Knowers	Surveys; Contact sessions; Student's views; cooperative and problem-based education; Recipience
Resources	Relativist	Access to information/media/internet; classroom capacity;
Support	Elite	Tutor programmes; Review sessions/supplemental instruction; Language and literacy; Staff development
Technology	Knowledge	Digital teaching assistants; Online/computer- based learning systems; Classroom engagement; Videos; Social media; Gaming systems
Eng. Practice	Elite	Practical application; Design; Setting context; ESCA Outcomes;
Eng. Profession	Elite	Graduate attributes; Workplace dynamics; Interdisciplinarity; Industry engagement;
Eng. Knowledge	Knowledge	Mathematics; Physics; Chemistry; Dynamics; Design; Computer Science; Theoretical/Subject Specific; General Knowledge
General	Not Included	Engineering profession; Academic pathway; Success rate; Community outreach; Motivation
Soft Skills	Knower	Holistic development; Language, literacy and communication; Teamwork & Undergraduate Management skills
First years	Knower	Integration and adaption
Identity	Knower	Race; Gender; Culture; Diversity; Self-efficacy; mental health;

The second part of our analysis considers a selection of publications gathered over a period of seven years by the T&L advisor along with several research assistants and collaborating academics. Selected publications are available via Google Scholar and institutionally accessible electronic databases and were identified using the search terms indicated in Table 1. These search terms represent primary REEP concerns around resources, large classes, deep learning strategies and assessment practices. A shared online spreadsheet system was set up, noting all search criteria and results. Each paper that addressed the key REEP concerns and was deemed relevant to our context was downloaded, and its details were added to the master EE library spreadsheet. This spreadsheet has been available to all the faculty engineering educators since 2017 for ease of access to literature to support their research and innovation proposals and EE writing.

When considering the geographic breakdown of these selected conference and journal publication, 274 publications originate from GN and 259 from GS (ranging from as early as 1990 until 2021). In the GN, literature sampled from the US (38%), continental Europe (17%), UK & Ireland (15%), Australia (9%), and Canada (5%) constitute approximately two-thirds of the literature reviewed. In the GS, South Africa constituted approximately 86% of studies considered, given their context-specific relevance to the REEP group. Effectively speaking, all these resources were partially accidental and pragmatic, but represented both the GN & GS. The subsequent thematic analysis presented in this paper arose as part of the need to manage the resources efficiently and enable thematic accessibility for the growing community of practice.

Papers were analysed for key themes and sub-themes relevant to the faculty REEP focal areas. Each publication was thereby classified according to a singular main theme, as seen in Table 1 and, if appropriate, multiple sub-themes. Subsequently, publications were combined into broader categories with an overarching 'soft-focus' thematic coding using the LCT Specialisation codes [17]. As such, the theme of assessment, for example, could see a relativist breakdown of statistics such as pass rates or grades. However, for the most part, the selected papers imply the assessment of knowledge areas and associated processes/strategies. In other words, many of the search criteria papers could manifest as dual/multiple codes. However, the dominant orientation of the papers in any given theme has been used in the Specialisation coding.

It should finally be noted that, as the papers that form part of this review were not selected randomly but purposively, a certain sampling bias is acknowledged. However, due to the large sample size of papers considered, and because the thematic and LCT classification applied in this article were not considered as part of the sampling process, but rather emerged after the fact, we deem this sampling bias to be acceptable and that our results notwithstanding provide a reasonable representation of the thematic and LCT specialization code differences in engineering education literature between the GN and GS.

V. DISCUSSION OF RESULTS

A. North-South Classification and Scientometric Analysis

From Figure 3 (top) we see that the GN remains dominant in terms of the number of education focused scholarly publications produced whilst also showing continued strong growth. Figure 3 (top) also shows, as depicted on the secondary axis, that the fraction of education focused literature produced by the GS has been growing – especially since the early 2010s. When considering citations as a proxy for research impact, we see from Fig 3 (bottom) that the GS remains strongly underrepresented. Publications from the GS are cited significantly less than those from the GN, though, as with the volume of publications, an increasing trend is seen in terms of the proportion of citations going to papers from the GS. Considering the GS's significantly larger population, as noted earlier, it is thereby clear that the GS remains significantly underrepresented both in terms of the volume of research output and representation.

B. Thematic and LCT Specialization Analysis

As seen in Figure 4 (top), it was found that the GN placed a significantly greater focus on Learning (Δ9.6%) and Engagement (Δ6.1%). The GS in turn placed greater focus on Curriculum (Δ7.5%), Soft Skills (Δ6.2%) and General (Δ 5.3%). Generally speaking, however, the thematic focus was found to be fairly similar between the North and South- i.e., less than 4% normalized difference was observed for the majority of thematic categories considered.

When including subthemes, as seen in Fig 4 (bottom) an even greater level of normalized parity was observed for the majority of thematic categories with two significant exceptions: the GN greater focus on Learning remained prevalent (7.2%) whereas the GS placed a greater focus on Resources (8.6%) – which may be understandable considering the socio-economic circumstances that remain prevalent in the GS.

The outcome of the LCT Specialisation analysis is shown on the polar-plot in Figure 5, where the values on the x-axis represent the percentage of reviewed studies classified according to each LCT Specialization code. Figure 5 reveals that the GS has placed a marginally greater focus on the Relativist (neither knowledge nor knower, rather quantitative or systemic foci) and Knowledge quadrants, while the GN has placed a greater focus on the Elite quadrants with a level of comparative parity for the Knowers quadrant. We suggest the marginally greater Knowledge focus in the GS is as a result of the attempts to understand the implications of curriculum shifts and poor student throughput over the past two decades [20]. Furthermore, the Relativist focus, in the South African context in particular, is a result of HE management grappling with persistently poor retention and throughput, which has a significant impact on potential economic growth, as reported across the BRICS (GS) countries [24].

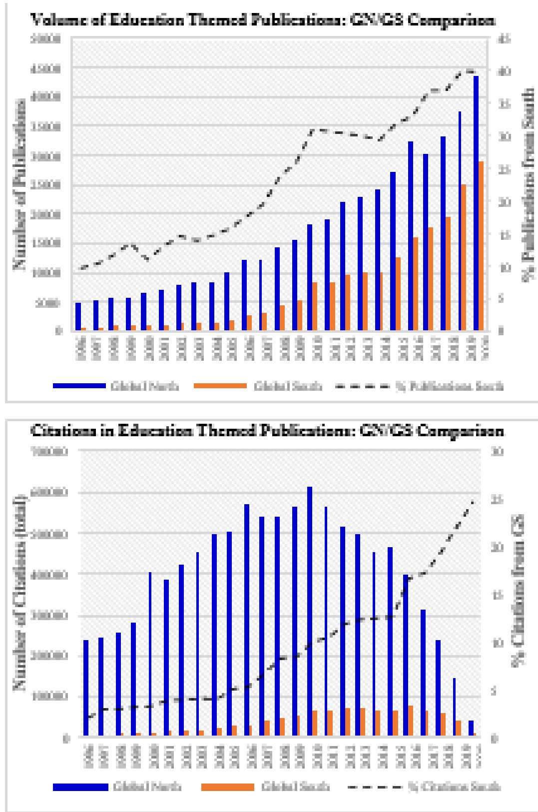

FIGURE 3: Number of Education themed publications (top) and total citations (bottom) by the Global North and Global South. Source [22]

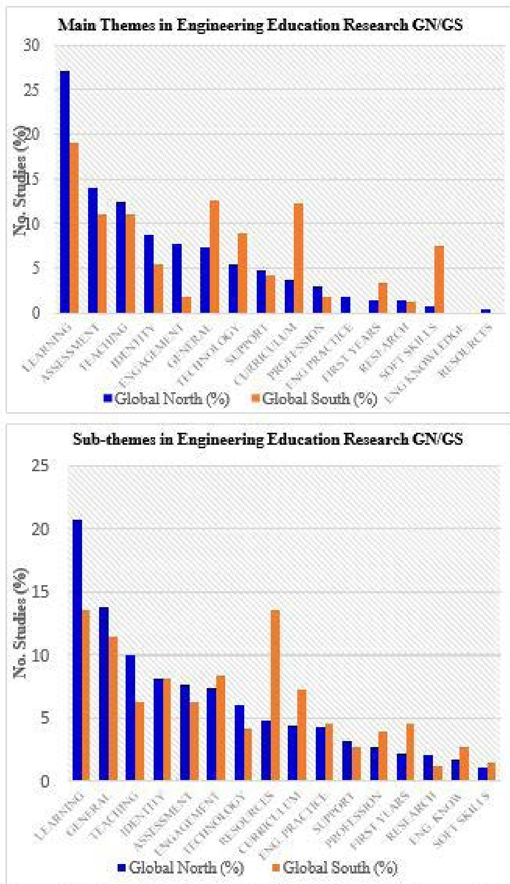

FIGURE 4: Primary theme (top) and sub-theme (bottom) differences in engineering education literature between the Global North and South

VI. CONCLUDING COMMENTS

A significant challenge faced by engineering education researchers in the GS is sourcing literature addressing their context specific needs in a space dominated by GN outputs. The study in this paper aimed to: (a) provide the reader with a broad-based quantitative overview of differences in representation between the GN and GS in education literature generally – thereby seeking to establish an empirical basis for a growing need to address this imbalance, and (b) to investigate the thematic differences between GN and GS publications in EER literature specifically.

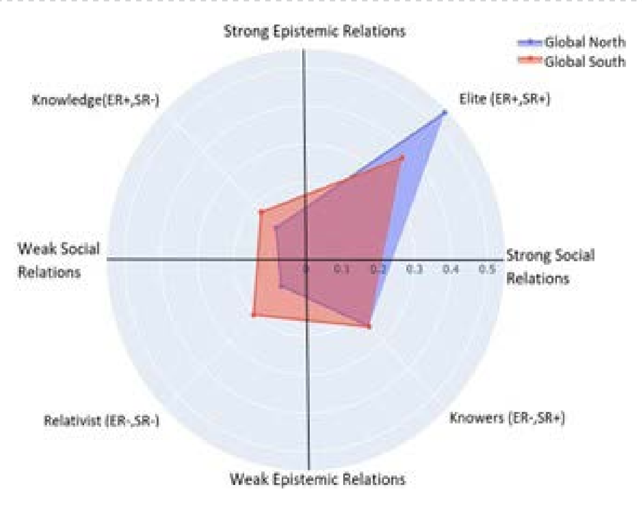

FIGURE 5: *Analysis of LCT Specialization Codes in engineering education literature between the Global North and South*

It was found that the GS remains underrepresented in education literature, both in terms of volume of publications and citations – especially within the context of its larger demographics. The comparative analysis of the research themes and associated LCT specialization codes in EER literature published by the GN and GS has revealed a level of relative parity in terms of themes studied and a general orientation towards the elite code on the LCT specialization plane. This bodes well for the increased focus on both knowledge and knowers as the basis of a potentially holistic engineering graduate. It is further encouraging to note that there is a general alignment of research interests between the GN and GS. The North's even greater focus on the elite code offers the opportunity for the GS to learn from and adapt possible approaches. The somewhat greater focus on the relativist LCT code in the South, specifically on resources, support and engagement amidst increasing financial constraints and massification, may offer lessons for an increasingly diverse GN.

This paper does not seek to preference the approach to EER as followed by the GN or GS. If seeking to interpret these results within the classical framing of the South as 'lagging-behind', we suggest that the GS has grappled with challenges in innovative ways that may well benefit EER in the GN. Similarly, simply seeking to 'follow' the GN fails to consider the structural differences that remain prevalent between the GN & GS, and of which one should remain cognisant [24]. Finally, we collectively bear the responsibility for global challenges: identifying 'what matters to whom' offers the opportunity for more efficient collaboration based on strengths, so that we as a global community of practice can tackle the challenges of our time.

REFERENCES

[1] C. Winberg, M. Bramhall, D. Greenfield, P. Johnson, P. Rowlett, O. Lewis, J. Waldock, and K. Wolff, "Developing employability in engineering education: a systematic review of the literature", Eur. J. Eng. Educ. 45 pp. 165–180, 2020.

[2] A.B. De Magalhães, M. Estima, and B. Almada-Lobo, "PUKHA: a new pedagogical experience", Eur. J. Eng. Educ. 32 pp. 711–719, 2007.

[3] R.M. Felder, "Engineering education: A tale of two paradigms", Shaking Found. Geo-Engineering Educ. pp. 9–14, 2012.

[4] B. Leibowitz, and V. Bozalek, "Access to higher education in South Africa", Widening Particip. Lifelong Learn. 16 pp. 91–109, 2014.

[5] K.E. Wolff, Enabling Access To Scholarly Engineering Education Practices, in: G. Young (Ed.), Acad. Dev. Its Pract., SUN Press, 2022: pp. 209–229.

[6] L. Auret, and K.E. Wollf, A control system framework for reflective practice: Design-based research applied to process control teaching, in: 2018 IEEE Glob. Eng. Educ. Conf., 2018: pp. 100–108.

[7] C. Winberg, H. Adendorff, V. Bozalek, H. Conana, N. Pallitt, K. Wolff, T. Olsson, and T. Roxå, "Learning to teach STEM disciplines in higher education: a critical review of the literature", Teach. High. Educ. 24 pp. 930–947, 2019.

[8] A.L. Porter, J.D. Roessner, S. Oliver, and D. Johnson, "A systems model of innovation processes in university STEM education", J. Eng. Educ. 95 pp. 13–24, 2006.

[9] B. Williams, P.C. Wankat, and P. Neto, "Not so global: a bibliometric look at engineering education research", Eur. J. Eng. Educ. 43 pp. 190–200, 2018.

[10] H.M. Inglis, and E. Matemba, "Starting the conversation with African engineering educators about student success", Proc. REES AAEE 2021. 2021. https://aaee.net.au/wp-content/uploads/2021/11/REES_AAEE_2021_paper_362.pdf.

[11] H.R. Max Roser, and E. Ortiz-Ospina, "World Population Growth", Our World Data. 2022.

[12] W. Brandt, North South: a programme for survival; report of the Independent Commission on International Development Issues, MIT, Cambridge, MA, US, 1980.

[13] N. Lees, "The Brandt Line after forty years: The more North-South relations change, the more they stay the same?", Rev. Int. Stud. 47 pp. 85–106, 2021.

[14] M.N. Hlatshwayo, and I. Alexander, ""We've been taught to understand that we don't have anything to contribute towards knowledge": Exploring academics' understanding of decolonising curricula in higher education", J. Educ. (University KwaZulu- Natal). pp. 44–59, 2021.

[15] L. Czerniewicz, N. Agherdien, J. Badenhorst, D. Belluigi, T. Chambers, M. Chili, M. De Villiers, A. Felix, D. Gachago, C. Gokhale, and others, "A wake-up call: Equity, inequality and Covid-19 emergency remote teaching and learning", Postdigital Sci. Educ. 2 pp. 946–967, 2020.

[16] K. Wolff, A.H. Basson, D. Blaine, and M. Tucker, Building a national engineering educator community of practice, in: Proc. 8th Res. Eng. Educ. Symp. Cape Town, South Africa, 2019: pp. 10– 12.

[17] K. Maton, Knowledge and Knowers, London and New York, 2014.

[18] K. Maton, “A TALL order ? Legitimation Code Theory for academic language and learning”, 8 pp. 34–48, 2014.

[19] L. Carvalho, A. Dong, and K. Maton, “Legitimating design: A sociology of knowledge account of the field”, Des. Stud. 30 pp. 483–502, 2009.

[20] S. Shay, “Curriculum reform in higher education: a contested space”, Teach. High. Educ. 20 pp. 431–441, 2015.

[21] International Engineering Alliance, “Graduate attributes and professional competencies”, Version 3. 2013.

[22] SCImago, “SJR — SCImago Journal & Country Rank [Portal]”, n.d. https://www.scimagojr.com/index.php (accessed May 2, 2022).

[23] H. Confraria, M.M. Godinho, and L. Wang, “Determinants of citation impact: A comparative analysis of the Global South versus the Global North”, Res. Policy. 46 pp. 265–279, 2017.

[24] V. Chang, Y. Chen, and C. Xiong, “Dynamic interaction between higher education and economic progress: a comparative analysis of BRICS countries”, Inf. Discov. Deliv. 2018.

[25] Jovan.gec, “The Brandt-line”, n.d. https://creativecommons.org/licenses/by-sa/4.0/?ref=openverse.

Technical papers

Positioning an integrated engineering education unit within a School of Engineering in the South African context

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***Abstract* — The coronavirus (COVID-19) pandemic has reemphasised the potential importance of having a unit or a formal structure that supports engineering students and faculty. Maintaining the integrity of teaching and learning during the pandemic necessitated collaboration, new skills, and new ways of thinking, for which many universities and faculties were unprepared. It is proposed that an Engineering Education Unit (EEU) would be able to facilitate new learning and thinking, an integrated view of collaboration and exploring new technologies. Therefore, this position paper provides a case for the establishment of an EEU and was aimed at answering the following research question: How can we position the integration of an Engineering Education Unit in South African universities which do not currently have such a formal structure? As a result, this paper aims to position how Engineering Education Research (EER) and engineering education practice can be integrated rather than separated. Furthermore, the scholarship of Engineering Education (EE) presents itself as an exciting space for collaborative thinking between engineering education scholars, engineering practitioners and engineering students. The researchers center their argument around three theoretically informed concepts in this position paper, namely (1) Community participation for skills development, (2) Crafting methodological relevance, (3) and Emerging economies such as the 4th Industrial Revolution (4thIR) / Industry 4.0. Although several studies have examined clear distinctions between engineering education as practice-based and engineering education as research-focused, a strong focus on how an alignment of both fields could inform the agenda of an EEU has been lacking. As such, this position paper provides additional insights into the ways in which theory can inform the teaching and practice of engineering curriculum by establishing a Unit that is dedicated to the practical application of engineering education research. The Unit would be a place for engineering faculty to seek meaningful exploration in building community towards equitable, social participatory, engineering education learning experiences. The growing number of local and global institutions that have been engaging extensively with work in both the engineering education space and the education research space, support the justification for the establishment of such a Unit. It is envisaged that other universities can use the results of this position paper as motivation to establish their own EEU. Similarly, it can facilitate an understanding of the possible benefits of such a Unit. The anticipated benefits of such a Unit are: (i) furthering the engineering education research agenda, (ii) breaking down silos, (iii) interdisciplinary collaboration, and (iv) increasing student success.**

Keywords — engineering education, engineering faculty, engineering students, unit, South Africa, student success

I. INTRODUCTION AND BACKGROUND

The global expansion of research in engineering education is championed by societies such as the American Society for Engineering Education (ASEE) and the National Academy for Engineering (NAE) which progressively advances research in engineering education in North America, the European Society for Engineering Education (SEFI) which promotes the field in Europe, the Australasian Association for Engineering Education (AAEE) in Australia, and the Centre for Engineering Education Research (CREE) at the University of Cape Town (UCT) in South Africa. More specifically in South Africa, the commitment to expanding research in engineering education can be seen in universities that have established PhD programmes in Engineering Education Research (EER) to facilitate learning in the field. In July 2019, the University of Cape Town (UCT) hosted the first Research in Engineering Education Symposium (REES) to be held on the African continent. As a community of scholars, the Research in Engineering Education Network (REEN) partnered with the South African Society for Engineering Education (SASEE) to host the 8th biennial conference. The emergence of such a collaboration signified a far-reaching linkage for EER which Borrego and Bernhard describe as an “internationally connected field of inquiry, paying particular attention to its relationships to other engineering education initiatives” [1].

In recent years, EER has moved to the centre of a paradigm shift in engineering targeted at bridging the gap between how engineering is taught and empirical research for engineering education, by means of its emphasis on building the latter. Two dominant perspectives have influenced this shift. To begin with, many scholars in the United States (US) hold the view that engineering education and educational research for engineering are fundamentally different. From this viewpoint, research and practice occur separately. Many researchers from the US are more comfortable with quantitative research because of the view that this approach produces more empirical research [2]. Meanwhile, in the European context, this paradigm shift is informed by an understanding that research and practice work alongside each other. This approach to research moves beyond the fixation on empirical evidence. It brings to the fore questions about the ontological, epistemological and theoretical underpinnings adopted when thinking about educating engineers and the value of educational theory for research.

While the two perspectives mentioned above seem divergent, perhaps the most important contribution made by both is that they seek to enhance the learning experiences of engineering students. Based on this philosophy and the continuous efforts to improve the retention of engineering students, faculty members in the School of Engineering (SoE) where this paper is positioned, sought a home for their curriculum interventions, co-curricular and student development efforts, and engineering education related action research. At an institutional level, integrating the practice of teaching engineering with the theoretical underpinnings of doing research has been receiving greater emphasis. Integration is particularly critical as engineering educators engage with and prepare students for a world of work beyond engineering education activities. In addition, the Nelson Mandela Bay is known as the "hub" of engineering, with major companies such as Volkswagen, Isuzu and Ford located in Gqeberha (previously known as Port Elizabeth) and Kariega (previously known as Uitenhage). This presents an institution such as the University with an indispensable advantage, enabling it to establish greater connections with the industry by locating the necessary research in the proposed Engineering Education Unit (Unit). The discussion below positions a case that the establishment of such a unit is necessary. Moreover, the case being put forward is grounded in the conclusions of this position paper which provide evidence for the need: i) to improve skills development among engineering students through community participation; ii) to craft relevant methodological approaches for research in engineering education; and iii) to consider the impacts of the 4th Industrial Revolution (Industry 4.0). Therefore, this research addresses the case of the why and how of establishing an engineering education unit.

II. A CASE FOR ESTABLISHING AN ENGINEERING EDUCATION UNIT

Graham, Crawley and Mendelsohn reviewed engineering education leadership practices internationally and no programmes were identified in Africa [3]. Furthermore, their study revealed significant international differences in attitude and approach to engineering education leadership. They proposed that a clear distinction is apparent between the US and the rest of the world, predicating that explicit engineering leadership education is likely to remain in the US domain for "at least the next 5-10 years". The concept of formal engineering education units at South African universities therefore appears to be non-existent or limited.

It becomes evident that the critical place for a formalised structure such as a formal Engineering Education Unit is rapidly becoming more important. Several challenges face engineering education for the future and effective, informed and well-rounded engineering education plays a vital role in developing graduates that are ready to enter industry. Furthermore, it is critical to prepare engineering graduates to respond to the numerous sustainability challenges facing the world [4]. Therefore, the engineering curriculum of the future would need to prepare students for the "new workplace", to generate innovative solutions to problems and to meet customer needs and community requirements. The engineering curricula must include complexity and a varied skill set [4].

In a report by the Royal Academy of Engineering, five levels of growth for engineering departments which are based on Maslow's hierarchy of needs are suggested:

1) Technology and/or teaching competence.
2) An environment that is safe and respectful to all engineering students.
3) A focus on inclusion, involving and including people.
4) Engineers growing in career confidence.
5) A healthy engineering and education environment that empowers engineering staff and students to be inclusive and confident, the use of data to enable innovation and problem-solving.

It is proposed in this article by Peters that the above benefits can be realised with a formal, structured engineering education unit.

III. CURRENT ACTIVITIES IN THE SCHOOL OF ENGINEERING

In a paper describing the key stakeholders and strategies that might be useful to leverage a global community for EER, Jesiek, Borrego and Beddoes found such stakeholders to be "staff/faculty interested in improving their teaching; staff/faculty presenting their scholarship of teaching and learning; engineering deans/heads of school and heads of department; researchers and other scholars who study engineering education; and industry/government employees or similar stakeholders in engineering education" [2].

The findings presented illustrate that the interest in EER stems from individuals who are primarily engineering faculty (staff) trained as educators. However, it is worth noting that most of the engineering faculty, at the current comprehensive South African university for which the case is being made, have experience of working within the engineering industry and were not specially trained as educators. Training of this kind has been the practice in the School of Engineering where the authors of this position paper are located. As early as 2008, a collaboration was initiated between academic and professional support staff (from academic development and student counselling) in an embedded approach informed by the educational philosophy of humanising pedagogy. A humanising pedagogy, as an educational philosophy, encompasses the teaching and learning policy at the specific comprehensive university where this case is situated. Mutual vulnerability [5] is linked to a critical humanising pedagogy to advance its dual purpose of humanising the pedagogical endeavour, whilst simultaneously linking the educational process to challenging structurally anchored inequalities. Moreover, South African educationalists argue that mutual vulnerability may be regarded as a conceptual and practical tool to respond to the challenges of contemporary pedagogy [5]. If the field of humanising pedagogy is to make a significant meaningful scientific impact it will need to accelerate its research profile and prioritise the use of recent developments in research methodology that are appropriate to address the urgent systemic needs for social justice in different socio-political contexts in South Africa [6].

The overall goal of the interdisciplinary collaboration was to provide a supportive and affirming learning community to ensure the increased retention of engineering students [7]. This is in addition to aspiring to equip engineering students to manage academic demands to prepare them for the world of work, and to provide an optimal learning environment and a sense of belonging. The aforementioned were achieved by developing and offering several co-curricular interventions and workshops.

From the above, it becomes evident that interventions have been developed for the past decade with the intention of developing, supporting and retaining engineering students. This process commenced with one department identifying at- risk students and progressed to the current situation of a dedicated academic advisor as well as a facilitator of learning communities (this included a subject-specific tutorial coordinator) for the entire School of Engineering. Special attention has been placed on support for female engineering students, first-year engineering students and mature part-time students. The interventions and workshop described were regarded as successful as the overall feedback received from engineering students has been positive. Generally, it was reported by engineering students that learning, study management and confidence improved after attending the various interventions and workshops [7].

IV. DISCUSSION

In view of the high numbers of unemployed youth, both within South Africa and internationally, institutions of higher learning are faced with a common question, "How does orientating the education and training system to address unemployment affect graduates whose educational qualifications are industry-focused?" This is particularly so as education and training have, since the first democratic elections, been central to the socio-economic development strategy of post-apartheid South Africa.

At policy level, the country is guided by the National Development Plan (NDP) which is enacted across the twenty- one Sector Education and Training Authorities (SETAs). The Manufacturing, Engineering and Related Services Sector Education and Training Authority (merSETA) is responsible for skills development in manufacturing, engineering and related services. Additionally, merSETA plays a critical role in monitoring and evaluating the quality of education and training programmes for the purpose of linking trained practitioners to the labour market. Most recently, the National Youth Policy (2015-2020) has called for an improvement in research in science and innovation, listing science and engineering as scarce skills that have been identified as being central to the reconstruction and development of post- apartheid South Africa.

A. Commmunity Participation for Skills Development

A common challenge in the context of South Africa is the disconnect between policy objectives and changes that occur within the education space. Evidence suggests that even though there is a clear recognition at policy level that the number of scientists and particularly engineers need to increase, educational efforts are not meeting this demand effectively. With regard to technical disciplines, it is necessary to recognise that the existing effects of a historically unjust educational system continues to disadvantage students. Vision 2020, a documented strategic plan of the University, notes that the quality of our student intake suffers from being predominantly drawn from the Eastern Cape, known for its poor school-leaving certificate results, with student success rates below the national benchmark of 80%. Therefore, the challenges experienced in engineering education are unlikely to be resolved by teaching methods alone, but also require integrated teaching and learning mechanisms that are sensitive to the sociocultural dynamics from which students emerge.

Against this backdrop, it might be useful to ask in what ways EER can expand the discussion on skills development for engineering students by moving beyond simply acquiring technical knowledge. Allie et al. make use of the notion of discursive identities to build an understanding of how learning through community participation can enhance the experiences of students [8]. The term 'discursive' relates to a shared discourse or language within the engineering community that students engage with while Gee describes identity as "the 'kind of person' one is recognised as 'being', at a given time and place" [9].

From the perspective of discursive identities, it is useful to frame the rationale for an EER unit by means of terms that take into account how engineering students 'are in the world'. To begin with, there is strong evidence that supports the need for technical learning framed by experiences that are a true reflection of the world of work that student engineers are being prepared for. This view suggests that learning ought to be viewed as a lifelong process that is rooted in participative methods which are not reliant on acquiring learning alone. Lifelong learning is particularly significant as it is an important Engineering Council of South Africa (ECSA) Graduate Attribute. This perspective recognises that learning means being a part of a community. The challenges of the world are multi-layered, often requiring solutions that transcend a single discipline or skilled expertise. The kind of community participation that students engage in must matter to them [10]. This study cites the challenges that are presented in engineering workplaces and how numerous consultative processes often guide solutions to these problems with individuals across different intellectual fields.

The formation of a discursive identity enables students to engage with teaching and learning that is context-specific and representative of the problems that engineers are faced with in the world today. As the nature of work changes rapidly, "to be competitive and taking role of leadership today and in the future, engineering graduates must have world-class engineering education that equips them with the latest technical knowledge and tools, and have adequate understanding of the social, economic and political issues that affect their work" [11]. Though it may be argued that an adequate understanding of the social, economic and political features of engineering challenges is most likely to be accessible to students from underrepresented groups, it is a continuing challenge for students from disadvantaged backgrounds to receive adequate representation in engineering.

Linked to the challenge of unskilled graduates are simplistic notions of learning which Allie et al. critique by explaining that "the goal of learning is being able to act in a particular environment, where 'acting' is defined as being able to use the specialist discourse of that community" [8]. The term 'community' here is not only used to refer to the world of the engineering profession that the student is being prepared for, but it also includes the community and local setting(s) that the student comes from. Participative learning in engineering that occurs in the context of a community supports the formation of the identity of a student by fostering an environment that prepares the student to form a connection between their existing identity and the emerging ones. It "brings workplace thinking into the classroom setting". This is not to say that participative learning is the only way to foster skill sets that are meaningful to engineering students, however, it is useful to infuse this approach to learning into ways that have more impact. This process requires research and theories from education that will build on teaching and learning programmes in engineering.

B. Crafting Methodological Relevance

Scholars have stated that there is a direct need for engineering educators to explore research in engineering education as a means of bridging the knowledge gap between research-focused and practice-based aspects in engineering education. EER follows the same research process that any other research project would follow to produce empirical research, therefore, the growth of EER as a research-intensive field depends largely on the methodological choices it uses. Though quantitative approaches used to be predominant, recently there has been greater latitude for engineering education scholars to borrow interesting methodological approaches from the social sciences that might be useful for EER.

Though the work of Borrego reports statements from participants that studies conducted in engineering made limited use of qualitative methods [12], in their paper about methods for research in engineering education, Case and Light provide a list of methodological approaches from the social sciences that have become increasingly powerful for research in engineering education [13]. They argue that methodological relevance is important to create a shift in engineering for the purpose of solving 21st-century problems. To put it another way, the questions that we ask inform the methodological approach we choose for research in engineering education. They further state that "the relationship between research questions and methodology is usually not unidirectional but is rather two-way or what might be described as 'dialectical'". Methodological approaches are about the choice of steps for action and design for a research process and are underpinned by theoretical frameworks and particular worldviews. Sometimes, theoretical underpinnings are from other scholarly fields and are then applied in different spaces. The result is an agreement that research collaboration between the engineering faculty and the social sciences, especially the education faculty, is the way forward in producing meaningful research in engineering education [14].

Case and Light identify seven methodological approaches that are viewed as emerging namely: Case study, grounded theory, ethnography, action research, phenomenography, discourse analysis and narrative analysis [13]. A key example of a shift in methodological approach can be seen in a study of an undergraduate course that implemented arts-based and humanities methods to foster reflective thinking about broader societal issues linked to social justice [15]. The establishing of a unit that focuses on research in engineering education is useful for building methodological relevance in scholarship and contributing to existing bodies of knowledge.

C. Emerging economies: 4th Industrial Revolution (4thIR) / Industry 4.0

The socioeconomic landscape in South Africa is such that education and training programmes are designed to facilitate economic growth. An unintended consequence of this approach is that post-secondary schooling and more specifically higher education, are not meeting the demand for skilled workers needed in the formal labour market. The transformation of the labour market affects both the formal (relating to the skills gap and underskilled workers) and informal labour market (limited access to decent work; marginalised groups that are unlikely to enter the labour market). The principle of the 4th Industrial Revolution (4thIR) / Industry 4.0 is that it is the "Internet of things". Essentially, as explained by Sakhapov and Absalyamova, "it assumes that each physical object ('thing') has an integrated technology that allows it to interact with other objects" [16]. A key feature of the 4thIR is that it makes use of cyber-physical systems, which are mechanisms that are controlled and monitored by computerised inputs. The growing realisation of the 4thIR is driven by the need for global competitiveness for fast generating means of production. The impact of the 4thIR is such that, although engineering remains a scarce skill, there is a certain need for engineering students to be able to combine technical learning in engineering with other learning, such as from cultural anthropological design, urban sociology and educational approaches to design engineering. Specialised fields in engineering are at a higher risk of job loss because of rapid changes occurring in modes of industrial production. Not only will this affect the nature of work, but the very ways in which learning happens, as Sakhapov and Absalyamova emphasise: "standard educational programs are giving place to individual educational trajectories in which people use different deinstitutionalised and institutionalised forms of education" [16]. The need for a research agenda in engineering education that focuses on the shifts that the 4thIR is currently producing is crucial.

V. WAY FORWARD: DEVELOPING ENGINEERING FACULTY MEMBERS AS ENGINEERING EDUCATION RESEARCHERS

The development of engineering faculty members as engineering educators is strongly shaped by practice-based work while very little of it is informed by "rigorous research". Furthermore, the question of whether educational research is scientifically rigorous has been widely debated. However, the Rigorous Research in Engineering Education (RREE):

Creating a Community of Practice funded by the National Science Foundation (NSF DUE-0341127) was one of the first programmes to focus on preparing engineering educators for education research.

The data gathered from participants led Borrego to provide a list of difficulties experienced by engineering faculty as they progress into education research [12]. She concluded that there are five levels of conceptual difficulty that faculty staff grapple with as they engage the education research space namely: (1) framing research questions with broad appeal, (2) grounding research in a theoretical framework, (3) fully considering operationalisation and measurement of constructs, (4) appreciating qualitative or mixed-methods approaches, and (5) pursuing interdisciplinary collaboration [12]. In Borrego's findings, she suggests that because the scientific paradigm which underpins engineering is rooted in a universal consensus about methods and standards used, a distinct challenge arises from the disparity in paradigms when educational research, with its limited disciplinary consensus about theoretical frameworks, is brought into play for engineering [12]. From this viewpoint, Borrego further asserts that "appreciation that collaborators from other disciplines can provide unique and necessary expertise is a natural extension of fully realising the differences between engineering and education research which require additional expertise" [12].

Bernhard [16] offers a critical counter-argument to Borrego [12] which suggests that the challenges that inform engineering education and educational research are broader than a simple disciplinary 'separated-ness'. He further notes that engineering practices have a lot to contribute to the educational research domain, more particularly as they unpack the nature of engineering knowledge. The argument put forward draws from a European didaktik tradition which focuses on asking the *w-questions* of engineering. The w-questions constitute the what, why, to what end, where and who of an analysis. In this instance, the contribution that engineering is to make in the education research space is centered around creating a deeper understanding of how students come to know what they know about engineering. This understanding then feeds into an improved understanding of the w-questions that follow in the analysis. He distinguishes between this approach and paying too much attention to a disciplinary separated-ness that does not recognise the critical contributions that engineering can make.

The *didaktik* analysis provides an important foundation which cuts across a few significant spheres of learning in engineering that is student-centered and pedagogically beneficial in terms of skills for the future. The use of a *didaktik* approach to EER was later discussed in a paper by Borrego and Bernhard [1] as a useful framework for describing what, why, to what end, where, who, and how EER is conducted. Moreover, the framework emphasises why it is important to remember that the field of EER is fairly new while engineering education has been drawn from a wide range of other disciplines over time. The *didaktik* approach to analysis allows one to go beyond the research focused or practice- based debates that continue to dominate the discourse on engineering education and its landscape for research. The *didaktik* approach brings attention to ways of knowing and the epistemological assumptions that underpin the ways that engineering is taught and learned. Cunningham and Kelly [18] describe the focus of this attention as a foundational questioning of "What counts as engineering knowledge? What knowledge counts, for whom, and under what conditions?". The disciplines of science more broadly and engineering education more specifically, focus on biology, mathematics and chemistry as requirements for pursuing a career in engineering. However, Cunningham and Kelly [18] further argue that engineering often requires other ways of knowing from other fields to build on the epistemic practices for research in EER.

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REFERENCES

[1] M. Borrego and J. Bernhard, "The Emergence of engineering education research as an internationally connected field of inquiry," Journal of Engineering Education, vol. 100, 2011, pp. 14–47.

[2] B. K. Jesiek, M. Borrego, and K. Beddoes, "Advancing global capacity for engineering education research: Relating research to practice, policy and industry," European Journal of Engineering Education, vol. 35, 2010, pp. 117–134.

[3] R. Graham, E. Crawley, B. R. Mendelsohn, "Engineering leadership education: A snapshot review of international good practice," unpublished.

[4] R. G. Hadgraft and A. Kolmos, "Emerging learning environments in engineering education," Australasian Journal of Engineering Education, vol. 25, 2020, pp. 3-16.

[5] A. Keet, D. Zinn, and K. Porteus, "Mutual vulnerability: A key principle in a humanising pedagogy in post-conflict societies," Perspectives in Education, vol. 27, 2009, pp. 109 -119.

[6] C. Macleod, "South African psychology and 'relevance': Continuing challenges," South African Journal of Psychology, vol. 34, 2004, pp. 613-629.

[7] A. S. Lourens, R. E. Connelly, R. C. Plaatjes, and P. J. Snyders, "Reflections on a multi-disciplinary approach to student-centred interventions in higher education: engineering," June 2013 [18th WACE World Conference on cooperative and integrated learning, Durban, South Africa].

[8] S. Allie, M. N. Armien, N. Burgoyne, J. M. Case, B. I. Collier-Reed, T. S. Craig, ... and N. Wolmarans, "Learning as acquiring a discursive identity through participation in a community: Improving student learning in engineering education," African Journal of Research in Mathematics, Science and Technology Education, vol. 14, 2010, pp. 6– 14.

[9] J. P. Gee, "Identity as an analytic lens for research in education," Review of Research in Education, 2001, pp. 99-125.

[10] D. Jonassen, J. Strobel, and C. B. Lee, "Everyday problem solving in engineering," Journal of Engineering Education, vol. 9, 2006, pp. 139– 151.

[11] K. M. Yusof, S. A. Helmi, F. A. Phang, and S. Mohammad, "Future directions in engineering education: Educating engineers of the 21st century," ASEAN Journal of Engineering Education, vol. 2, 2015, pp. 8–13.

[12] M. Borrego, "Conceptual difficulties experienced by trained engineers learning educational research methods," Journal of Engineering Education, vol. 96, 2007, pp. 91–102.

[13] J. M. Case and G. Light, "Emerging methodologies in engineering education research," Journal of Engineering Education, vol. 100, 2011, pp. 186–210.

[14] F. A. Phang and K. M. Yusof, "Taking the "Guess-work" out of engineering education: Establishing the virtuous cycle of research," Procedia - Social and Behavioral Sciences, vol. 102, 2013, pp. 212– 220.

[15] R. C. Campbell, D. D. Reible, R. Taraban, and J. Kim, "Fostering reflective engineers," 2018 [World Engineering Education Forum - Global Engineering Deans Council, WEEF-GEDC].

[16] R. Sakhapov and S. Absalyamova, "Fourth industrial revolution and the paradigm change in engineering education," 2018 [MATEC Web of Conferences].

[17] J. Bernhard, "Is engineering education research engineering?," Sefi, 2013.

[18] C. M. Cunningham and G. Y. J. Kelly, "Epistemic practices of engineering for education," Science Education, vol. 101, no. 3, 2017, pp. 486–505.

Technical papers

Investigating and evaluating factors influencing undergraduate engineering students' choice of university

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***Abstract* — There is a need to have a better understanding of the quality of education at higher learning institutions (HEI). Good quality education strives to help students obtain the knowledge and skills so that they can be responsible and productive citizens. Quality is the most competitive weapon for HEI to attract and gain loyalty from students. Student enrolment is the most imperative outset for the success of any HEI. Thus, it is crucial to investigate the factors influencing students' choice of university to allow effective planning for student recruitment strategies. This study sought to critically analyse the success factors that influenced students' choice of university. The study adapted a descriptive survey design which employed a structured questionnaire to collect data. The targeted population of this study was the undergraduate students in the department of Mechanical and Industrial Engineering Technology (MIET) from various levels of study. A sample of 135 was selected through a convenience sampling from a population of 625. Data was analysed using a statistical software named Statistical Package for the Social Sciences (SPSS) with the assistance of a statistician from Statistical Consultation Services (STATKON). Findings of the study revealed that university reputation, variety of courses to choose from as well as safety and security were the top factors influencing students' choice of university. Factors such as the cost of the course and location and logistics did not have a high influence on students' choice of university.**

Keywords — Higher education institutions, quality education, factors, students' choice, university

I. INTRODUCTION

The world is constantly changing and therefore it requires society that is well informed about problems that arise in our everyday lives. Good quality education helps shape society. It contributes to the society's growth and its socio-economic development [1]. Education is not only about the knowledge that one gets from school or from reading books but it is also about the lesson of life [2]. Because we are living in an ever- changing world, continuous improvement is imperative in the education system [3]. Like the corporate, HEIs need to ensure continuous innovation in order to administer for good quality education.

There is a wide range of public and private HEIs in South Africa that students can choose to enrol at. There are also different factors that students consider before choosing an institution. These are the factors that enables their success in higher institutions [4]. These factors include, but not limited to, university reputation, the location of university, safety and security at university, variety of courses offered at the university as well as the cost of the course [4]. Monitoring the quality of the service as well as committing to delivering quality service are momentous in any HEI [5]. One way that HEI can monitor the quality of education it offers to the students, is to adapt a customer-orientated quality approach. HEI need to incorporate students in the service delivery process and regard them as the primary reason for their existence [6].

According to [7], university reputation is a consideration in a students' university choice. Fernandez [7] further says that institution marketing activities influences students' perception of the university image. Research has consistently shown that location can have a significant influence in selecting a university [8]. Sia [8] states that students who live close to the university are more likely to attend all their classes as opposed to living far from the university. Zain [9] also find that location has significant influence on the students' choice of university. According to Zain [9] safety and security are the most imperative factors for student enrolment. A study conducted by [7] concluded that safety and security is a consideration in a students' university choice.

Different universities offer different courses. Having a variety of courses to choose from is what draws students' attention [10]. This means that variety of programmes to choose from has a significant influence on students' choice of university. Sia [8] also find that students will choose to enrol at a university that has a variety of courses to choose from. According to Sia [8], high cost of fees has a negative influence on students' choice of university while financial assistance has a positive influence on students' choice of university. A study conducted by [11] found that financial assistance has a significant influence on student enrolment.

II. AIM AND RESEARCH QUESTON

A. Aim of the Research

Student enrolment is the most imperative outset for the success of the university [10]. Thus, it is crucial for the university to ensure students' continuance to enrol by continually improving and being involved in understanding how students perceive the education quality. The aim of this study is to investigate and analyse the factors influencing undergraduate Engineering students' choice of university. This study strives to understand the impact of these factors on students' enrolment.

B. Research Question

The main research question of this study is: what are the factors influencing undergraduate Engineering students' choice of university?

These various factors considered in this study include university reputation, location and logistics, safety and security, variety of programs to choose from, and the cost of the program. These factors will be elaborated under findings.

III. RESEARCH METHODOLOGY

A. Research Design

The study adapted descriptive quantitative design to investigate and evaluate the factors influencing undergraduate Engineering students' choice of university. According to [16], the main purpose of descriptive research design is to describe the characteristics and behaviour of the variables the researcher is interested in. The researcher is interested in the factors influencing students' choice of university. The study adopted quantitative design which is based on the measure of quantity. Therefore, data collected will be presented in graphs and analyzed statistically (with numeric).

B. Sampling

Kumar [12] defines sampling as a procedure where a researcher selects a subgroup from a population of interest. The targeted population of this study was the undergraduate mainstream students in the department of Mechanical and Industrial Engineering Technology from various level of study. A sample of 135 was selected through a non-random judgement sampling from a population of 625. According to [12], a non-random judgemental or purposive sampling is when the researcher deliberately selects items that can provide the best information in order to achieve the aim of the study. Willemse & Nyelisani [17] states that the researcher usually has the experience of these items chosen. Researcher used purposive sampling to select students from MIET because the researcher is also a student in MIET department and this would mean easy access to resources for the researcher.

C. Data Collection

Research data was collected through a questionnaire survey. A well-structured questionnaire containing closed and open-ended questions was developed and administered to respondents. This study adopted two ways to administer the questionnaire. Firstly, it used internet administration where a link was created with the questionnaire using Google forms and posted online for students to access it. Secondly, the study used a collective self-administration with and without the presence of the researcher where hard copies of questionnaires were handed over to students in classrooms either by lecturers or by the researcher. According to [12], collective self- administration is the quickest way of collecting data and it allows a high rate of responses.

D. Data Analysis

Data analysis was carried out in three phases; preparation of data, statistical analysis and presentation of results. Data was first prepared by eliminating incomplete responses. Mahanti [13] explains that data is of high quality if it does not have any defects such as incompleteness, unreliability, inconsistency and invalidity. After cleaning the data, the next step was to code respondents and questions for ease of data analysis. Leavy [14] defines coding as the process of allocating identifying words or phrases to data. Data was analyzed using a statistical software named SPSS with the assistance of a statistician from Statkon. According to [15], SPSS has the capability to analyze large amounts of data and minimizes making mistakes in data analysis. Lastly, data was organized and presented in the form of graphs and tables.

E. Data Quality Assurance

Mahanti [13] defines data quality as the capability of data to serve its purpose in any given context. Mahanti [13] further explains that data is of high quality if it does not have any defects such as incompleteness, unreliability, inconsistency and invalidity. During data collection, questionnaires were self-administered to students and a link was made available to students to collect data. Not all questionnaires administered to respondents were used. To ensure quality and consistency, incomplete questionnaires were not included in results.

IV. FINDINGS

A. Analysis of background information

The background information captured by the study was relating to the level of study of students and the course they were studying. However, this study only focused on the undergraduate students. Therefore, the level of study was from first year to fourth year and the courses were Mechanical and Industrial Engineering Technology.

1) ***Distribution of sample according to course of study:*** Students had to choose whether they were studying Industrial Engineering or Mechanical Engineering by placing a cross (x) on the relevant block. Table I illustrates how the question was structured.

TABLE 1: *Course of study*

Industrial Engineering	1
Mechanical Enineering	2

The findings on Figure 1 shows that all 135 respondents answered this question. Figure 1 reveals that 52.6% of the respondents were studying Mechanical Engineering and 47.4% were studying Industrial Engineering. These findings demonstrate that the department of MIET is dominated by students studying Mechanical Engineering. This is true because there were 625 undergraduate registered students in the department of MIET for the 2021 academic year where 409 were studying Mechanical Engineering while 216 were studying Industrial Engineering.

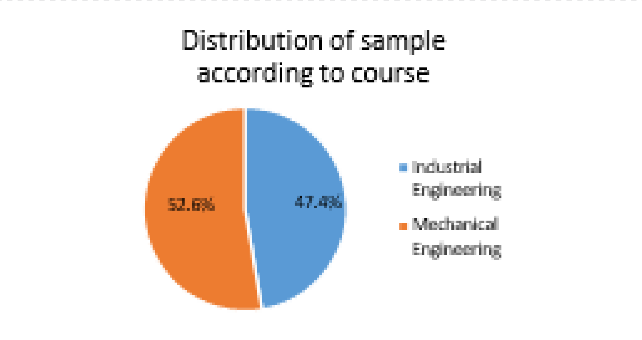

FIGURE 1: Respondents' course of study

2) ***Distribution of sample according to level of study:*** Students had to specify the level of study by placing a cross (X) on the relevant block. Table II illustrate how the question was structured.

TABLE 2: Level of study

1st year	1
2nd year	2
3rd year	3
4th year	4

The data distribution according to level of study reveals that all respondents answered this question. Figure 2 reflects that 26.7% of the students were first years, 28.1% of the students were second years, 28.1% of the students were third years and 17% of the students were fourth years. Data is distributed almost equally between first to third year students with a difference of 1.4% between first year to second and third year while fourth year students accounted for a smaller percentage of 17%. The researcher included fourth level of study to accommodate those who may be repeating any modules or were unable to complete their studies in record time due to unforeseen circumstances. The researcher included these students as they have more experience of being at the University and they understand how the University operates.

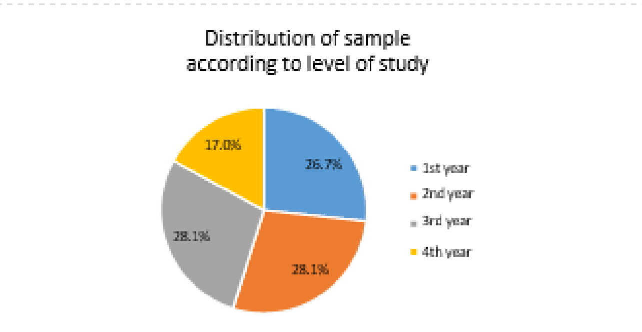

FIGURE 2: Respondents level of study

B. Factors influencing undergraduate Engineering students' choice of university

This question sought to understand important factors that students took into consideration before choosing a university. These factors included reputation, logistics, safety and security, variety of courses to choose from and the cost. This question allowed respondents to choose one or more answers that were applicable to them. Students also had the opportunity to add to the list of factors that they consider when choosing a university. Table III illustrates how the question was structured.

TABLE 3: Success factors for students' enrolment

University reputation	1
Location and logistics	2
Safety and security	3
Variety of programs to choose from	4
The cost of the program	5
Other (specify)	6

Findings in Figure 3 reveals that majority of respondents considered university reputation as the most important factor in selecting a university. This indicate that they wanted to enrol in a university that is well recognized and respected by many. Variety of courses to choose from was ranked second followed by safety and security. Location and logistics as well as the cost of the course were ranked lowest by the respondents. Finally, respondents were given opportunity to add to the list under the category 'other' and this category was ranked last by respondents. For the category 'other', respondents added factors such as university rankings and marketing.

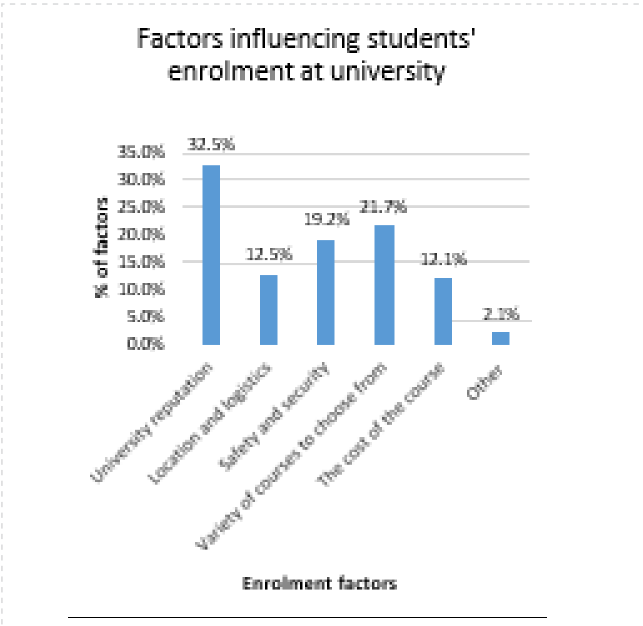

FIGURE 3: Factors influencing students' enrolment at the university

V. CONCLUSION

The aim of this paper was to investigate and evaluate the factors influencing undergraduate engineering students' choice of university. It has been found that university reputation was the most considered factor when selection a university. This indicated that students wanted to enrol in a university that is well recognized and respected by many as it is believed that a well-recognized institution produces quality education and successful graduates. In order to improve students' satisfaction, universities are advised to have variety of courses that are in high demand so that more students will be attracted to enroll. It is also recommended that universities recruit highly skilled and experienced lecturers in order to administer for good quality education.

REFERENCES

[1] N. Senthilkumar. & A. Arulraj, "SQM-HEI: Determination of service quality measurement of higher education in india," Journal of modelling in management, vol. 6, no. 1, pp. 60-78, 2011.

[2] R.M. Tchamdjeu, Retention of Engineering students in a South African higher education. MTech, (Industrial Engineering). [Unpublished]: University of Johannesburg. Accessed: Feb. 10, 2022 [Online]. https://ujcontent.uj.ac.za/vital/access/manager/Index?site_name=Rese arch%20Output.

[3] P. Gupta. & N. Kaushik, "Dimensions of service quality in higher education – critical review (students' perspective)," International journal of educational management, vol. 32, no. 4, pp. 580-605, 2018.

[4] J.K. Sia. & A. Abbas, "Facing the unknown: Pandemic and higher education in malaysia. Asian education and development studies," vol. 10, no. 2, pp. 263-275, 2021.

[5] R. Jain, G. Sinha, & S. Sahney, "Conceptualizing service quality in higher education," Asian journal on quality, vol. 12, no. 3, pp. 296- 314, 2011.

[6] T. Gueorguiev, Quality Management in Higher Education, 2006, pp. 1-7.

[7] J. Fernandez, "An exploratory study of factors influencing the decision of students to study at universiti sains malaysia. Kajian malaysia," Journal of malaysian studies, vol. 28, no. 2, pp. 107-136, 2010.

[8] J. Sia, "Institutional factors influencing students' college choice decision in malaysia," A conceptual framework. International journal of business and social science, vol. 1, no. 3, 2010

[9] F.M. Zain, & S.N. Sailin, Students' Experience with Flipped Learning Approach in Higher Education. Horizon Research Publishing Co., Ltd. Pages 4946, 2020.

[10] M.A. Hossain, M.M. Hossain & T.H. Chowdhury, "Understanding the success of private universities," International journal of quality & reliability management, vol. 35, no. 1, pp. 145-162, 2018.

[11] M. Yusof, S.N.B. Ahmad, M. Tajudin & R. Ravindran, "A study of factors influencing the selection of a higher education institution," UNITAR, vol. 4, no. 2, pp. 27-40, 2008.

[12] R. Kumar, Research methodology: a step-by-step guide for beginners, London: Sage Publications Ltd, 2014.

[13] R. Mahanti, Data quality: dimensions, measurement, strategy, management, and Governance, Milwaukee: American Society for Quality, Quality Press, 2018.

[14] P. Leavy, Research Design: Quantitative, Qualitative, Mixed Methods, Arts-Based, and Community-Based Participatory Research Approaches, London: The Guilford Press, 2017.

[15] K. McCormick, & J. Salcedo, SPSS for dummies. New Jersey: John Wiley & Sons, Inc, 2015.

[16] V. Bairagi. & M.V. Munot, Research Methodology: A Practical and Scientific Approach, New York: Taylor & Francis Group, 2019

[17] I. Willemse. & P. Nyelisani, Statistical Methods and Calculation Skills, Cape Town: Juta & Company (Pty) Ltd, 2015.

Technical papers

Evaluation of e-learning in engineering education in higher and tertiary education institutions in Zimbabwe

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Abstract — **The adoption of ICTs and e-learning tools in institutions of higher education provides several benefits including enhancing engineering education. The Covid 19 global pandemic forced most institutions to adopt e-learning in order to improve access and quality of education. In order to evaluate the e-learning in higher and tertiary institutions, a cross sectional survey comprising of 32 instructors from the 5 departments in the faculty of engineering at Chinhoyi University of Technology (CUT) was carried out. Data collected using a survey questionnaire was analyzed using IBM SPSS Grad Pack version 28.0 premium. On average 23.34 % of the instructors never practiced e-learning, 18.96 % practiced e- learning rarely, 15.84 % practiced e-learning moderately, 12.48% practiced e-learning substantially and 26.66 % practiced e- learning extensively in their teaching and learning. The usage of virtual laboratories and online assessment was found to be extremely low at 11.4 % respectively. The study revealed that CUT has an official e-learning strategy embedded in the ICT policy. About 63 % of the respondents were satisfied with the e- learning systems and affirmed that their productivity and performance improved through the use of the e-learning system. The existence of a sound e-learning policy has a direct impact on educational delivery. Although instructors had computers 88 % had no access to web cameras for online teaching and learning. The most prevalent challenge was power failure. The study recommended the development of e-learning quality assurance standards to ensure consistency and uniformity in the conveyance of e-learning in engineering education. The output of this will provide useful insights on the current usage of e- learning and recommendation to address the challenges affecting the adoption of ICTs and e-learning in higher and tertiary education institutions in Zimbabwe.**

Keywords—e-learning, engineering education.

I. INTRODUCTION

Zimbabwe has twenty Higher and Tertiary Education Institutions (HTEI) comprising of fourteen State Universities and six private universities. All these higher education institutions are registered and accredited with the Zimbabwe Council of Higher Education (ZIMCHE). The mandate of ZIMCHE is to promote and coordinate education provided by institutions of higher education and act as a regulator in the determination and maintenance of standards of teaching, examination, academic qualifications and research in higher education [1].

In most of these institutions offering engineering related field programmes, the engineering curriculum consists of three fundamental components namely theoretical, practicum and research project work. Theoretical topics are mainly taught in the conventional traditional classrooms, experimental work and practicals are directed in discipline specific laboratories and workshops. Individually and/or in group's learners collaborate to complete allotted project based work. The performance of learners is evaluated independently based on scores obtained in summative assessments.

The Covid 19 global pandemic disrupted curriculum implementation across the globe affecting over 1.2 billion learner's word-wide. In Africa and Zimbabwe in particular 297 million and 4.6 million learners were affected respectively [2]. In responses to the pandemic most governments and institutions of higher and tertiary education were forced to migrate to e-learning in order to improve access and quality of education.

E-learning is an approach to teaching and learning, representing all or part of the educational model applied, that is based on the use of electronic media and devices as tools for improving access to training, communication and interaction that facilitates the adoption of new ways of understanding and developing learning [3].

Most engineering related programs are unique, integrating sciences and mathematics making them difficult to teach on line when compared to other disciplines. Laboratories to teach abstract concepts and equation manipulation software's are required in most cases. However technological advancements now permits the use of virtual laboratories, and complex structures representation by computers easy. Several research scholar have shown that e-learning can augment engineering education by use of e-resources, online courses, blended learning, lecture management systems, and other communication and collaboration tools [4-6]. A study conducted by Henry [7] revealed that the use of learning tools such as simulations, animations, and virtualized demonstrations in laboratories can be more productive than conventional classroom teaching.

Prior to the Covid 19 pandemic, e-learning initiatives in most, HTEIs in Zimbabwe were on a limited scale. The Covid 19 global pandemic certainly expedited the need for e- learning solutions, however most of the HTEIs in Zimbabwe are using e learning in a blended mode due to implementation challenges.

Several challenges hinder the adoption of e-learning in higher and tertiary institutions. These challenges can be categorized into institutional and personal factors. Personal factors include factors such as motivation, student and instructor characteristics. Common institutional factors include, poor ICT infrastructure, power supply, computer laboratories, and lack of ICT policy.

A study by Aung and Khaing [9] found 30 specific challenges to implementing e-learning and grouped them into four categories; courses, individuals, technology, and context. In a similar work Annika [10] identified seven challenges to implementing e-learning in the following areas: student support, flexibility, teaching and learning activities, access, academic confidence, localization of content and attitudes on e-learning. A study conducted by Tarus et al [11] on Universities in Kenya revealed the following salient challenges to implementing e-learning: inadequate ICT and e- learning infrastructure, financial constraints, lack of operational e-learning policies, lack of technical skills on e- learning content development by teaching staff, lack of interest and commitment among staff to use e-learning, amount of time required to develop e-learning content.

Several researchers have provided benefits derived from the adoption of e-learning technologies into higher and tertiary education [12-15]. Given its numerous advantages e-learning is considered among some of the best teaching and learning delivery modes. Therefore it is imperative to evaluate e- learning in engineering education in higher and tertiary education institutions in Zimbabwe in order to harness the benefits associated with utilizing e–learning effectively.

The main aim of this work is to examine the adoption and use of ICTs and e-learning tools in engineering education in HTEIs in Zimbabwe. The specific objective of this work was to identify and investigate the factors affecting the use and adoption of ICTs and e-learning The research is important in developing and evaluating e-learning theories. The output of this research will provide useful empirical insights on the current e-learning usage and recommendations to addressing challenges affecting the use and adoption of ICTs and e- learning tools by HTEIs in Zimbabwe.

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II. E-LEARNING

The e-learning term was originated in the mid-1990s when the Internet began to gather the momentum, emerging as a contender to the classical face-to-face learning [16].
There are different terminologies for e-learning, such as online education, web-based training/learning (WBT, WBL), computer-based training (CBT), virtual university, advanced distributed learning, web-based instruction, online learning and open/flexible learning, digital education, mobile learning, Technology enhanced learning, etc. [17]. These terms are often used interchangeably, but their conflation is not always accurate or appropriate.

All e-learning forms must be based on four major components namely; the learner or the student, the content, the instructor, and technology as shown in Figure 1

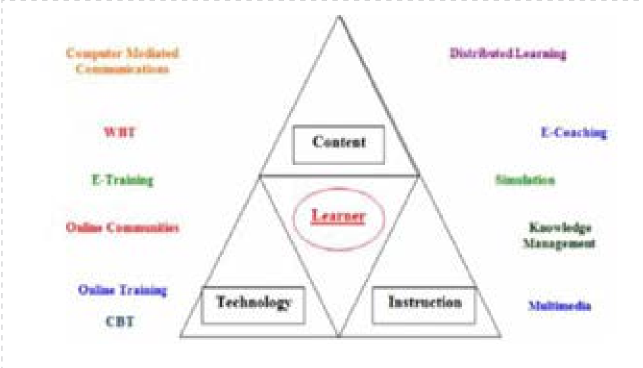

FIGURE 1: Basic structure of e-learning and its types. Source [17] cited in [18].

III. CHARACTERISTICS OF E-LEARNING

The e-learning approach is learner-centred, interactive, self- paced, repetitious and customizable [19]. According [20], the e-learning system must have the subsequent three conditions: (1) e-learning is networked; (2) e-learning is delivered to the end-user via a computer using standard Internet technology; (3) e-learning focuses on the broadest view of learning— learning solutions that transcend the traditional training paradigms.

The characteristics and elements of the e-learning approach are summarized and presented in Figure 2.

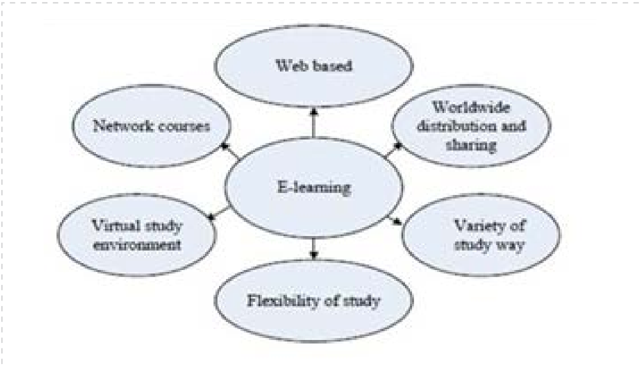

FIGURE 2: Characteristics of e-learning. Sources [21].

IV. THE STUDY POPULATION AND SAMPLE

The study population consisted of all instructors in the School of Engineering Sciences and Technology (SEST) at CUT. Stratified sampling was used to ensure the representatives of the population in the sample to reflect the significant characteristics of the wider population, such that the demographic characteristics of the age and gender are reflected.

During the cross sectional survey a total of 43 questionnaires were distributed to faculty members / instructors during the March-June Semester of 2021. A cross sectional study permits the collection of data from a sample population at a single point in time. The questionnaires used in the survey consisted of several sections. Section A aimed at gaining demographic data. Section B, C, D and E aimed at determining the knowledge and views of the instructors on e- learning.

A total of 32 questionnaires were received representing a 74 % response rate. These 32 questionnaires were analyzed using IBM SPSS Grad Pack version 28.0 Premium. Figure 3 shows the distribution of survey participants among various departments within the SEST.

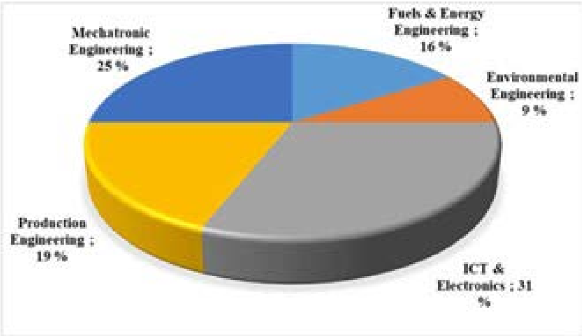

FIGURE 3: Distribution of survey participants among various Departments within the SEST.

V. ANALYSIS OF VALIDITY OF THE RESULTS

Cronbach's alpha α, Composite Reliability (CR) and the Average Variance Extracted (AVE) were employed to test the internal consistency reliability and validity. Internal consistency is a measure and /or an indicator of how well the different items measure the same concepts in the survey. Cronbach's alpha coefficient alpha (α) measures internal consistency among a group of items combined to form a single scale. It is a statistic that reflects the homogeneity of the scale. Composite reliability (sometimes called construct reliability) is a measure of internal consistency in scale items, much like Cronbach's alpha, and the criterion implies that

$$= \frac{{}_i{}^2}{{}_i{}^2 \qquad {}_i{}^2} \qquad (1)$$

λi = completely standardized loading for the i th indicator

CR is a less biased estimate of reliability than Cronbach's Alpha. In general, reliability co-efficient of 0.70 or more are acceptable. To measure the convergent validity the study employed the average variance extracted (AVE) using the value expression:

$$AVE = \frac{{}_i{}^2}{{}_i{}^2 \qquad {}_i{}^2} \qquad (2)$$

(2)

Where λi = completely standardized loading for the ith indicator.

AVE measures the level of variance captured by a construct versus the level due to measurement error, values above 0.7 are considered very good, whereas, a value of 0.5 is acceptable since more than 50 % construct variance should be explained by its variable.

In this present study the Cronbach's α, Composite reliability CR and the AVE were calculated using the SPSS and the results are presented in Table 1

***TABLE1:** Internal consistency reliability and convergent validity results*

Part	Construct	Items	α >0.70	CR≥0.70	AVE ≥0.50
B	Adoption and use of e-leaning	17	0.754	6.140	0.672
C	Instructor characteristics and system dimension	12	0.871	3.743	0.596

Table1 shows that all the values meet the minimum requirements for internal reliability. Also the average extracted variance employed to assess the convergent validity was ≥ 0.5 for all the constructs.

VI. ADOPTION OF E-LEARNING

The survey instrument categorized the e-learning component usage into five broad categories namely; digital content, learning objects, laboratory practice, assessment and communication with students on line. On average 23.34 % of instructors never practiced e- learning, 18.96 % practiced e- learning rarely, 15.84 % practiced e-learning moderately, 12.48 % practiced e-learning substantially and 26.66 % practiced e-learning extensively in their teaching and learning. Considering moderate usage as the minimum acceptable standard, usage of the Learning Management System (LMS) was about 91%. The majority of the instructors in the school of engineering science and technology used the LMS as the institution has a Moodle learning management system in place.

Figure 4 shows the current usage of e-learning components. The usage of digital content in the form of lecture notes, power point presentation (PPT) and lecture videos was about 95 %. The current usage of teaching objects was about 72%. The usage of virtual laboratories and online assessment was found to be extremely low at 11.4 % respectively.

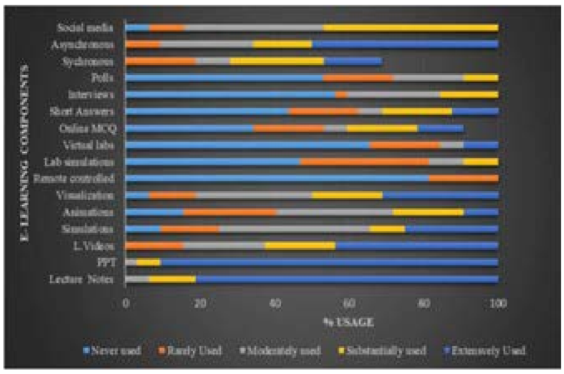

***FIGURE 4:** E- learning components /tools vs % usage*

The advantages of using virtual laboratories according to researchers from Lab share are: (1) increase access to laboratories, (2) reduce laboratory management and maintenance cost, (3) improve quality of learning, (4) encourage the exchange of knowledge, expertise and experience, (5) reducing laboratory equipment supplier cost. Despite these enormous advantages associated with virtual laboratories their usage has remained extremely low. Virtual laboratory experience can provide an alternative or supplement to traditional hands on labs.

Therefore there is a general need to set up virtual laboratories that can be shared among HTEIs in Zimbabwe in order to overcome several perennial problems associated with inadequate laboratory equipment to achieve learning goals especially for abstract concept in engineering education.

The online Multiple Choice Questions (MCQs) were found to be the most prevalent assessment method among the instructors with a 46.9 % usage. The popularity of this assessment method can be attributed to the fact that MCQs are general easy to use, highly secure, economical, offer quick turnaround time and they make automatic scoring and auto grading by a computer easy. The remaining assessment methods in their decreasing order of their prevalence were online interview (40.6 %), online short answers (37.6 %) and online polls (28.2 %). Assessment using online short answer was not popular with instructors because the subjective answers produced normally require manual grading for which examiner need to invest additional time.

Communication with students online was found to be about 55 %. The use of asynchronous communication was prevalent with a percentage usage of 91%, while synchronous communication and social media were found to be at 81 % and 85 % usage respectively. From the analysis it is clear that the use of social media is gaining traction in engineering education. The use of social media in education helps students to get more useful information, connect with various learning groups and other educational systems making education convenient. Social networks tools afford students and institutions with multiple opportunities to improve learning methods. Integration of social media with LMS can be beneficial for institutions to have the best reach and effect.

A recent study by [22] revealed that online social media used for collaborative learning had a significant impact on interactivity with peer, teachers and online sharing behaviour.

VII. INSTRUCTOR AND INSTITUTIONAL CHARACTERISTICS

The efficacy of the instructors were obtained using frequencies from descriptive statistics based on the constructs and the indicators of the survey study. The results shows that all the instructors feel that the use of ICTs improved their work organization and presentation. Over 90 % of the instructors indicated that they are able to navigate the CUT Moodle LMS with ease. This finding is consistent with the high LMS usage, digital content and learning objects usage. Thus most of the instructors are able to upload digital content and learning objects on the virtual learning environment to promote engineering education.

The results also indicate that about 22 % of the instructors were not able to use online assessment while 34% were not able to use virtual laboratories. Although a significant number of the instructors were neutral on their efficacy or ability to use online assessment and virtual laboratories, the finding collaborates well with the reported extremely low usage of virtual laboratories and online assessment. There is therefore a general need to instigate a training need analysis to identify the specific training and development needs of the instructors in these two critical areas so that they can effectively execute their mandates.

Approximately 63 % of the respondents were satisfied with the e-learning system, 69.4 % felt that their productivity and performance improved through the use of the e-learning system, while 62.5 % think that the e-learning system is an effective mode of learning.

Figure 5 shows the perception of the instructors on the existence of an e-learning policy. An e-learning policy provides an official strategy for adopting the e-learning approach.

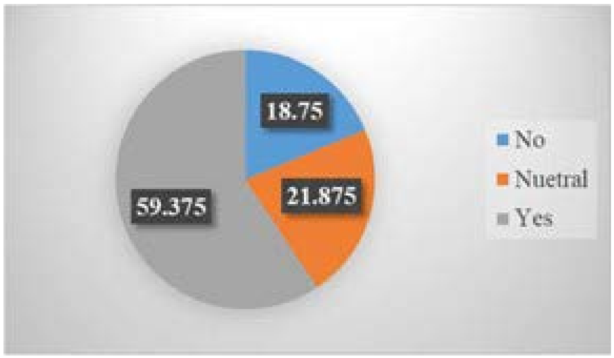

FIGURE 5: Perception of the instructors on the existence of the e-learning policy.

About 60 % of the instructors are of the view that CUT has an official e-learning policy. Informal interviews with the executive ICT director and the director of the academy of teaching and learning revealed that CUT has an official e-learning strategy though embedded in the ICT policy. The existence of a sound e-learning policy has a direct impact on educational delivery.

Figure 6 highlights some of the challenges instructors face during online teaching and learning. Close to 72 % of the instructors had no online writing tools, while 84 % had no microphone and headsets

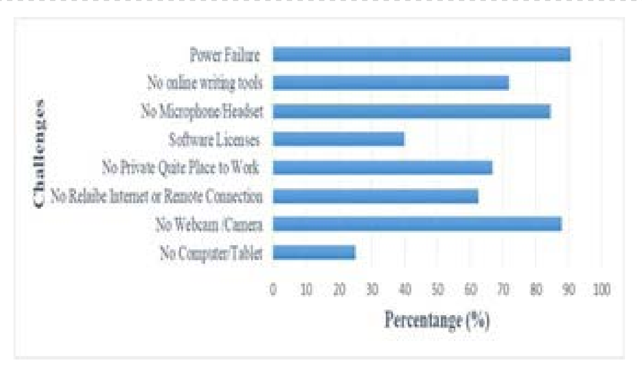

FIGURE 6: *Challenges/ barriers to e-learning.*

Although the instructors have computers, 88 % had no access to webcam or camera for online instruction. The most prevalent challenge was power failure. Frequent power cuts more often than not disrupt online sessions. The country at large is facing an acute shortage of power due to depressed generation capacity. However efforts are being made to solarize the university campus to ensure uninterrupted power supply during online teaching and learning.

VIII. CONCLUSIONS

The study revealed that e-learning and ICTs are not extensively used in the teaching and learning of engineering education in Zimbabwe. Furthermore the usage of virtual laboratories and online assessments were found to extremely low. It emerges that adequate training in ICTs and e- learning tools is essentially required in order to use the e- learning effectively to harness the benefits associated with its use.

ACKNOWLEDGMENT

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REFERENCES

[1] Zimbabwe Council for Higher Education (ZIMCHE) Act (2006).

[2] Mandikiana, M. R. V. (2020). Rethinking Zimbabwean education during and beyond the COVID-19 pandemic. Quest Journal of Management and Social Sciences, 2(2), 290-306.

[3] Sangra A, Vlachopoulos D and Cabrera N. The international review of research in open and distance learning

[4] Naidu S (2006) E-Learning: A guide of Principles, Procedures and Practices 2nd edition, Commonwealth of e-learning, Commonwealth educational media center for Asia.

[5] Kumar Basak, S., Wotto, M., & Belanger, P. (2018). E-learning, M- learning and D-learning: Conceptual definition and comparative analysis. E-learning and Digital Media, 15(4), 191-216.

[6] Latchman, H. A., Salzmann, Ch.; Gillet, Denis, "Information Technology Enhanced Learning in Distance and Conventional Education", IEEE Trans. on Education, Vol. 42, No. 4; November 1999; page 247-254.

[7] Henry, P., 2001. E-learning technology, content and services. Education Training, 43 (4), 249–255.

[8] Heap, N.W., Kear, K.L., Bissell, C.C., (2004). An overview of ICT based assessment for engineering education, European Journal of Engineering

[9] Aung, T. N., & Khaing, S. S. (2015, August). Challenges of implementing e-learning in developing countries: A review. In International Conference on Genetic and Evolutionary Computing (pp. 405-411).

[10] Andersson, A. (2008). Seven major challenges for e-learning in developing countries: Case study eBIT, Sri Lanka. International journal of education and development using ICT, 4(3), 45-62.

[11] Tarus, J. K., Gichoya, D., & Muumbo, A. (2015). Challenges of implementing e-learning in Kenya: A case of Kenyan public universities. The International Review of Research in Open and Distributed Learning, 16(1).

[12] Wentling T.L, Waight C, Gallagher J, La Fleur J, Wang C, Kanfer A. (2000). E-learning - a review of literature. Knowledge and Learning Systems Group NCSA 9.1–73.

[13] Klein, D. & Ware, M. (2003). E-learning: new opportunities in continuing professional development. Learned publishing, 16 (1) 34-46

[14] Hameed, S., Badii, A., & Cullen, A. J. (2008, May). Effective e-learning integration with traditional learning in a blended learning environment. In European and Mediterranean conference on information systems (Vol. 60, p. 14).

[15] Algahtani, A. (2011). Evaluating the effectiveness of the e-learning experience in some universities in Saudi Arabia from male students' perceptions (Doctoral dissertation, Durham University).

[16] Nichols, M. (2003). A Theory for E-Learning, Educational Technology and Society, Vol. 6, No.2, 1-10.

[17] Khan, B.H., 2001. A framework for web-based learning. Engelwood Cliffs: Educational Technology Publications.

[18] Benchicou, S., Aichouni, M., & Nehari, D. (2010). E-learning in engineering education: a theoretical and empirical study of the Algerian higher education institution. European journal of engineering education, 35(3), 325-343

[19] Broadbent, B. (2002). ABC's of e-learning: Reaping the benefits and avoiding the pitfalls. John Wiley & Sons, Inc..

[20] Twigg, C., 2002. Quality, cost and access: the case for redesign. In: M.S. Pittinsky, Ed. The wired tower. Upper Saddle River, NJ: Prentice-Hall, 111–143.

[21] Mohammed, A. K., El Zoghby, H. M., & Elmesalawy, M. M. (2020, October). Remote controlled laboratory experiments for engineering education in the post-COVID-19 era: Concept and example. In 2020 2nd Novel Intelligent and Leading Emerging Sciences Conference (NILES) (pp. 629-634). IEEE.

[22]]Wang, Y. (2014). Technology and products supporting e-learning by knowledge management-A review. International Journal of Emerging Technologies in Learning (iJET), 9(4), 56-59.

Technical papers

Leveraging digital tools to design an integrative hybrid learning experience

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***Abstract* — The past decade has seen a redesign of engineering education to accommodate the supercomplexities of the modern world. In preparation for this world, integrative teaching and learning approaches that highlight connections between different concepts, and between theory and practice, develop the critical thinking attributes of engineering graduates. One means of facilitating integrative learning experiences that was further impelled by the COVID19 disruption is the adoption of digital tools within a hybrid module design. This paper presents and evaluates various digital interventions within an integrative, hybrid-learning mode applied to a content-dense materials science module in the second year of a Bachelor of Engineering degree programme. The evaluation focuses on analysing students' perceptions on the effectiveness of the different digital tools that were used to support integrated learning in a theory-rich module. Quantitative and qualitative feedback drawn from questionnaires revealed that, overall, students valued the well-structured, logical online format of the module and recommended this as a standard for other modules. Students also expressed appreciation for the explicit theory- practice links in the case studies and virtual practical sessions. Challenges with time management were also highlighted with students associating this with the wide range of activities that are employed in a hybrid, integrated approach to module design. Additionally, it was clear that there is a wide range of digital fluency across the student cohort. Students' level of competence relating to basic computer and data analysis skills directly influences their ability to engage and perform well in activities that required these skills, such as the projects and virtual practical sessions. It was concluded that the success of the current approach in preparing students for supercomplexity relies on restructuring other curricular items in a similar digitally aided integrative manner whilst providing support for time management and digital skills.**

Keywords — integrative approach, hybrid learning, digital tools, supercomplexity, holistic learning

I. INTRODUCTION

Engineering fields are epitomes of a supercomplex world, characterised by a proliferation of new forms of knowledge and frameworks, advancing technologies and changing norms of professional identities [1]. Such pressures are contemporaneously reflected in the adoption of emerging models of teaching in lieu of traditional versions within engineering curricula of tertiary institutions [2]. In preparing engineering students for this world, which has been further compounded by COVID-19 disruptions, universities face the challenge of creating organisational conditions that allow for holistic student learning and development [3]. Addressing this challenge in a bottom-up approach requires educators to provide cognitive, affective and systemic learning support [4] around a curriculum designed for supercomplexity, which embodies epistemological (E) or knowledge, ontological (O) or being, and praxis (P) or doing elements [1]. Illustratively, E elements are those pertaining to understanding the module content and draw anatomical parallels with the "head/brain" of the student. O elements are equated to the "heart" of the student and embody the sense of being or what defines the "feeling of belonging" to a particular group (such as professional engineers). Praxis elements are the "body/hands" of the student which involve practical skills and application of theory.

Within epistemological dimensions of engineering modules, critical thinking remains one of the core skills specified within graduate attributes by professional accrediting bodies [5]. Employers consistently rate critical thinking and analysis skills as one of the most desirable qualities of graduates [6]. Despite the ubiquitous requirement of this ability, there are many interpretations of the definition of critical thinking within the engineering education context which often makes it difficult for educators to structure their course delivery to enhance critical thinking in undergraduate cohorts [7]. This is further exacerbated by dense, content-rich modules packed within a credit-heavy curriculum that contribute to the issues of "information overload", academic stress and lack of peer interaction especially in the Emergency Remote Teaching (ERT) and post-ERT era (2020 – current) [8], [9]. Consequently, there is a lack of development of critical thinking and approaches to deep understanding as course content and activities are treated as discrete, isolated units in a rushed manner with minimal cohesiveness between module topics and applications to real-world contexts [2], [5], [10].

Systemically, several challenges surfaced from the forced adoption of various technologies and digital tools during ERT. Ordinarily face-to-face lectures and laboratory practicals were replaced with online versions with students experiencing various levels of frustrations in navigating the systemic challenges of the digital learning tools [11]. For instance, Kruger et al. [12] found the epistemological goal of a virtual mechatronics engineering practical was overshadowed by its systemic complexity as students struggled with hardware and software compatibility (praxis). Not only is there a diverse range of accessibility to technological resources (computers, communication devices, software, internet, etc.) amongst students, but also a range of digital fluencies, both in staff and students, in the context of hybrid (mixed online and in- person), ERT and post-ERT module delivery [9], [11]. Technology-supported learning underpinned by Learning Management Systems (LMS) is commonplace in most modern universities, but if these tools are not implemented in an accessible and standardised manner then student energy and time is directed to addressing the digital complexity rather than to developing deep understanding of concepts and the associated critical thinking capabilities [11], [13].

In this paper, we aim to present and evaluate an intervention that leverages various digital tools to address the refinement of critical thinking skills on two related fronts: (i) fostering deep understanding by forming connections between concepts and generalisations through integrative approaches to teaching [14] and (ii) linking theory with practice [5]. This approach is adopted in the hybrid learning environment of a large-class (350-400 students), theory-rich materials science module in the second year of a bachelor's degree in engineering at a research-intensive university. Digital tools that explicitly address and integrate the E-O-P needs of the students form a vital part of the module design. This paper addresses the questions: (i) how effective were different digital tools leveraged to promote an integrative approach for learning in a theory-heavy materials science module for engineering students that is presented in the hybrid mode and (ii) how effective was this approach in facilitating the development of understanding of module content and critical thinking skills? The paper first describes the context of the materials science module that is being evaluated; this is followed by descriptions of the theoretical and analytical frameworks that are used to present the research; the methodology used to collect the data and analyse the results is then presented, along with a discussion of the findings.
The research, including data collection and analysis methods, is aligned to a faculty-wide impact evaluation initiative with ethics clearance.

II. ENGINEERING STUDENTS IN THE MATERIALS SCIENCE CONTEXT

This study is focussed on a materials science module for second-year mechanical, mechatronics and industrial engineering students at a contact-based, research-intensive university in South Africa. The course hosts large classes and the module content is dense and theory-rich, covering approximately 18 chapters of a textbook spread across over 600 pages. At its core, this materials science (MS) course consists of five underlying principles: structure of various classes of materials (metals, ceramics, polymers and composites) at different length scales (atomic to macroscale), processing and synthesis methods, properties, performance and characterisation methods of the various classes of materials. These principles and the complex interrelationships between them are often represented as the vertices and edges, respectively, of a "materials tetrahedron", as illustrated in Figure 1 [15].

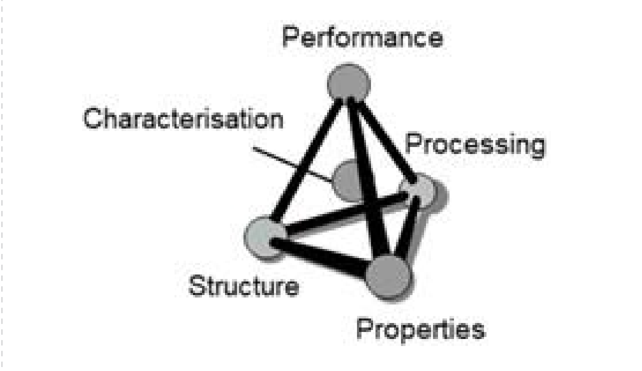

FIGURE 1: *Materials tetrahedron presenting the five, interdependent principles of materials science: Performance, Processing, Properties, Structure and Characterisation*

The density and variety of the module content, as well as the complex interconnections between the different topics covered in the module, present epistemological challenges. Furthermore, within MS, ontological tensions exist between the identities associated with MS, materials engineering and mechanical or industrial engineering disciplines [16]. Student's ontological beliefs about the identities of engineers (i.e., what it means to be an engineer in this world) within a multidisciplinary MS module has an impact on the assimilation of the module concepts [17].

Past presentations of this module involved traditional face-to-face lectures, tutorials, laboratory-based practical sessions and an individual project. From lecturer observations, it was recognised that students tended to rote-learn the five principles in isolation, with little consideration afforded to connections between segmented themes and to real-life contexts. Under the actions of a faculty-wide initiative known as Recommended Engineering Education Practices (REEP), MS has formed part of an ongoing renewal effort to address the scattered learning of topics that students perceive are isolated from one another. In order to develop critical thinking and foster the development of deeper, contextual understanding of the module content, a holistic framework for hybrid module presentation is used. Even before ERT, the module underwent a conversion to hybrid mode with a combination of online activities and face-to-face question and answer and practical sessions. This work, however, recognised the additional need for a digitally-supported integrative framework to tie together the web of concepts and module tasks to foster critical thinking, cumulative learning and holistic (addressing all three domains: E, O and P) student development in the ERT era (2021 – 2022).

III. THEORETICAL AND ANALYTICAL FRAMEWORKS

The goal of any teaching model is to present structured learning experiences that achieve deep understanding of the module content and develop critical thinking abilities. There are several deep approaches to learning discussed in literature that all share common attributes including [14], [18]: clear learning objectives and effective teaching strategies to meet these objectives; guided examples and representations of the study material and continuous monitoring of learning progress. These approaches simultaneously develop critical thinking that involves the ability to (i) confirm and evaluate conclusions based on relevant, unbiased and factual evidence [14] and to (ii) dynamically oscillate between abstract theory and real-life contexts [5]. Students' critical thinking abilities and deep understanding of interrelated topics are simultaneously developed using an "Integrative Model" that is situated within schema theory: guided mapping of networks of organised bodies of knowledge stored within memory units (schemata). Kipper and Rüütmann [14] describe the following steps for implementing the Integrative Model (IM):

- IM1: Identify organised bodies of knowledge from textbooks, curriculum or other guides
- IM2: Establish patterns by identifying generalisations, relationships, explanations and hypotheses backed by evidence for culturing critical thinking skills
- IM3: Analyse information and consider possibilities under different conditions
- IM4: Present data for background knowledge in order to construct understanding
- IM5: Take advantage of technology and various digital tools

As a complement to the Integrative model, Ahern et al. [5] ties the development of critical thinking skills to the weaving across different levels of abstraction ranging from abstract and broad generalities to the real and context bound, termed cumulative learning. This weaving is captured in the Legitimation Code Theory (LCT) Semantics dimension [19], which is used as an analytical tool to describe the "connection of the dots" between weak semantic gravity (SG) abstract or theoretical concepts and more contextualised examples with stronger SG. The use of LCT Semantics in theory-rich modules like MS enables lecturers to use the cumulative learning approach to link E-O-P elements by moving up and down the semantic dimension. Learning is structured so as to anchor abstract concepts with weak SG (such as descriptions of a material's microstructure) to concrete examples with strong SG (such as a real-life case study of the failure analysis of a steel shaft) through different forms of application spanning the SG continuum (such as metallographic analysis and mechanical testing techniques) thereby intending to facilitate cumulative learning while simultaneously fostering motivation, improved insight into critical concepts and critical thinking [14], [18].

Integrated approaches that promote cumulative learning are considered successful if they effectively prepare students for the modern supercomplex world characterised by a multiplicity of new forms of knowledge, challenges and frameworks [1]. The E-O-P theoretical framework, proposed by Barnett [1], describes the need for a holistic embrace of epistemological (knowledge), ontological (being) and praxis (skills) elements within curriculum and (by extension) module design for students to adapt to supercomplexities. This know- be-do (E-O-P) trident of curricular dimensions is supported by cognitive, affective and systemic domains [20] and allows for an evaluation of: (i) whether theoretical course content supports epistemological transitions and conceptual understanding; (ii) whether learning environments cultivate students' ontological requirements of confidence, motivation and identity; and (iii) whether skill development through engineering praxis is effectively supported by technological infrastructure [8].

IV. METHODS

Digital transformation of engineering education has seen accelerated proliferation due to a combination of factors including industry pressure for digital literacies, emerging technologies, the Fourth Industrial Revolution, generational preferences for internet-based learning and, more recently, the forced adoption of ERT due to the COVID19 pandemic [12], [21]. The approach in this work was to leverage several digital tools for an integrative and hybrid module design of MS. The various module activities and associated digital formats, active/passive nature, setup expertise required and integrative model goals are described in Table 1 and a brief summary is provided here. Using a design-based, collaborative research approach, the module content was graphically mapped in an infographic according to knowledge areas and weekly themes from the textbook. Through the infographic, knowledge areas and themes were aligned to learning activities, both active and passive, that made use of both in-person and different digital formats within a highly structured online LMS. As illustrated in Figure 2, integration of module content, knowledge areas, different levels of abstraction and different E-O-P elements was achieved through connecting textbook (E) references to pre-recorded theory lecture videos (E), weekly low-stakes online quizzes (E), virtual practical sessions (E, P), peer- assessed projects (E, O), and self-study, self-assessed case studies (E, O, P). The infographic categorises and connects all topics and activities to scaffold students' understanding across all the E-O-P domains. Additionally, the LCT Semantics dimension is superimposed over the different learning activities presented in Figure 2, to illustrate the cumulative learning that is achieved by translating through the different levels of abstraction [19].

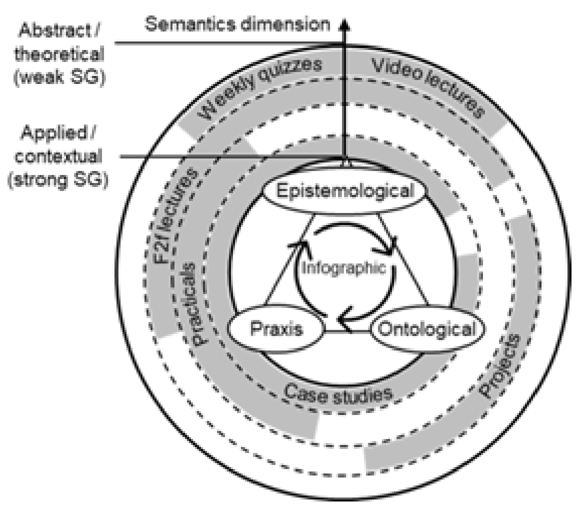

FIGURE 2: *Mapping of integrative activities according to levels of semantic gravity and epistemological, ontological and praxis domains*

Evaluation of the approach was performed qualitatively and quantitatively in the form of a voluntary, anonymous questionnaire that was implemented as part of the final case study quiz at the end of the course. A quantitative survey (based on a 5-point Likert scale) was used to assess the student-perceived effectiveness of the approach. The first part of the quantitative survey was aimed at assessing the perceived understanding of the connections, illustrated by the "edges" of the materials tetrahedron shown in Figure 1., between the core principles of MS. The second part specifically focused on the perceived effectiveness of the different learning activities and resources: INF, F2F, WQ, VL, PJ, PR and CS, as defined in Table I. Qualitative responses were collected in the form of online reflective feedback (RF) from the comments section of the survey, and from institutional student feedback (SF) forms that assess the best/worst/in need of improvement parts of a module, and from lecturer observations. Thematic analysis was performed on the qualitative student feedback to codify themes aligned with the E-O-P elements of the student learning experience.

V. FINDINGS AND DISCUSSION

Based on lecturer observations and student feedback, the following findings are emerging for the digital interventions as viewed through the lens of the E-O-P domains for supercomplexity.

A. Student-perceived Effectiveness of Activities

Out of ~380 students, 115 responses were received on the questionnaire (30% response rate), with 83% of the qualitative responses consisting of positive feedback. Figure 3 shows the quantitatively rated effectiveness and the counts of recurring codes from the thematic analysis of the qualitative feedback, for each of the integrative activities. All elements scored (on average) above neutral (3) scores for the perceived impact on learning. The WQ, despite its low-stakes and surface-level conceptual nature, scored the highest with the main reasons attributed to improved affective dimensions of motivation and self-regulation that direct metacognitive processes [22].

TABLE 1: *Summary of integrative activities for a materials science module*

Activity Description	Digital Format	Active/Passive; Setup Level of Expertise Required	Integrative Model Goal [14]
Infographic (INF) – graphic organiser showing interconnections between concepts and learning activities/assignments	Hyperlinked portable document format (PDF) and editable version created using presentation software	Passive; Expert lecturer	IM1, IM2, critical thinking, deep understanding, explicit organisation
Face-to-face lectures (F2F) review of traditionally difficult to grasp (threshold) concepts, example problems, sharing of helpful resources, reminders of deadlines	In-class projector, tablet, e-book, internet and MS software (e.g., visualisation of atomic arrangement within crystal structures)	Passive + active; Expert lecturer	IM1, IM4, deep understanding
Pre-recorded video lectures (VL) – presenting theory in higher density compared to face-to-face lectures, references infographic	Time-stamped, downloadable videos embedded in LMS	Passive; Expert lecturer	IM1, IM4, IM5, retain focus through non-linguistic presentations
Weekly online quizzes (WQ) – low-stakes, test- your-basic understanding, surface-level questions, self-assessment	Online, multi-format quiz (multiple-choice, arrange in particular order, pick the correct word, label the figure, etc.)	Low active; Tutor/expert lecturer	IM4, IM5, effective feedback + practice
Practicals (PR) – virtual, combination of testing standards and information, video demonstrations and report/data analysis in the form of a deeper-level quiz	Standard and instructional PDFs, online video demonstrations of standard materials testing and characterisation methods, real-life material test data (spreadsheet), multi-format online quiz	Active; Tutor	IM2-IM5, critical thinking, balance of abstract theory and concrete data, methods and application
Projects (PJ) – covers metals, polymers, ceramics and composite self-study chapters, independent learning, student-posed examination questions with memos, peer assessment of 3-4 other submissions, higher marks for integration of content from other activities (for e.g. CS and PR)	Peer workshop submission on LMS, built-in rubric and peer feedback system, online peer assessment enquiry journal	High active; Expert (rubric), tutor (setup)	IM2-IM5, critical thinking, deep understanding, questioning of peers, reward creativity (rubric), self-efficacy
Case studies (CS) – lessons that cover material failure analysis, material selection and performance in real-life contexts and tested in higher-stakes, deeper-level quiz	PDF document, pre-recorded walkthrough videos, multi-format online quiz casings made from composites?)	Passive + active; Expert lecturer	IM2-IM5, critical thinking, deep understanding, connect learning to personal experience (e.g. why are drill

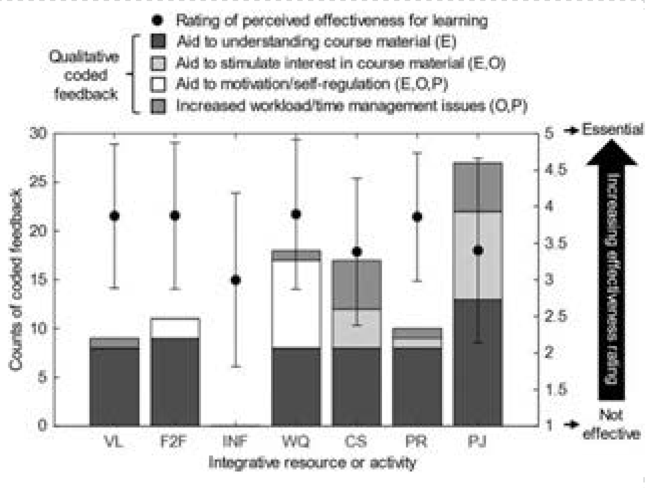

FIGURE 3: *Student-perceived rating of effectiveness (quantitative) of integrative activities and associated coded themes (qualitative) from student feedback*

Although some students recognised the low-level thinking required to complete the WQ, they also acknowledged the benefit of systemically guided learning and the (unexpected) development of time- and self-management skills:

Quote (RF): *It forces you to open your textbook and familiarise yourself with it (even if you just look everything up in the textbook and not necessarily study it still helps you to familiarise yourself)*

Quote (RF): *Quizzes helped make sure I kept up with work weekly so that I wouldn't fall behind on work*

A wide spread of rated effectiveness is evident for PJ with 81% of the responses indicating that peer assessment and the question-posing format motivated deep understanding through creative thinking and exposure to other opinions and explanations. Boud et al. [23] associates peer learning and assessment with the fostering of lifelong learning through critical reflection and development of various soft skills such as teamwork and reciprocal feedback. The PJ also stimulated the ontological senses of identity of some students through strong SG ties [20].

There are also metacognitive advantages associated with the task of creating quality, exam-level questions as part of the PJ assignment that foster critical thinking [14]. Some of these introspections include:

Quote (RF): *Viewing someone else's opinion or explanation was also beneficial as it deepened my own understanding*

Quote (RF): *The projects required a lot of research and understanding to complete. I found myself looking up topics I would never have searched for otherwise and actually found them very interesting. I feel that the projects have been a great aid to my studies and helped me see where material science is used in real life*

Quote (RF): *Doing...[projects]... furthered my understanding of topics, especially the projects. Because you have to know what's going on to ask a question on the topic*

Appreciation for understanding theory through contextualisation (stronger SG) was most evident in the feedback for the CS along with the most frequent coding of the word "interesting" that signify self-regulated learning [22]. This further supports the sense of what it is like to "be" a material scientist/engineer through the semantic weaving from foundational theory to real-world application in the shoes of a product designer (CS 1), forensic materials engineer (CS 2) and materials selection expert (CS 3). Practical sessions, although originally intended to be more P-centred (Figure 2), were perceived to be more of an integrative tool for deep understanding (E-centred):

Quote (RF): *The practicals by far. They are and have been crucial to me understanding the very big and important sections*

Kruger et al. [12] ties a similar observation in virtual mechatronics engineering course practical sessions to the cognitive facilitation and mediation of the conceptual understanding of various concepts. We believe this is only possible through a careful integration of each learning activity within the whole module design and E-O-P domains so that critical thinking is facilitated through connection-forming and fluctuation within semantic ranges [5], [14]:

Quote (SF): *The...[practicals]... displayed how intergrated [sic] all parts of the module was*

Interestingly in Figure 3, although the INF is considered to be the main integrative hub by the lecturers, it scored the poorest rating, albeit with a mean neutral response, despite anecdotal feedback from students indicating that they found it useful to their learning. Students cited that the INF and VL (which, in turn, incorporate the INF to introduce and summarise the weekly themes) helped "...navigate the content and the links between various topics and provide a good starting point for the..." other activities. As such, the INF and VL provided systemic support in helping students grapple with the content-heavy module.

B. Challenges and Successes of the Integrative Approach

Globally, engineering education experienced affective challenges resulting from ERT [11] and this module was no exception. Difficulty to manage the workload for MS as well as for other modules was a common theme reported across all integrative elements:

Quote (RF): *I feel like because there's so many things to do in this module, no student after a while actually takes everything seriously, so with the practicals and the case studies and the projects it almost feels like sometimes they are something we are just trying to get over and done with and don't actually take the time to learn properly from these exercises...*

Despite consistent deadline reminders posted on several official and unofficial communication platforms, many students would still request extensions or miss out on assignments. This is most likely due to the post-COVID19 context of hybrid learning combined with students misallocating time to certain tasks which highlights the importance of conveying time allocations within the module time budget. Ironically, there is a push-pull dynamic between the goal of cognitive development using this integrative approach and the discouragement of deep approaches to learning due to poor self-regulation, time management, sociological and workload stresses associated with multiple activities [8], [9]. Mirroring global challenges encountered with ERT [9], systemic challenges and the lack of digital literacies (primarily P dimension) were also evident as students struggled with basic document conversion, spreadsheet calculations, network/computer accessibility, LMS navigation and multi-modal communication platforms (forums, chats, e-mails, video conferencing) as they engaged with the multiple digital tools of the approach:

Quote (SF): For the practical...we were not told that we would need to be using excel. And my old laptop took about 15 mins to open excel.

It was also evident from the thematic evaluation that there is no digital replacement for contact sessions (more F2F and in-person PR):

Quote (RF): *I can confidently say that nothing trumps attending the in-person/F2F lectures for Mat. Sci - it is one of the only modules we have had this year that provides that contact session and it has created a more focused and enthusiastic learning environment for me.*

Quote (SF): *I would have loved to see some of the practical aspects in person. I know this is not up to you, but the experiments were very interesting and going into the workshops and seeing live experiments is very fun.*

Contact sessions motivate learning through peer interaction [23], ground abstract theories more effectively with real-world contexts [12] and develop "engineering" identities especially within marginalised groups [24] – all with deep O-domain implications.

Despite these challenges (which cannot be separated from the frustrations of the ERT reality), the E-domain was well supported within the integrative approach. Figure 4 shows the feedback of student-perceived understanding of the interrelatedness of the five principles of materials science and engineering, the "materials tetrahedron" shown in Figure 1. Survey questions probed the specific interrelatedness of the different principles (vertices) over the different activities (CS, PR, PJ) in addition to the VL and F2F. Students perceived that the activities achieved their goals in integrating content, as is evidenced by the high ratings (average of >3) for all digital tools or activities. Therein lies the main advantage of the initiative: having multiple, integrated, highly structured and digitally based activities in hybrid synergy with in-person lectures and guided by a lecturer-designed INF reduce cognitive loads as students use different parts of their working memory to engage with different aspects of the module and enhance their learning experience [25], [26]. A fine balance is also evident in Figure 4 in the motion from left to right: the mean perceived understanding (and implied confidence of understanding) dropped to slightly lower levels as the number of related activities increased, suggesting how easy it is to enter cognitive overload and lose the E-O-P benefits of the integrative approach, especially when there is no scaffolding of digital skill development to use the digital tools.

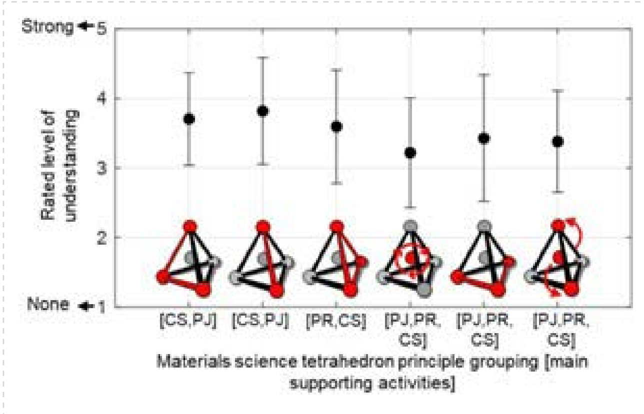

FIGURE 4: *Student-perceived rating of understanding of the interrelatedness of the five principles of the materials tetrahedron paradigm, as embedded in various digitally supported activities*

VI. CONCLUSIONS AND IMPLICATIONS

The "supercomplex" world [1] demands that universities adapt curricula to holistically support students through epistemological (E), ontological (O) and praxis (P) domains. This world also has many parallels with the constantly shifting "digital world" that requires engineering education to not only teach but also teach with different technologies. The approach of work was to leverage several digital tools within a holistic (E-O-P), integrative module design of a MS course. This course is traditionally very theory-dense with many interconnected principles and organised bodies of knowledge. At the onset of the course, students were introduced to an online infographic that graphically organises the interconnections between weekly themes of the textbook and module activities (in-person lectures, video lectures, case studies, projects, practicals and weekly quizzes) that each address different parts of the E-O-P domain. This integrative approach along with the structured weaving between concrete theory and real-world contexts is aimed at fostering deep approaches to learning and critical thinking skills – the shield and sword for the supercomplex world.

Feedback did highlight challenges with time management; students associated this with the wide range of activities that are employed in a hybrid, integrated approach to module design. Additionally, it was clear that there is a wide range of digital fluency across the student cohort. Students' level of competence relating to basic computer and data analysis skills directly influences their ability to engage and perform well in activities that require these skills, such as the projects and practicals. There is also a yearning (in the ERT context of 2021) for more face-to-face contact with the lecturer and with physical practicals that function as additional support for the O and P domains through peer interaction, a sense of "engineer" identities and navigating levels of abstraction from abstract to concrete.

These findings cannot necessarily be generalised beyond the specific context. Furthermore, MS is usually one of five modules that second year engineering students must complete within a credit-heavy semester. The success of the current approach in preparing students for supercomplexity therefore relies on systemically restructuring other curricular items in a similar digitally aided integrative manner whilst providing support for time management and scaffolding of digital skills. One approach considered in future work is easing tight deadlines and cognitive loads by, for instance, keeping case studies open for the entire semester, supplying more low-stake assessments and scaffolding digital skill development with additional pre-recorded videos. Nonetheless, the current approach provided a good spread across E-O-P elements of the student experience and can serve as a template for other theory-dense modules. As one student succinctly stated:

Quote (RF): …*Although online learning is possibly nearly at an end I feel a unified approach to [the LMS] and the format of module pages can have a massive impact on a student's [sic] state of mind, as it stands now Materials Science should serve as an schematic of how effective online studies can be, I know from first year to now much of online has improved, but when thoughtfully implemented [LMS] does not have to mean a compromise for the student/student's marks when compared to f2f.*

REFERENCES

[1] R. Barnett, "University knowledge in an age of supercomplexity," High. Educ., vol. 40, no. 4, pp. 409–422, 2000.

[2] R. M. Felder, "Engineering education: A tale of two paradigms," J. of Food Sci. Educ., vol. 20, pp. 8–15, 2021.

[3] K.M. Quinlan, Developing the whole student: leading higher education initiatives that integrate mind and heart. London, UK: Leadership Foundation for Higher Education, 2011.

[4] A. Tait, "Planning student support for open and distance learning," Open Learn., vol. 15, no. 3, pp. 287–299, 2000.

[5] A. Ahern, T. O'Connor, G. McRuairc, M. McNamara, and D. O'Donnell, "Critical thinking in the university curriculum – The impact on engineering education," Eur. J. Eng. Educ., vol. 37, no. 2, pp. 125– 132, 2012.

[6] World Economic Forum, "The future of jobs report," 2020. [Online]. Available: https://www3.weforum.org/docs/WEF_Future_of_Jobs_2020.pdf.

[7] E.P. Douglas, "Defining and measuring critical thinking in engineering," Procedia Soc. Behav. Sci., vol. 56, pp. 153–159, 2012.

[8] N. Korsten, K. Wolff, and M. J. Booysen, "Time for mentally healthy engineering students," in 2021 World Engineering Education Forum/Global Engineering Deans Council (WEEF/GEDC), 2021, pp. 101–109, doi: 10.1109/WEEF/GEDC53299.2021.9657375.

[9] L. Czerniewicz, N. Agherdien, J. Badenhorst, D. Belluigi, T. Chambers, M. Chili et al., "A wake-up call: Equity, inequality and Covid-19 emergency remote teaching and learning," Postdigit. Sci. Educ., vol. 2, no. 3, pp. 946–967, 2020.

[10] E. Sola, R. Hoekstra, S. Fiore, and P. McCauley, "An investigation of the state of creativity and critical thinking in engineering undergraduates," Creat. Educ., vol. 8, pp. 1495–1522, 2017.

[11] D.C. Blaine, C. Fussenecker, J. Niemann, and K. Wolff, "Did the Covid-19 pandemic improve engineering education? – A South African-German perspective" presented at the Int. Conf. on Comp. Manuf., Stellenbosch, South Africa, Mar. 9-11, 2022.

[12] K. Kruger, K. Wolff, and K. Cairncross, "Real, virtual or simulated: approaches to emergency remote learning in engineering," Comput. Appl. Eng. Educ., vol. 30, pp. 1–13, 2021.

[13] K. Wolff, K. Kruger, R. Pott, and N. de Koker, "The conceptual nuances of technology-supported learning in engineering," Eur. J. of Eng. Edu., in press.

[14] H. Kipper, and T. Rüütmann, "Teaching for understanding in engineering education," Int. J. of Eng. Pedagogy, vol. 3, pp. 55–63, 2013.

[15] C.J. Donahue, "Reimagining the materials tetrahedron," J. of Chem. Educ., vol. 96, pp. 2682–2688, 2019.

[16] C. Fredriksson, H. Melia and J. Cesonis, "An introductory teaching resource for materials science and engineering," presented at the 122nd ASEE Annu. Conf. & Expo., Seattle, WA, USA, June 14-17 2015.

[17] D. Verdín, A. Godwin, and M. Ross, "Stem roles: How students' ontological perspectives facilitate stem identities," J. Pre-Coll. Eng. Educ. Res., vol. 8, no. 2, pp. 31–48, 2018.

[18] T.A. Litzinger, L.R. Luttuca, R.G. Hadgraft, and W.C. Newstetter, "Engineering education and the development of expertise," J. of Eng. Edu., vol. 100, pp. 123–150, 2011.

[19] K. Maton, Knowledge and knowers: Towards a realist sociology of education. London, UK: Routledge, 2014.

[20] C. Lewis, K. Wolff, and B. Bekker, "Supporting project-based education through a community of practice: A case of postgraduate renewable energy students," World Trans. Eng. Technol. Educ., vol. 19, pp. 35–40, 2021.

[21] O. Miliou, and C. Angeli, "Measuring the internet skills of Gen Z students in higher education: Validation of the internet skills scale in university settings," presented at the Int. Conf. High. Educ. Advances, Valencia, Spain, June 2021, pp. 1059–1068.

[22] S. Krause, J. Kelly, and A. Tasooji, "Effect of pedagogy on conceptual change in repairing misconceptions of differing origins in an introductory materials course," Int. J. Eng. Educ., vol. 26, no. 4, pp. 869–879, 2010.

[23] D. Boud, R. Cohen, and J. Sampson, "Peer learning and assessment," Assess. Eval. High. Educ., vol. 24, no. 4, pp. 413–426, 1999.

[24] C. McCall, L.D. McNair, and D.R. Simmons, "Advancing from outsider to insider: A grounded theory of professional identity negotiation in undergraduate engineering," J. Eng. Educ., vol. 110, no. 2, pp. 393–413, 2021.

[25] S.N.H. Hadie, A.A. Simok, S.A. Shamsuddin, and J.A. Mohammad, "Determining the impact of pre-lecture educational video on comprehension of a difficult gross anatomy lecture," J. Taibah Univ. Medical Sci., vol. 14, no. 4, pp. 395–401, 2019.

[26] T. Colliot, and E. Jamet, "Asking students to be active learners: The effects of totally or partially self-generating a graphic organizer on students' learning performances," Instr. Sci., vol. 47, pp. 463–480, 2019.

Technical papers

Engineering student's flexibility for learning during education disruption

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***Abstract* — Due to the recent education disruption, engineering-related module classes have to rapidly and effectively move online because of unpredictable changes. For design-related technical modules, not much literature focused on how students and tutors can adopt the latest technologies in a relatively short span. This paper is an effort to find students' experiences and preferences around various interactive educational tools used in online synchronous teaching, such as interactive live zoom lectures, slide annotations, breakout rooms, recorded videos, and many more, which have been used at the University of Glasgow, Singapore, for the module known as Design and Manufacture 1, during the 2021 COVID-19 crisis and beyond. From this work, we were able to find how an online synchronous learning approach affects design engineering students' learning experience. To understand students' perception of online learning tools to be effective in enhancing their learning during a sudden change in the arrangement of physical classes to online classes due to the pandemic situation. Survey results were collected using google forms at the end of the trimester, which was offered to 65 students enrolled in the module based on the student experience. The response rate is around 70%. The survey result showed that students engaged very well with the technologies and took little time to adjust to online learning. Students found learning very comfortable using the latest online teaching tools during their online learning journey in the design engineering module.**

Keywords — Flexibility in learning, Engineering Education, Online Learning

I. INTRODUCTION

In this paper, a case study conducted at the University of Glasgow, Singapore of an online approach adopted in engineering education is presented in the context of a requirement for moving rapidly from regular face-to-face teaching to online teaching due to sudden change in Singapore government policies for Covid 19 situation during September 2021.

When the world first faced the pandemic, not much publication was found on how to use digital technology during this sudden urgency [1], where students couldn't travel from one place to another and had to be inside a house and study online using digital tools. Although it's been around two years, plus some work has been taken care of and published as the crises have deepened [2] and become normal in some parts of the world.

The research presented in this paper aims to add some information by investigating how tutors adopted the online strategies to deliver engineering modules and students' reaction to those new strategies – experience and perception of students [3]. Also, how the learning outcomes had been achieved using online synchronous learning during an abrupt change in teaching from physical to online learning due to the COVID-19 situation. The paper outlines the aim of this study, methodology, findings, and conclusion from students' perceptions and experiences.

The general approach to teaching students due to the COVID-19 situation is discussed at the university level. A case study of synchronous online teaching of the module known as Design and Manufacture 1 is explained. The aim behind this work was to investigate students' experiences and preferences around various interactive educational tools used in online synchronous teaching; hence, at last, the paper presents some conclusions based on findings from the students' survey, which can be helpful to look forward in the situation which is similar to Covid 19 situation in future.

II. UNIVERSITY'S APPROACH AMIDST DISRUPTION

To understand principles related to engineering design, it is essential to design a module based on team-based open- ended project work [4-8]. The first project-based module for mechanical engineering students is frequently used to orient students to the engineering design process, which establishes the norms for process, performance, and collaboration that will be expected in later design experiences [9]. To fully explain product design to students, which focuses on leveraging students' knowledge concepts learned in previous years based on physical science and their prior knowledge, the University of Glasgow, Singapore, had two different team- based project work modules. The one is known as Design, and Manufacture 1 teaches them how to work in a team for projects, engineering design process, concept generation, concept selection, the final concept, and its soft prototyping using any CAD software. The other module, known as Mechanical Design, focuses on prototyping iterations, testing, and refinement.

The development of the coronavirus started in China in January 2020. The second phase of this pandemic was declared around September 2021 in Singapore and lasted longer, around six months, as a heightened alert [10]. During this period, strict measures were implemented by the Singapore government. Initially, due to the sudden rise in cases, teaching for higher education shifted to home-based learning immediately. This meant that from Sep 2021, e- learning became a mandatory requirement in higher institutions. The Singapore Institute of Technology (SIT) and the University of Glasgow (UoG), where this study is performed, run a joint degree program in mechanical engineering. This joint degree course has a trimester system. In the year 2021, Trimester 1 started in September. It was running in blended mode as students had lectures online (due to the limitation of 50 students in a room) and for studio/lab sessions conducted on campus with less than 50 students in a room. This arrangement lasted for the first two weeks of the trimester out of a total of 13 weeks but later, due to a change in government policies for Covid 19 pandemic, everything converted into the online mode for the rest of the trimester for around ten weeks. As a result, the online mode, which is traditionally known as the e-learning mode for a long back, has become [11-13] mandatory for higher education in Singapore.

Students and educators faced many implementation challenges in other parts of the world mentioned in literature [14, 15], but they were overcome and achieved many significant results. As online education becomes the norm during covid 19, universities need a structured and readily accessible learning management system (LMS) [16]. To be ready with this requirement, some basic guidelines were given by the university where educators have to upload some lecture material, PowerPoint slides, the live recording of the lecture, and supportive other documents on the LMS. During this E- learning phase, LMS becomes a sustainable, accepted model in this technology development [17, 18]. Zoom platform was used to deliver an online lecture as well as for studio sessions where breakout rooms were used by educators. Recorded videos became an essential part and core support for students during these e-learning periods [19, 20]. Due to the requirement of accreditation and some basic pedagogy for engineering, such as student engagement and active learning, some [21, 22] additional learning facilities for e-learning were used are listed below,

- xSiTe: Learning management system which was used to circulate news, upload lecture notes and other related materials, posting of online links for live online lectures and studio sessions, chat during live sessions, quizzes, grading, grouping, and many other activities.
- MS-Team, along with xSiTe for instant messaging and group chat.
- MS Office tools such as Outlook, Sharepoint, and Forms.
- MS PowerPoint and zoom for online delivery, lecture recording, and breakout rooms for group discussion.

III. ONLINE TEACHING ADJUSTMENT IN A DESIGN AND MANUFACTURE 1 MODULE

The effectiveness of the flexible online learning approach due to Sudden Change in Government Policies for Covid 19 Situation has been examined through a second-year Mechanical engineering module in design specialization, entitled MEC 2131' Design and Manufacture 1'. There were 65 students enrolled. The module contributed five credits.

A. Module Background

This module consists of lectures, case studies, lab sessions, projects, and CAD modeling/visualization. It aims to introduce the systematic industrial design process, including defining the customer needs, concept design generation and selection, embodiment design, detailed design, etc. Students learn how to create/sketch out product/engineering ideas and drawings to effectively communicate design ideas and solutions using freehand sketching, which ensures that students can effectively communicate design concept ideas and solutions. In contrast, the CAD tool doesn't do that. Students will be exposed to the working team dynamics, the engineering design process, report writing, oral presentation, and project management during project work. There was no exam and a 100% continuous assessment module.

The primary learning outcomes for this module are for students to be able to:-

- Apply the engineering design process in a collaborative engineering environment.
- Sketch out product/engineering ideas and produce engineering drawings creatively to effectively communicate design ideas and solutions; and
- Present the design concepts and final design technically through reports and oral presentations.

B. Standard Module Structure

The lectures cover the theory and methods used in engineering product design, the development of concept generation and methodology, and the examination of case studies. They also cover the design, analysis, and simulation for manufacture alongside 3D printing and tooling concerns. The lab sessions involve the development of creative thinking and problem-solving skills and work on a small group design project that links these to engineering requirements. The student selects a project from a shortlist; each project aims to allow the students to apply their acquired creative thinking and problem-solving skills to develop a conceptual design for a product that extends the application of an existing product into new markets and/or develops the design to expand sales in existing markets and reduce manufacturing costs. The lab session work also involves the detailed design/modeling and analysis of a component or small assembly for high-volume manufacturing. This will be achieved via a small group design project that applies knowledge gained through the lectures and the creative thinking and problem-solving skills practiced in the first year of engineering studies. The project provides a challenging technical problem to which the student can develop and present workable and manufacturable solutions at various levels of automation.

C. Module Delivery under Educational Disruption

A fully flexible online approach was implemented within the Design and Manufacture 1 content [3]. This includes synchronous lectures and studio sessions to improve delivery effectiveness [23, 24]. The teaching delivery also allows for annotation of teaching material [25, 26], live online classes, and studio sessions using breakout rooms via the zoom platform [27]. Adopting this kind of module delivery helps achieve better student engagement during the COVID-19 situation [28, 29].

- A laptop was used to deliver live lectures on Zoom. Synchronous teaching was used when providing both lectures and studio sessions. Digital ink helped use the digital whiteboard smoothly and replaced the physical classroom whiteboard.
- In planning for an interactive online teaching approach, it was decided to maintain the contact hours of teaching and studio sessions as per the original timetable, though online rather than in a physical classroom.
- Informal opportunities for students to discuss modular issues ('Office hours') were arranged upon request, either through chatting by text or using audio/video short sessions for further interactive discussion.

Discussions between the tutor and students took place privately on the MS-Teams platform to enhance students' engagement and provide pastoral care.

D. Lecture preparation during the outbreak

The total number of students enrolled for this module MEC 2131 Design and Manufacture 1, was 65. Before starting the trimester, the government rule was allowing lectures to be online (as students enrolled were more than 50), but studio sessions with the capacity of 50 students can take place on campus with a group size limit of 5. Considering government rules, we planned to deliver lectures online and studio sessions with two different teams having 33 and 32 students, respectively, on campus. Students were divided into groups of 4 or 5 on each team. xSiTe was used as a learning management system to upload the module brief, profile, and all other details.

Fortunately, all students enrolled in this module were domestic students only. In the first teaching week, a student representative was nominated by students to facilitate communication among the students and the convenor for each team. Online lectures were delivered using Zoom and PowerPoint, recorded, and later uploaded for students' reference on xSiTe. The students used their own devices and internet connections to access the teaching material and engage in the live classes. All students confirmed that they were able to watch the uploaded videos smoothly. The virtual classroom was booked on Zoom, and the invitation was sent to all students through announcements on xSiTe. Studio sessions were conducted physically at the campus. After two weeks, due to the sudden rise in the number of Covid patients, government rules were changed, and now just a group of 2 students can work together, and studio sessions are also not allowed on campus. So suddenly, there was a change in teaching pattern, and have to shift studio sessions also online along with lectures.

E. Online lecture delivery

We followed the timetable and Zoom platform to conduct live lectures announced before starting the trimester for lecture delivery for 1 hr per week. We also took advantage of different features of the Zoom platform, such as chat, polls, quizzes, whiteboard, raising hands, and many more. We asked questions, shared recorded lectures, and shared annotated slides using electronic ink during classes to support palliate students' issues.

F. Studio Session

During the studio session, students were expected to work on some projects. Studio sessions are used to reinforce and deepen understanding of the module material. Students are expected to actively participate in the studio and go through provided study material to teach themselves relevant skills in Mechanical Engineering. Concepts from "Team-Based Learning" are used. Students work in groups on a project involving knowledge learned from the class and applying the outcome from the weekly studio. For both groups, the pre-planned timetable was also followed for delivering studio sessions online using Zoom and many features of it. In addition, the discussion took place with individual teams on their weekly progress for the given project using breakout rooms.

Students were asked to submit an interim report, interim presentation, logbook, final report, and final presentation in xSiTe folders as a part of the assessment. Also, an online quiz was conducted at mid of trimester as a part of the assessment.

IV. METHODOLOGY

The current study mentioned in this paper attempts to understand how MEC 2131 Design and Manufacture 1 students perceive various online learning tools to help enhance their sudden learning change during the covid-19 situation. In this study, a questionnaire was designed using google form and given to all 65 students who enrolled in the module, and Forty-five students completed it. Students answered questions regarding the teaching method's helpfulness, the technology used for teaching, student engagement, and student preferences.

The invitation to participate in the survey was sent to all students as an announcement on xSiTe, with a few follow-up reminders. Around 70% of students completed the entire survey.

V. RESULTS AND DISCUSSION

The survey questionnaire responses are described in the following paragraphs.

The students were asked to provide their feedback to know if their intervention was successful following questions were asked using a rating. (Students need to give their answer in terms of rating from 1 to 10, where one is least helpful, and ten is most helpful, Except for the question. 3, which is an open- ended question.)

1. Did you find it easy to use online technology?
2. Did the online, live lectures used in this subject help you learn effectively?

Results on learners' perception of the Questions listed above are illustrated using an excel clustered data chart below in Figure 1.

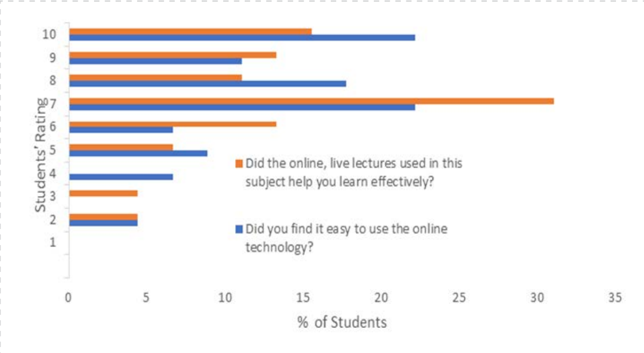

FIGURE 1: Students' response to the success of online technology and lectures.

Around 73% of students rated seven or higher than seven as their satisfaction rating out of 10, where ten is most helpful. Students felt that they found the technology easy to use, and online live lectures helped them learn effectively.

The student mentioned that this module delivery is better than other modules as it focuses more on communication and brainstorming with peers instead of utilizing much technical understanding than other modules. Students praised about effort taken by educators to teach them online. These results reflect that online live lectures will be one of the motivations for students' engagement during online course delivery.

To understand which tools were more impactful for students' online learning following questions were asked during the survey.

1. Did you feel that the use of the electronic whiteboard improved your learning experience?
2. Do you think that the teacher's annotations on the lecture slides advanced your understanding of the content?
3. Were the live lectures better than the prerecorded lectures for helping you learn?

The results are presented in Figure 2 below.

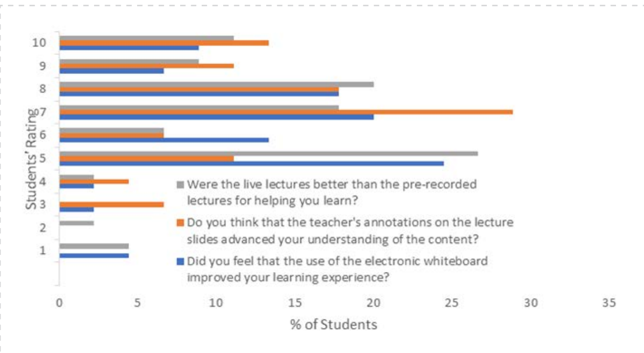

FIGURE 2: Evaluation of students' preferences

Around 91% of students were satisfied with using a whiteboard during their online module delivery. 89% of students preferred annotations on lecture slides during lectures for more understanding. 91% of students preferred live lectures over prerecorded lectures by rating either five or higher on a scale of 10 as most helpful. This result demonstrates that using a whiteboard and annotation on lecture slides is considered the most helpful tool in their learning. Also, annotating slides during lectures improves their understanding of the concept, and more preference is given to live online lectures over prerecorded lectures.

Students were asked to rate their experience with distraction during online class compared to in-class learning.

The results are presented in Figure 3 below.

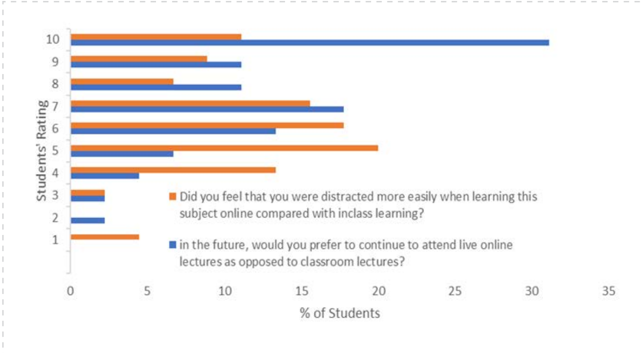

FIGURE 3: Student Preferences and Distractions

Around 80% of students found no or some distraction during online lectures, and thus it seems that students are happy to replace in-class studies with online studies if it's a matter of distraction. Also, in the response on future preference to replace classroom lectures with online live lectures, almost 91% of students are ok with going ahead with the online live lecture.

Some of the responses we got on the open-ended qualitative question, 'You felt this module was better or worse than other modules taken online? Why?' were listed below.

"It was alright because we did not have to create a physical prototype."

"Better cause it's more on communication and brainstorming with peers instead of utilizing much technical understanding compared to other modules."

"Better since it is interesting and has practical uses in life."

"Better, the subject is theory and project-based, which can be easily clarified through zoom."

"I think that online lecture is useful because it is recorded, and it can be reviewed again."

VI. RECOMMENDATIONS FOR FUTURE

Considering the students' responses to the survey and their comments, the following essential recommendations are presented:

1. Online technology for learning is simple if the institution selects the platform very carefully.
2. Online live lectures are more efficient than prerecorded lectures during online teaching as students find themselves more engaged in live lectures.

3. Simply delivering a lecture like a webinar will not be effective, so teacher annotations on slides during the online live lecture were considered the most helpful intervention in students' learning.
4. It turns out that live online lecture improves students' engagement compared with prerecorded lectures. Therefore, live online lectures should be the priority for effective online lecture delivery.
5. Aiming for comfortable and engaging online learning during education disruption, a combination of online live lectures with an electronic whiteboard and slides annotations will be much more beneficial. Uploading learning material in advance for students' use, prerecorded lectures, supporting videos, and extra notes will help students prepare in advance, leading to a highly engaging class.

VII. REFLECTION

The results contribute to the field of engineering education through a theoretical framework that guided the data collection and analysis, which in turn confirmed the suitability of the proposed framework. The study reflects the most important factor influencing students' readiness for any sudden disruption is effective communication between tutor and student at every stage is very important to help students understand the need and benefits of the change. It is interesting to note that the result of this study allowed us to discover new dimensions in the online teaching of engineering modules. During the pandemic period of Covid 19, as mentioned before, online education was implemented using different technological tools and methods available. As a result, at the university level, many modules are developed using digital learning techniques, including e-learning platforms, video conferencing, video recording using annotation, voiceover slide presentations, computer-based simulations, online examinations, etc. With growing awareness and competence of digital learning skills by faculty members, integrating these methods to support students learning will be an ongoing trend for the future of engineering education.

On the other side, the survey and module results confirm that this synchronous online learning approach is very effective in achieving the mentioned learning outcomes as students collaborated for learning very well by using the zoom platform, breakout room, and also live chat using Teams. During the presentation at mid-term and the end of the term, students communicated their design ideas very well to all via an online oral presentation.

VIII. CONCLUSION

In this study, we sought to explore students' (learners') experience of going through online live lectures and studio sessions during Education disruption developed due to the sudden change in government policies for Covid 19 situation. The effectiveness of this approach was measured through a survey conducted with students at the end of the trimester, and it has been evaluated based on the survey results presented in the results and discussion. From that, we can conclude that students found themselves comfortable using technology and engaged well with technologies to gain subject knowledge during online learning. The approach adopted by universities and educators was adopted easily by students and helped achieve the learning outcomes. Even though students are happy to continue with a similar approach in future learning, we may find some differences between students' preferences for the use of different online learning tools as well as we as an educator need to keep in mind that students' perception of online learning may change over some time according to the situation.

REFERENCES

[1] Carmel McNaught, "Using Narrative to Understand the Convergence of Distance and Campus-Based Learning During the Time of SARS in Hong Kong," Educational Media International, vol. 41:3, pp. 183-193, 2004.

[2] Huang, R.H., Liu, D.J., Tlili, A., Yang, J.F., Wang, H.H., et al., "Handbook on Facilitating Flexible Learning During Educational Disruption: The Chinese Experience in Maintaining Undisrupted Learning in COVID-19 Outbreak", Smart Learning Institute of Beijing Normal University. March 2020.

[3] S. Welsen, P. Morgan and J. Walker, "Flexible Learning During Educational Disruption: A Case Study of Teaching Integrated Circuits Design", IFEES World Engineering Education Forum - Global Engineering Deans Council (WEEF-GEDC), pp. 1-5,2020.

[4] Awatramani, Mihir and Diane T. Rover, "Team-based learning course design and assessment in computer engineering." IEEE Frontiers in Education Conference (FIE) 1-9, 2015.

[5] Eberhardt, Alan & Johnson, Ophelia & Kirkland, William & Dobbs, Joel & Moradi, Lee, "Team-Based Development of Medical Devices: An Engineering-Business Collaborative", Journal of Biomechanical Engineering. 2016.

[6] Hodgson, Antony & Ostafichuk, Peter & Sibley, James, "Team-Based Learning in the Design Modules of a New, Integrated, 2nd Year Curriculum at UBC", Proceedings of the Canadian Engineering Education Association, 2011.

[7] Parappilly, Maria & Woodman, Richard & Randhawa, Sharmil, "Feasibility and Effectiveness of Different Models of Team-Based Learning Approaches in STEMM-Based Disciplines", Research in Science Education, 2021.

[8] Kuppuswamy R and Mhakure D, "Project-based learning in an engineering-design course– developing mechanical-engineering graduates for the world of work. Procedia CIRP 91 565- 570, 2020.

[9] J. Buckley, H. Malladi, A. Trauth, and M. G. Headley, "Novel Hands- on Product Design Module for Online, Large-enrollment FYE Courses," accepted for publication, ASEE Annual Conference & Exposition 2021.

[10] Dr. Mathew Mathews, Syafiq Suhaini, Dr. Mike Hou, and Fiona Phoa, "Living With Covid-19 In Singapore: Attitudes, Challenges and The Way Ahead", Ips Working Papers No. 43, Dec 2021

[11] Karen Smith, and John Hill, "Defining the nature of blended learning through its depiction in current research", Higher Education Research & Development, vol. 38:2, pp. 383-397. 2019.

[12] F. Rennie, and T. Morrison, "E-learning and social networking handbook", Resources for higher education, Taylor & Francis, 2013.

[13] Turnbull, D., Chugh, R. & Luck, J., "Transitioning to E-Learning during the COVID-19 pandemic: How have Higher Education Institutions responded to the challenge?". Educ Inf Technol 26, 6401– 6419, 2021

[14] Yan Wang, Xuan Liu, and Zhenhong Zhang, "An overview of e- learning in China: History, challenges, and opportunities," Research in Comparative and International Education, vol. 13:1, pp 195-210. March 2018.

[15] James Kariuki Njenga Louis Cyril Henry Fourie, "The myth about e- learning in higher education," British Journal of Educational Technology, vol. 41:2, pp. 199-212, February 2010.

[16] Navarro, Maricar & Prasetyo, Yogi & Young, Michael & Nadlifatin, Reny & Redi, Anak Agung Ngurah Perwira, "The Perceived Satisfaction in Utilizing Learning Management System among Engineering Students during the COVID-19 Pandemic: Integrating Task Technology Fit and Extended Technology Acceptance Model". Sustainability. 13. 2021.

[17] Alkabaa, A.S. "Effectiveness of using E-learning systems during COVID-19 in Saudi Arabia: Experiences and perceptions analysis of engineering students". Educ Inf Technol 2022.

[18] Alturki, U.Aldraiweesh, A. "Application of Learning Management System (LMS) during the COVID-19 Pandemic: A Sustainable Acceptance Model of the Expansion Technology Approach". Sustainability 13, 2021

[19] Lindsay, E., Evans, T., "The use of lecture capture in university mathematics education: a systematic review of the research literature". Math Ed Res J 2021.

[20] Lapitan, L., Jr., Tiangco, C. E., Sumalinog, D., Sabarillo, N. S., & Diaz, J. M., "An effective blended online teaching and learning strategy during the COVID-19 pandemic". Education for Chemical Engineers, 35, 116–131, 2021

[21] Taraban, R., Anderson, E.E., DeFinis, A., Brown, A.G., Weigold, A. and Sharma, M. (2007), "First Steps in Understanding Engineering Students' Growth of Conceptual and Procedural Knowledge in an Interactive Learning Context," Journal of Engineering Education, vol. 96:1, pp. 57-68. January 2013.

[22] Kebritchi, M., Lipschuetz, A., and Santiague, L. (2017), "Issues and Challenges for Teaching Successful Online Courses in Higher Education: A Literature Review," Journal of Educational Technology Systems, vol. 46:1, pp. 4–29. August 2017.

[23] Fita A., Monserrat J.F., Moltó G., Mestre E.M., and Rodriguez Burruezo A., "Use of synchronous e learning at university degrees," Computer Appl Eng Educ, vol. 24:6, pp. 982-993. November 2016.

[24] Goodridge Wade H., Lawant Oenardi, Santoso Harry B., "A Learning Style Comparison between Synchronous Online and Face-to-Face Engineering Graphics Instruction," International Education Studies, vol. 10:2, pp.1-14. 2017.

[25] Nguyen, Ken & Rahman, Muhammad, "On-Demand Video Tagging, Annotation, and Segmentation in Lecture Recordings to Enhance E- learning Effectiveness". 9th International Conference of Security, Privacy and Trust Management, 2021

[26] M. Malchow, M. Bauer, and C. Meinel, "Enhance learning in a video lecture archive with annotations", IEEE Global Engineering Education Conference (EDUCON), Tenerife, pp. 849-856, 2018.

[27] Agustina, Ema & Suharya, Toto, "Zoom breakout room for students' collaborative skill enhancement in history learning during Covid-19 outbreak", IJRICE, Vol 5, No 1,2021

[28] Higgins, M.C.M., Taylor, A.H., Rocco, S.A "COVID-19 pandemic student engagement strategies for materials science and engineering courses". MRS Bulletin 47, 5–9, 2022.

[29] Talar Agopian, "Online Instruction during the Covid-19 Pandemic: Creating a 21st Century Community of Learners through Social Constructivism", The Clearing House: A Journal of Educational Strategies, Issues and Ideas, 95:2, 85-89, 2022

Technical papers

Strategies for improving online student learning in undergraduate material science

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***Abstract* — Since the outburst of the Covid-19 pandemic it is very common that students widely use videos in higher education. In an introductory material science course for mechanical and automotive engineers lecture videos have successfully been implemented in inverted classroom teaching scenarios at HTW Berlin. Inspired by former students a set of lecture videos is produced during a one term project each semester. This peer-to-peer approach is an important aspect because students` needs and their perspective on teaching material is directly included in the videos. In this study five different lecture film types were investigated with regard to students` performance and micro grading comprising of: swipe technique, stop motion, power point animation, hand drawn and video scribe. In general, students` performance was found to be more successful before the pandemic. However, the type of lecture film types could not directly be related to student grades but are rated successful regarding concentration, responsibility and attentiveness as well as depth of discussions during class.**

Keywords— lecture films, first year students, inverted classroom, peer to peer, material science.

I. INTRODUCTION

A growing deal of interest in using various types of media in conjunction with (or sometimes in place of) more traditional teaching methods commonly comprises the use of audio or video recordings. Also short lecture videos of relevant course material are established providing an audio and visual stimulus covering different learning methodologies. Inconclusive evidence of improved understanding of course material, effective use of time in class, and retention of course material was demonstrated by Gulley and Jackson [1]. In general, students perceived the inclusion of videos in the lectures as significantly useful [1], [2], [3] and viewed them as easy to use and effective learning tools [4]. Students also prefer interpolated questions within online videos. These may increase the learner's engagement with the material [5] and help to improve actual performance [6]. However, students tend to be overconfident in their learning from video-recorded modules [6].

Note, that there is a difference between audio or video recordings of lectures comprising at least 5 different techniques [7] and short lecture videos of relevant course material [8]. To be aware of these differences is important for the practitioner who is now increasingly involved in developing network-based resources for learning. Of course it is discussed whether both lecture videos and lecture recordings might outgrow traditional teaching methods [7], [8]. Presupposed the video included is analogous to the desired learning outcomes of the lecture [2] and the backgrounds and experience as well as the discussion arrangements of participants are considered [9] lecture videos are definitely a reinforcement, rather than a replacement for lectures [10]. In general, the lecture technique (in-front teaching or video support [11]) does not determine or enhance the learning outcome unless lectures demonstrate practical work [12]. The amount of video motion in lecture video formats does not enhance learning outcome while hand-drawn lecture videos increase student engagement [13].

At HTW Berlin, materials science is taught to first year mechanical engineering students via the "design-led" teaching approach [8], [13]. In a blended learning setting, lecture videos were implemented into inverted classroom teaching scenarios. Various authors state that inverting the classroom has a positive effect on self-efficacy beliefs and intrinsic motivation [8], [14], [15], [16]. When students are directly involved in teaching activities (preparation of lecture videos), critical thinking is enhanced [17], [18] and deeper learning outcomes are achieved [19]. Therefore, lecture videos are prepared using the peer-to-peer approach ("from students for students" [20]) at HTW Berlin [21]-[24]. Generally, four to six students worked on a full concept and implementation and integration of three to six lecture films, each two to eight minutes long [22], [23].

In this practical study the author depicts inverted classroom scenarios from her undergraduate classes in which lecture films are implemented. Strengths and weaknesses of the teaching method are discussed and results on students` performance are given. Weakness of the study is that different video formats are used to teach different topics in addition to the complexity of the different concepts in materials science using different teaching methodologies (self-study, peer learning). Still, because effective operation of the lecture films is based on students` acceptations and their special needs when preparing for specific topics in materials science, the aim of this study is to gain qualitative student feedback on types of video lecture support provided and evaluate students` perception of how effectively lecture film formats aided their understanding. Students` performance was taken from summative micro assessment after each lesson. After each semester students evaluated lecture film formats with regard to quality of assets and voice-over, depth of topic, joy of use, understanding of content, ability to apply content to complex problems and personal acceptation with regard to improving individual learning outcome.

II. LECTURE VIDEO FORMATS

Lecture videos are preferred by students and provide excellent requirements when inverting the classroom. They appeal to many students and are therefore a probate media to encourage students to self-study. In the first year materials science course lecture videos were not add-on, but (in most scenarios) the only source of material with no face-to-face or online lecture on the particular theme.

Up to now, there are 73 lecture films ready available on Moodle HTW and YouTube. These comprise of different film formats (Table 1) and have all been produced following the peer to peer approach https://www.youtube.com/c/Werkstofftechnik-HTWBerlin.

TABLE 1: *Lecture film formats*

Lecture film formats	Rating*	Acceptance#
Swipe technique	difficult	medium
Adding motion pictures	difficult	medium
Fast motion real time drawing,	easy to moderate	medium
How to video	moderate	very high
Motion picture	easy	high
Screenplay	easy	high
Screenplay including: power point animation	very difficult	medium
Hand-drawing	difficult	medium
Stop-motion technique	difficult	high
Power-point animation	difficult	very high
Video scribe using hand drawn	moderate	very high

* Experience of students producing lecture films considering production and post-production (pre-production is valued equally challenging and independent of lecture film format)

\# Acceptance of students studying lecture films (evaluation after each semester from 2014 up to now)

III. LECTURE SCENARIOS

Five inverted classroom teaching scenarios using different lecture film formats are introduced: hand drawing, video scribe, power point, stop motion and swipe-technique. All lectures were followed by exams. Note, that red columns reveal results from fully online semesters in 2020 and 2021.

A. Hand-drawing: Polymers

Due to the nature of a first year materials science course for mechanical engineering students polymer structures are only briefly discussed, declared as self-study lectures based on lecture videos (Figure 1) with the possibility to ask questions via chat set for a certain time (here: 19.00 to 22.00 o`clock). A compulsory online exam via Moodle (open until 2 am the next morning, (30 questions in 45 minutes)) added to the credits of the course [15]. Over six semesters (SS2016 until SS2019) approximately 50% of the students passed the exam with A- and better accounting to their good study skills and deep learning outcome (Figure 2). Less than 25% scored C or worse. The fully online teaching during the Covid-19 crisis and also summer semester 2022 delivered less successful grades. The author relates these findings most likely to missing engagement in student learning when forced out of social grouping during studying as experienced during isolated studying during the pandemic.

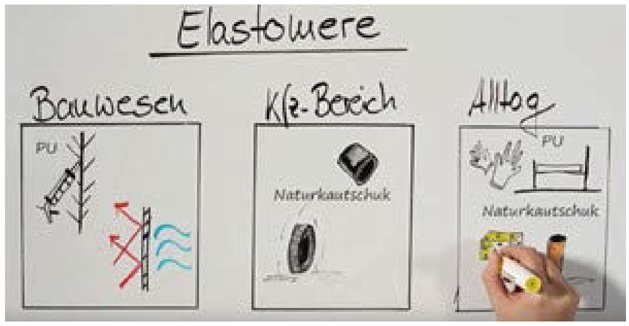

FIGURE 1: *Lecture films: polymers: hand drawing. (5) (22:43 min): https://www.youtube.com/playlist?list=PLUOlZMSZYz5wUlfwge0VTxKokobD_OOK7.*

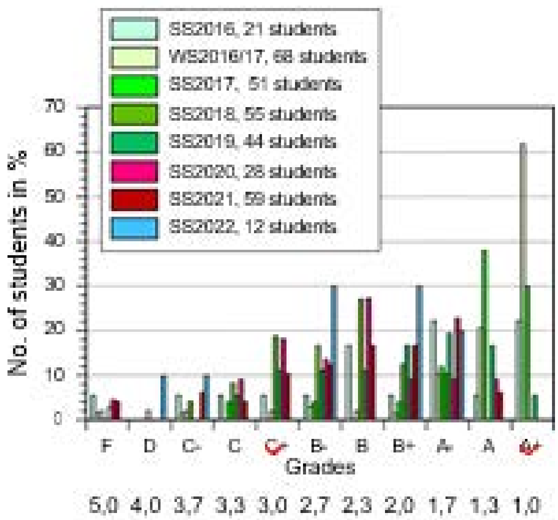

FIGURE 2: *Results of compulsory nightly online exams on polymers.*

B. Video scribe: Defects in crystals

Defects in crystals are source of strengthening and plastic deformation within the microstructure of solid state materials. Students study the scientific background at home working on Moodle-lectures and an easy-to-read scientific research paper dealing with microstructural properties. Heart of the self-study period are five video scribe (https://www.videoscribe.co/en/) lecture videos – each covering one type of defect: point -, line -, 2-D - and 3-D defects and plastic deformation (Figure 3) (25 questions in 35 minutes). Students were given quizzes during self-studying. One specific defect and its mechanism had to be explained in a topic related glossary. This was commented and corrected by the lecturer the same week.

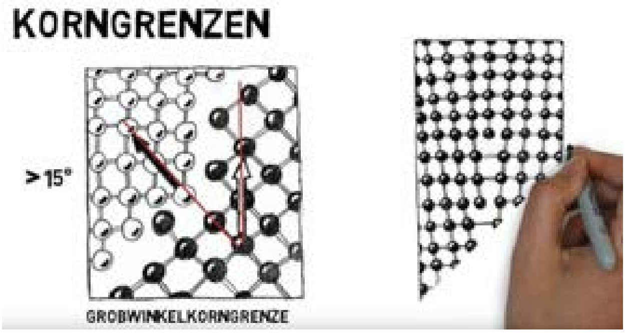

FIGURE 3: Lecture films: defects in crystals: video scribe. (5) (32:55 min): https://www.youtube.com/playlist?list=PLUOlZMSZYz5wlO3gea5jL FhxgAr3IiOja.

The open-source software invote helped to assess the study progress and offer the lecture an overview of the student`s actual knowledge. A Q&A-session helped students to answer questions and discuss important issues individually. Student groups of four to six students each summarized one of the 15 defects including: microstructural changes and impact on mechanical properties. Students who did not work at home were given extra assignments and later intermixed with the starting groups. Using a strict template to guarantee similar information, the student groups presented their work which was commented, added and corrected by the plenum and uploaded to Moodle later. Subsequent a typical engineering problem was assigned to student groups of two which evoked discussions among the students. The compulsory test proved good understanding of defects and delivered very good results (Figure 4).

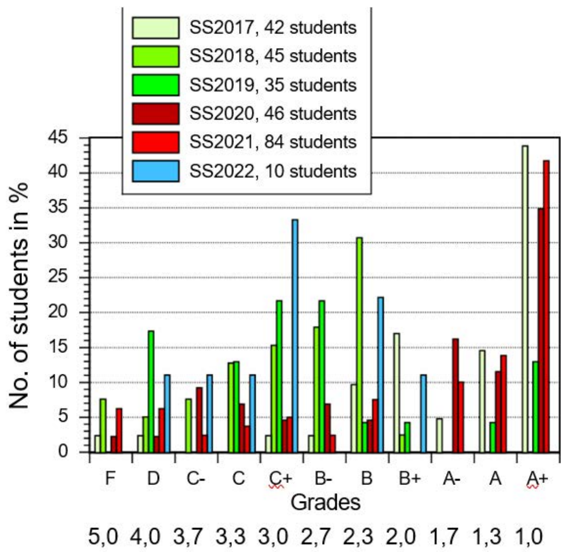

FIGURE 4: Results of compulsory online exams on defects in crystals.

C. Powerpoint animation and stop motion hand drawn:

Tensile testing was briefly introduced in class and the stress-strain diagram explained briefly. At home students were asked to work on a set of three lecture films (Figure 5) demonstrating the actual testing method and explaining how to interpret the stress-strain diagram. Group assignments accompanied the self-study period that had to be handed in the following week. Also, five short lecture films on hardening mechanisms designed via stop motion technique were assigned and the following face-to-face lecture was conducted similar to the lecture on defects in crystals. Results of the online-test (30 questions in 45 minutes) are depicted in Figure 6. Students generally score less successful on this test due to the more complex topic but again students` grades were a lot higher before the pandemic.

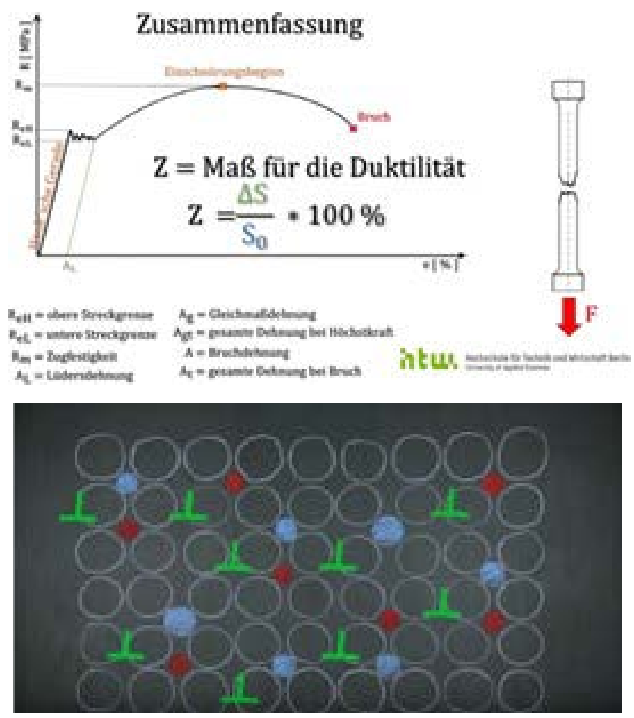

FIGURE 5: Lecture films: Reading of the stress-strain diagram and hardening mechanisms: power point, stop motion hand drawing. (6) (38:17 min): https://www.youtube.com/ playlist?list=PLUOlZMSZYz5wm7m- ahbD8r4dCjDU498mV.

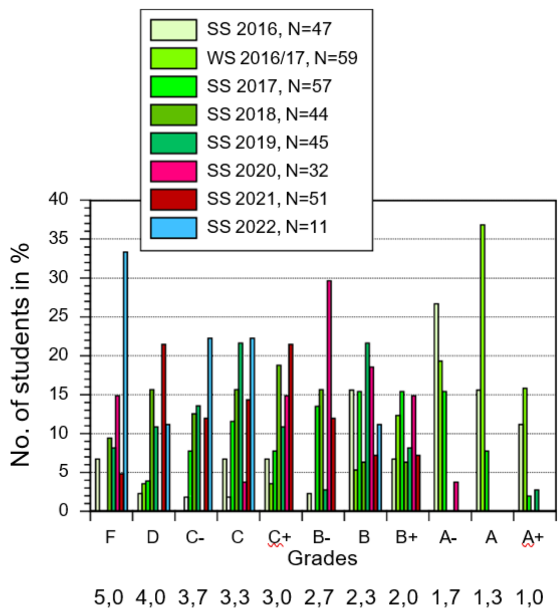

FIGURE 6: Results of test strength, plastic deformation and hardening mechanisms (4/60).

D. Paper cut-out animation: Fiber reinforced polymers

Fiber reinforced polymers (frp) were introduced to first year students using six lecture films (Figure 7)

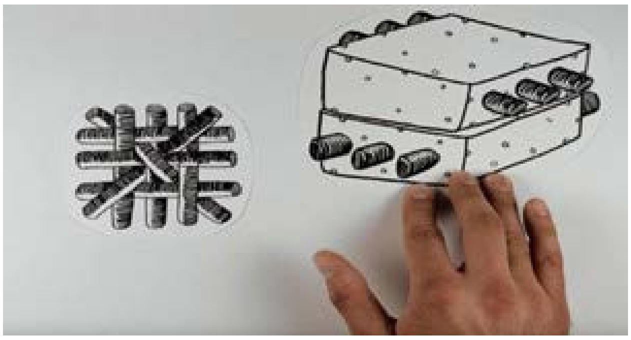

__FIGURE 7:__ Lecture films: Fiber reinforced polymers: swipe technique (paper cut-out animation): (6) (35:31 min): https://www.youtube.com/playlist?list=PLUOlZMSZYz5y8XYE1S0 9HIH60tSxlUERe

Groups of four students had to prepare one lecture film being able to explain the scientific background properly. Additional optional lecture films were accompanied by voluntary lectures and small quizzes:

After checking on the learning progress via invote, students who prepared the same lecture film worked as one of six groups were given 30-40 minutes to summarize the main points of the lecture film on a special template in a first session. This guaranteed the correctness of the teams` final summary made available to all students. In a second round, students were divided into groups with six students each, so that each team had one expert for each of the lecture film topics. All students were then asked to briefly present their most important issues to the new team members and explain open questions arousing from the summary sheets [22].

All students taking the voluntary exam passed. 20% of the students scored with 70% or more (Figure 8) which accounts for a very good result considering that this test was voluntarily.

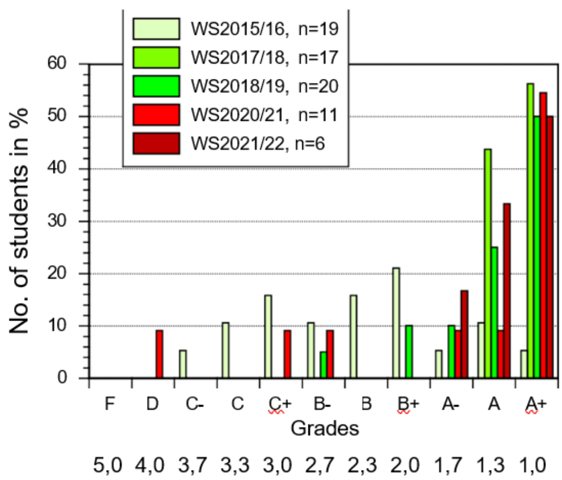

__FIGURE 8:__ Results of voluntary nightly online exam on fiber reinforced polymers: swipe technique (paper cut-out animation).

V. EVALUATION

Embedded in the Moodle-based grading [15], the combination of interactive online lectures, tests and quizzes with the lecture videos provided a highly appreciated learning environment. The high workload for both students working on the films and the lecturer [22] requires the production of lecture films for repeatable basic materials science topics that do not change over time. Due to the nature of the peer-to-peer approach, each set of lecture films is different offering a great variety and "surprise" keeping students motivated throughout the semester. All lecture videos are implemented in inverted classroom teaching scenarios and the self-study periods lasted one week before a test was taken. During the self-study periods introduced lecture films are main teaching resource in materials science course. Generally, first year students request lecture films for study content requiring a high level of abstraction. These lecture films fill the gap between the results presented in texts and the pathway of methods to gain these results. All lecture film formats cover content that are only described by models (e.g. plastic deformation of materials) and cannot be displayed in an experiment or graphically such as pictures of components.

Students rate lecture videos as supporting and entertaining especially for materials science. They were generally well prepared and able to work on strategies to solve hands-on problems stating that the film format has nearly no influence on the "joy of use" and on their learning progress, but Figure 9 shows that power point, stop motion and swipe technique (paper cut-out animation) are less preferred. This finding contradicts earlier results stating that "human contact" (as the hand in the swipe technique) is preferred over technically perfect video formats (power point, stop motion) [21]. Possibly, students know these three techniques widely in every-day life and therefore the lecture films offer no additional audio-visual stimulus. Another possible explanation is that these lecture films cover more difficult or less favored content. However, the swipe technique is basically used for easy introductory content (due to the nature of the format only presenting frame by frame with no development in between). It may be assumed that students did not vote for videos as they did not watch them explaining the rather low acceptance rate. In general, students prefer lecture films with motion pictures and contact to lectures such as video scribe [21] but especially lightboard videos [23] and lecture films with integrated questionnaires such as H5P elements. Pre-Covid results show that slow motion hand- drawn and video scribe technique were mostly preferred whereas lightboard lectures and lecture recording offering human interaction within the videos along with H5P lecture films were the most preferred formats during the online semesters of the Covid-19 pandemic. (Note, that H5P elements comprise of different lecture film formats and various multiple choice questions types and H5P videos have not been available during the pre-Covid era.) During the Covid era students rate the human involvement more necessary whereas results of the post-Covid era showed no preference. It may be assumed that remote teaching requires lecture film formats with human involvement to gain students interest and help their understanding.

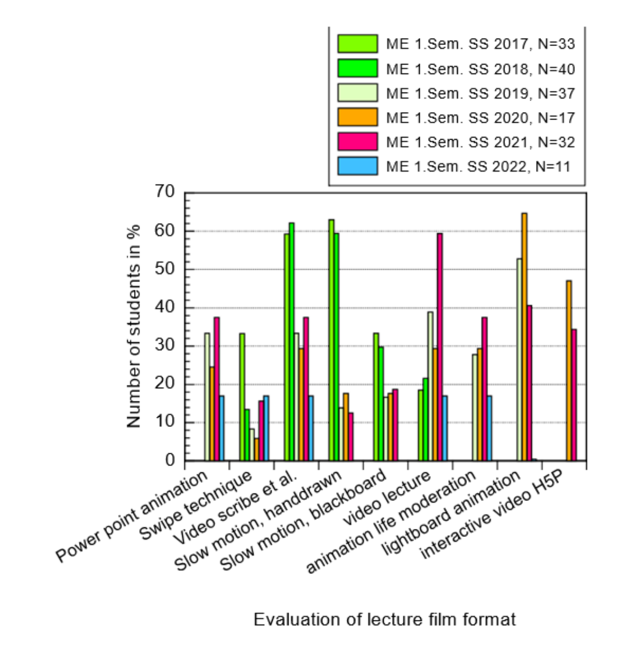

FIGURE 9: *Preference of video format in first year materials science. (Multiple choices were possible).*

Although students rate the swipe technique not among their favorites, results are the best out of the four tests indicating that the lecture film format has no influence on test performance. Test results after preparing lecture video formats swipe technique and video scribe technique show general better grades than power point/stop motion hand drawing and real time hand drawing techniques. However, results deviate strongly from one semester to the next allowing for assuming that the cohort of students has more influence on test results than the lecture film format. The same results account for preparation of lab courses in an earlier study [24]. It is important to note, that tests results were better before the pandemic indicating a severe loss in terms of commitment, motivation and ability to self-study properly. Despite these findings, students were able to interconnect science and practical work, discussed findings critically and started experimental work right away without time consuming detailed explanations. Lecture videos therefore could be rated as a method to reach a transient stage of deep understanding because the scientific knowledge is directly combined with three-dimensional images. These give the possibility to be transferred to a related problem and help understanding as well as solving complex engineering problems.

Another difficulty arouses regarding different teaching concepts for the different topics. The paper cut-out animation technique used for fiber-reinforced polymers entailed far more active group learning in that students were required to collaboratively summarize the key points around a particular technique and explain the scientific background. A second stage grouping sees groups where each student is an expert in a particular technique ('Jigsaw teaching & learning technique'). Therefore, the high marks achieved are most likely a result of more engaged peer learning and cannot be related to the video format.

Different lecture strategies along with missing significant test results as a function of lecture film format indicate that the individual cohort and teaching strategy in relation to the concepts being taught will far more likely impact student performance and not the teaching tool. Future research aims at one theme being covered by different lecture film formats and taught using the same teaching strategy. Student learning can then be related to lecture film formats exclusively.

V. CONCLUSION

Different lecture film formats: hand-drawing, video scribe, power point, stop motion and swipe technique were produced as guided student projects. This self-studying teaching material is used in inverted classroom lecture scenarios in an interdisciplinary concept of teaching materials science. All lectures were followed by exams.

Results of tests and questionnaires and the more student evaluation showed that the implementation of lecture videos in a material science introductory course was assessed as beneficial in terms of understanding, concentration, motivation and attentiveness as well as ability to transfer theoretical scientific knowledge to engineering problems because underlying science is directly combined with three-dimensional images. Students particularly prefer lecture film formats involving human contact such as hand-drawing or lightboard lectures – especially during the remote teaching Covid-19 era. First findings indicate that the lecture film format has no influence on test performance and indicate that the individual cohort and teaching strategy in relation to the concepts being taught will far more likely impact performance and not the film format as chosen teaching tool. In future different lecture video formats will be prepared for one topic to directly compare results.

REFERENCES

[1] O. D. Gulley, A. L. Jackson, "A case study on using instructor-recorded videos in an upper level economics course," Intern. Review of Economics Education, vol. 23, pp. 28–33, 2016.

[2] B. A. Al-Jandan, I. Farooq and S.Q. Khan, "Students' perspectives on the relevance of internet-based educational videos in dental education," Journal of Taibah University Medical Sciences, vol. 10, no. 3, pp. 288-292, 2015.

[3] H. Kon, M. G. Botelho, S. Bridges, K. Chiu Man Leung, "The impact of complete denture making instructional videos on self-directed learning of clinical skills, journal of prosthodontic research," vol. 59, pp. 144–151, 2015.

[4] R. Kay, I. Kletskin, "Evaluating the use of problem-based video podcasts to teach mathematics in higher education, Computers & Education," vol. 59, pp. 619–627, 2012.

[5] E. Rose, I. Claudius, R. Tabatabai, L. Kearl, S. Behar and P., "The flipped classroom in emergency medicine using online videos with interpolated questions," The Journal of Emergency Medicine, vol. 51, no. 3, pp. 284–291, 2016.

[6] K. K. Szpunar, H. G. Jing, D. L. Schacter, "Overcoming overconfidence in learning from video-recorded lectures:Implications of interpolated testing for online education," Journal of Applied Research in Memory and Cognition, vol. 3, pp. 161–164, 2014.

[7] C. Crooka, L. Schofield, "The video lecture," The Internet and Higher Education, vol. 34, pp. 56–64, 2017.

[8] A. Pfennig, "Inverting the Classroom in an Introductory Material Science Course," Procedia - Social and Behavioral Sciences, vol. 228, pp. 32-38, 2016.

[9] Th. Hatch, J. Shuttlewort, A. T. Jaffee, A. Marri, "Videos, pairs, and peers: What connects theory and practice in teacher education? Teaching and Teacher Education," vol. 59, pp. 274-284, 2016.

[10] Havergal "Videoing lectures 'has no impact' on attendance, says study, 2015, https://www.timeshighereducation.com/news/videoing- lectures-has-no-impact-attendance-says-study

[11] T. J. Saun, S. Odorizzi, C. Yeung, M. Johnson, G. Bandiera and S. P. Dev "A Peer-Reviewed Instructional Video is as Effective as a Standard Recorded Didactic Lecture in Medical Trainees Performing ChestTubeInsertion: A Randomized Control Trial," Journal of Surgical Education, vol. 74, no. 3, pp. 437-442, 2017.

[12] Sarıhan, N. Colak Oray, B. Güllüpınar, S. Yanturali, R. Atilla, B. Musal, "The comparison of the efficiency of traditional lectures to video supported lectures within the training of the Emergency Medicine residents," Turkish Journal of Emergency Medicine, vol. 16, pp. 107-111, 2016.

[13] H.-T. M. Chen, M. Thomas, "Effects of lecture video styles on engagement and learning," Educational Technology Research and Development, vol. 68, no. 5, pp. 2147–2164, 2020. https://doi.org/10.1007/s11423-020-09757-6.

[14] Berrett, "How 'flipping' the classroom can improve the traditional lecture," The Chronicle of Higher Education, 2012.

[15] A. Pfennig "Improvement of learning outcome in material science through inverted classroom techniques and alternative course assessment," Proceedings of the HEAd`17, vol. 1, pp. 82-90, 2017 [3rd HEAd`17 conference Valencia Spain, 23-25.6.2017].

[16] N. T. T. Thai, B. De Wever, M Valcke, "The impact of a flipped classroom design on learning performance in higher education: Looking for the best "blend" of lectures and guiding questions with feedback," Computers & Education, vol. 107, pp.113-126, 2017.

[17] Colorado State University, "Using Peer Teaching in the Classroom," Retrieved from: http://teaching.colostate.edu/tips/tip.cfm?tipid=180, 2015.

[18] T. Lord, "101 reasons for using cooperative learning in biology teaching," The Am. Biology Teacher, vol. 63, no. 1, pp. 30-38, 2012.

[19] K. Goto and J. Schneider, "Learning through teaching: Challenges and opportunities in facilitating student learning in food science and nutrition by using the interteaching approach." Journal of Food Science Education, vol. 9, no. 1, pp. 31-35, 2010.

[20] M. Ware, "Peer review: benefits, perceptions and alternatives, Publishing Researching Consortium. Retrieved from: www.publishingresearch.net/documents/PRCsummary4Warefinal.pd f 2015, 2015

[21] A. Pfennig, J. Maier-Rothe, ""Making of" - Successfully Planning and Implementing peer-to-peer Lecture Films," PEOPLE: International Journal of Social Sciences, vol. 5, no. 1, pp. 795-815, 2019

[22] A. Pfennig, ""Making it Work" - Practice Examples of Preparation and Embedding Peer-to-Peer Lecture Films in Successful Inverted Classroom Scenarios," PEOPLE: International Journal of Social Sciences, vol. 5, no. 1, pp. 640-655, 2019

[23] A. Pfennig, "10 practical leads for effective implementation of lecture videos in an introductory course. Practical marginal conditions to succeed lecturing science supported by lecture videos." Proceedings 5th International Conference on Education and Multimedia Technology (ICEMT 2021) pp. 246-253, 2021.

[24] A. Pfennig, "Lessons learnt –The role of peer-to-peer lecture films in a first year material science laboratory course," Proceedings of the HEAd`20, vol. 1, pp. 9-16, 2020 [6th HEAd`20 conference Valencia Spain, 21-23.6.2020].

Technical papers

Engaging the social in engineering

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***Abstract* — The inclusion of complementary studies courses in undergraduate engineering curricula was advocated and promoted by accreditation bodies worldwide to 'augment and broaden' engineering education [1]. This can be understood in terms of ongoing efforts to graduate holistic engineers and has resulted in innovations in curricula globally [2]. In South Africa, complementary studies courses are often seen as providing 'soft skills'—although discussion about the value of these courses seems to result in polarised views from staff and students [3], [4]. Given that engineering science persists as the dominant discourse in engineering education [5], this conceptual paper draws on various theoretical tools to explore the development of a more inclusive approach to complementary studies. Starting from the notion of discourse, we draw on the concepts of structure and the hidden curriculum to provide a more substantive way to think about what constrains student engagement with complementary studies courses. We conclude with proposed engagements to extend a positive hidden curriculum emphasising the socio-technical engineering discourse.**

Keywords — complementary studies courses, discourse, hidden curriculum, intransitive entities.

I. INTRODUCTION

The Engineering Council of South Africa (ECSA) prescribes that accredited BSc(Eng) or B(Eng) programmes must contain a minimum of 56 credits or 10% of complementary studies content. This refers to topics such as engineering economics, management, and effective communication as well as those from the 'humanities, social sciences or other areas that support an understanding of the world in which engineering is practised' [6]. For most engineering educators, 10% is more than enough for a degree that has traditionally had strong theoretical underpinnings and is technical in nature. Indeed, engineering educators who are faced with lecturing complementary studies often struggle to convey the relevance of the topics to students who themselves appear unmotivated to engage with—or even actively resist— such courses [7].

In the Department of Mechanical Engineering at the University of Cape Town, a multidisciplinary course called 'Engineer in Society' was developed with the intention of improving this situation. It was deliberately not framed as 'complementary' in the sense of simply augmenting engineering science knowledge but specifically designed to shift the boundary of what is seen to constitute appropriate engineering education by troubling the dominant perspective of engineering as applied science and technical problem solving. By privileging the context in which engineering activity takes place and being more inclusive of discourses about society, this course aspires to provide students with an opportunity to develop as socially responsive and environmentally aware graduates.

Pienaar [4] identifies various types of complementary studies courses in engineering. Writing for the South African context, he identifies eight types including engineering economics, ethics and professional practice, and environmental management. It is interesting to note that Pienaar omits courses that focus on engagement with society among his types. This is significant given the ECSA definition of complementary studies mentions 'the social sciences' and that engineering itself is often thought of as a socio-technical endeavour. We contend that the reason for this is that complementary studies offerings are traditionally designed to serve the dominant discourse of engineering sciences rather than being seen as inherently valuable. Topics such as ethics, environmental management and engineering economics—and other types that Pienaar mentions such as communication skills and entrepreneurship—fit neatly with the technical perspective of engineering. Discourses from the social sciences have a different epistemological basis and for this reason are often relegated to the margins of the engineering curriculum. Their value for engineering is thus lost.

This conceptual paper uses the Engineer in Society course as an example of a complementary studies offering that specifically engages the social aspects of engineering. Drawing on the framework of [8] for conceptual papers, we mobilise various concepts to understand the marginalisation of the 'social' in the engineering curriculum. This type of conceptual paper seeks to build a framework between concepts, starting with a 'focal phenomenon… that warrants further explanation' [9].

II. BACKGROUND

A. The origins of the course

As part of a comprehensive re-curriculation exercise in the Department of Mechanical Engineering, two of the authors were tasked with renewing the complementary studies streams of both undergraduate programs (the Department offers mechanical and mechatronics engineering). The long-standing courses that fulfilled this role were quite narrow and dealt with the topics of engineering professionalism, project management and industrial ecology (a course focusing on the environment). With the intention of making the new offerings more holistic and relevant, two larger courses were developed that followed each other. The first was a third-year course designed to be outward-looking in that it addressed issues relating to the role of the engineer in society (broadly speaking). The second course was to be offered in fourth year and was designed as inward-looking, i.e., focusing on the role of the engineer within the organisation and the workplace. The outward-looking course was named Engineer in Society—in reference to the seminal work by Mills [10]—and is the focus of this paper.

Given the importance of the issues at stake, it was decided that both courses should be core to the curricula (i.e., compulsory for all students). Having the experience of teaching what might be called 'non-technical' or 'complementary' courses for many years, the authors realised there would inevitably be some student resistance to the decision that these courses should be core. Nevertheless, the decision was made, and the Department assured us of its support for this approach. As a way of ensuring that the course was effective, we spent about two years preparing for the first offering, taking the approach that is should be delivered by engineering educators well versed in both engineering and social discourse rather than being taught by academic staff from the humanities. We also consulted with students and staff to ensure that we included topics, outcomes and issues that would be seen as worthwhile and interesting.

Engineer in Society was designed as a whole-year course worth 16 credits (designed to take the average student 160 hours to complete) and was offered for the first time in 2020. Course content was divided into four modules, each dealing with an aspect of broader society. These were: human society, the biophysical environment, economic systems, and political structures. Given that the first democratic elections in 1994 was such a singular moment in the history of South Africa, the course deals directly with apartheid—the infamous political regime that gripped South Africa for 48 years before democracy—and its impact on engineering activity. One of the primary objectives of the course was to provide an opportunity for the students to engage with a plurality of perspectives and to develop a critical awareness of the role of engineering—and engineers—in society. This was facilitated by including a field trip to District Six (a site of social and political importance in Cape Town—[10]), exposing students to a range of guest lecturers from industry and academia, and having regular group work sessions. The learning activities directed students towards reflection and discussion to deepen their thinking about the complex ways in which engineering activity intersects with issues in all realms of society.

B. Course structure and assessment

The course was structured over two semesters with about 40% of students' time to be spent in lectures and tutorials. This was to include two 45-minute lectures a week with an afternoon tutorial every second week. About 25% of students' time was to be spent engaging with readings or video documentaries. Two field trips were planned which were to take 10% of the course time.

The remainder of the time was to be dedicated to assessment activities. Because of the absence of a comprehensive textbook appropriate for the course, the content was supplemented with a combination of academic readings, video material and popular publications for each module. Informal writing was included through online forum discussions. Formal writing included tests or quizzes, writing essays and reflective assignments. We thought it appropriate that the most important assessment was a capstone essay which required the students to reflect on the course and make explicit links between the modules. Given that engineering students often find essay writing difficult, we decided to provide support and feedback on the earlier formative essays that were assessed using a rubric that was shared with students.

In conjunction with the continued development of the course itself, we embarked on a multipronged research project to explore the fascinating issues that are arising from this course, and to ensure that our approach to curriculum development was (and remains) theoretically informed. This project is ongoing and includes: i) a systematic literature review of the political, historical and social evolution of engineering and engineers in the South African context; (ii) interviewing academic staff and engineering practitioners about their experiences of working in apartheid South Africa; (iii) interviewing students about their experiences of the course; (iv) conceptual engagement to understand how the 'social' aspect is marginalised in engineering education. This paper reports on the final research focus.

III. THEORETICAL TOOLS FOR ANALYSIS

The theoretical concepts that we put to work to understand curriculum constraints are the notion of discourse, the concept of the hidden curriculum, and the philosophical idea of structure.

Discourse commonly refers to a connected series of words or ideas, but it can also refer to systems of thought that govern the ways that we view—and behave in—the world [12]. In the context of engineering, it refers to the types of knowledge that the discipline privileges, the influence that this has on patterns of thought and how this regulates the social practice of engineering. Johnston et al. [5] contend that while engineering is composed of multiple discourses, it is the discourse of engineering science has on overbearing influence on the curriculum and marginalises other discourses. By showing how engineering education in the UK was strongly apprentice based, they convincingly argue that '[t]here can be little doubt that engineering education had become captive to the dominance of a discourse of engineering science, losing touch with the social context of engineering' [5].

The notion of the hidden curriculum is similar, but it more closely relates to the knowledge and practices in the context of a particular course offering. This concept indicates that the curriculum is infused with values, behaviours, procedures, and norms [13], [14] conveyed by actions and words exchanged in the classroom through course materials and everyday styles of communication. These implicit and explicit engagements privilege some forms of knowledge, discourses and engineering identities, rendering them more powerful than others as their perceived value has been established and reinforced through practice and narratives over time.

While some of these unspoken or implicit values are accessible to the rational understanding of participants in social contexts, there are those that structural and are this intransitive, i.e., they 'exist and act independently of our descriptions of them' [15]. The inclusion of intransitive entities into our conceptual understanding of the social context of teaching and learning serves to account for aspects that endure over time while cohorts of students come and go, and curriculum revision exercises take place. The theories that we generate is considerate of the provisional nature of our knowledge while seeking to understand the intransitive dimensions inherent therein.

How these intransitive elements work to perpetuate the dominance of engineering science in the curriculum are important for us to understand in order to both surface the hidden curriculum and make appropriate interventions to augment the formal curriculum. Therefore, the theoretical concepts that we draw on help to negotiate deeply embedded 'curriculum constraints' that serve to marginalise the social aspects of engineering in the curriculum.

IV. ENGAGING CURRICULA CONSTRAINTS

Articulating the perspective of engineering as a socio-technical activity requires meaningful connection with the social context of engineering, something that is becoming recognised as necessary for the development of globally competent engineer [16]. This necessitates revealing messaging that is unconsciously transmitted to students with inherent positivist epistemological positions as part of an engineering science discourse. For example, by 'focusing on mathematics-based engineering analysis, students are also practicing the view that engineering problem solving led only to right or wrong answers' [16]. Such exposure should include an invitation to explore other forms of knowledge, with the aim of shifting students along the epistemological continuum towards interpretivism while reinforcing the value of all knowledge for understanding the needs of societies for engineering solutions and engagement with engineering artefacts.

In the course, students learn about the origins of mechanical engineering in the first industrial revolution, the historical evolution of the discipline and how this relates to its contemporary status. Furthermore, how these developments coincide with social, political, and economic developments nationally, and also internationally, provide a holistic perspective of the role of engineering in society. The shift from the dualism of right and wrong answers to the importance of both technical and non-technical knowledge for understanding problems and contextually relevant solutions is best supported by drawing on practical real-world examples that illustrate what engineering knowledge looks like in practice. The examples provided in the course include the historical links between engineering and mining, political organisations, arms manufacturing, energy provision in the South African context. The need for engineers in South Africa was largely motivated by the need for mineral and other resources, and a local workforce by countries that colonised South Africa [17]. These topics and examples inform debates about the role of engineering in relation to society and ethical considerations for engineering practice.

V. DISCUSSION

This approach of using social discourse to extend the engineering discourse, necessitates engaging with and revealing the hidden curriculum and structural aspects of the engineering discipline. For example, the course content, field trips, and assessment strategies clearly signal and affirm the social aspects of engineering through formal and informal contact. The positive hidden elements that we deliberately incorporate include a social justice stance on engineering activity including, for example, in the context of a developing country, innovation should not only be focused on technological development but also social development and development that incorporates ecological and social sustainability. This means that in class discussions and online student discussion forums we, as facilitators, have to be generative and responsive to the transitions that students may be engaging with. We have seen and heard how students are navigating and exploring new engineering identities that are aligned with more diverse engineering identities that incorporates roles concerning society. This means that they see the engineering endeavour more broadly and conceptualise engineering problems as including the social.

Our research has shown that students experience discomfort and epistemological dissonance from this approach [18], something that needs to be supported and managed. Our attempts to manifest the hidden curriculum of engineering involve providing students with the tools to engage critically with the purpose and role of the engineer and to actively engage in exploring the discourse of engineering more broadly. We set out to achieve this through formal, informal, and positive hidden curricula elements. We recognise that while the course can be seen as a site of struggle to provide access and participation for students and opportunities for them to explore a broader range of identities, our colleagues may reinforce more conventional role modelling. This is to be expected but if engineering educators can contribute to reinforcing broader, holistic views of what constitutes engineering, it would go a long way to making the discourse of engineering more inclusive to better prepare students to make an impact in the lives of others.

VI. LIMITATIONS AND CONCLUSIONS

The course was disrupted by the Covid-19 pandemic that struck South Africa in mid-March of 2020. The two 45-minute lectures were condensed into a single hour-long lecture (with PDF slides) that was released at the start of the week. In- person engagement was substituted by online forum discussions via the university's course management system.

Other impacts were that a field trip planned for the latter part of the year was cancelled and guest speakers had to make online lecture videos where possible.

In this conceptual paper, we focus on structural aspects of the curriculum using the case of one course, in a single university. Our engagement does have relevance for engineering curricula more broadly, given the prevalence of the binaries of technical vs non-technical, hard vs soft skills set in tension with each other with social aspects valued less.

Engineering in South Africa ensures class mobility and promising career trajectories and, since ECSA is a Washington Accord signatory, engineering graduates also have global mobility. As with any profession, there are a range of reasons why students are attracted to study engineering. While many are attracted by the prestige and economic benefits, others are attracted by the desire to improve the lives and circumstances of the communities from which they hail [19] and viewing engineering as a socio-technical endeavour helps them to imagine and anticipate a range of trajectories and engineering identities.

REFERENCES

[1] Shaeiwitz, J. A., Whiting, W. B., Turton, R., & Bailie, R. C. (1994). The holistic curriculum. Journal of Engineering Education, 83(4), 343–348.

[2] Grasso, D., & Burkins, M. B. (Eds.). (2010). Holistic engineering education: Beyond technology. New York: Springer.

[3] Bernhardt, H. W. (2013) Using case studies to promote meaningful engagement in complementary studies for Engineering students. Paper presented at the 2nd Biennial SASEE Conference. Cape Town, 11–12 June.

[4] Pienaar, G. (2001). The integration of complementary studies into the university education of engineers. South African Journal of Higher Education, 15(3), 162–167.

[5] Johnston, S., Lee, A., & McGregor, H. (1996). Engineering as captive discourse. Society for Philosophy and Technology Quarterly Electronic Journal, 1(3/4), 128–136.

[6] Engineering Council of South Africa. (2019). Qualification Standard for Bachelor of Science in Engineering (BSc(Eng))/ Bachelors of Engineering (BEng): NQF Level 8. E-02-PE

[7] Hitt, S. J., Holles, C. E., & Lefton, T. (2020). Integrating Ethics in Engineering Education through Multidisciplinary Synthesis, Collaboration, and Reflective Portfolios. Advances in Engineering Education.

[8] MacInnis, D. J. (2011). A framework for conceptual contributions in marketing. Journal of Marketing, 75(4), 136–154.

[9] Jaakkola, E. (2020). Designing conceptual articles: four approaches. AMS review, 10(1), 18-26.

[10] Mills, J. (1946). The Engineer in Society. New York: D. Van Nostrand Publishers.

[11] District Six Museum (2022, Sept. 25) [Online]. Available www.districtsix.co.za.

[12] Tenorio, E. H. (2011). Critical discourse analysis, an overview. Nordic Journal of English Studies, 10(1), 183–210.

[13] Alsubaie, M. A. (2015). Hidden curriculum as one of current issue of curriculum. Journal of Education and practice, 6(33), 125-128.

[14] Villanueva, I., Di Stefano, M., Gelles, L., & Youmans, K. (2018). Hidden curriculum awareness: A comparison of engineering faculty, graduate students, and undergraduates. World Education Engineering Forum, 2018, Albuquerque, NM.

[15] Archer, 1998 in Archer, M., Bhaskar, R., Collier, A., Lawson, T., & Norrie, A. (eBook published in 2013). Critical realism: Essential readings. Routledge.

[16] Gary, L. D., Lucena, J. C., Moskal, B. M., Parkhurst, R., & Nichols-Belo, A al, e. (2006). The globally competent engineer: Working effectively with people who define problems differently. Journal of Engineering Education, 95(2), 107-122.

[17] Kloot, B., & Rouvrais, S. (2017). The South African engineering education model with a European perspective: History, analogies, transformations and challenges. European Journal of Engineering Education, 42(2), 188–202.

[18] Shaw, C., Kloot, B. and Ahmed, N. (2021). Re-imagining engineering education in South Africa. In Proceedings of the 49th Annual SEFI Conference: Blended Learning in Engineering Education: challenging, enlightening – and lasting? Technische Universität Berlin (online), 13– 16 September.

[19] Reed, B., and Case, J. (2003), 'Factors influencing learners' choice of mechanical engineering as a career', African Journal of Research in SMT Education, Vol 7, pp 73–83.

Technical papers

Designing for holistic learning opportunities: Reflections from the Engineering for People Design Challenge

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***Abstract* — The World Economic Forum's Global Risk Report in 2022 highlights the severe global risks in the next decade as; climate action failure, extreme weather events due to climate change, biodiversity loss, and the erosion of social cohesion. Mitigating these risks will require a transition in every industry, organisation and profession to imagine and create a better future together with civil society. Engineering is uniquely placed to help address global issues. We put forward that there is a need to prepare future engineers to adopt a mind-set of responsible and ethical practice into their skillset, in order to tackle today's various challenges. The need to create globally responsible engineers is great. Engineering education needs to prepare future engineers to adapt to an uncertain future. The Engineering for People Design Challenge, taught through a project-based learning pedagogy, has been completed by over 60,000 university students from over 40 universities. This program is currently run in partnership with Engineers Without Borders South Africa, and Engineers without Borders UK. During a pivotal moment in an undergraduate student's career, the Design Challenge encourages students to broaden their awareness of the social, environmental and economic implications of their engineering solutions. This paper aims to explore the affordances in learning that the Engineering for People Design Challenge provides participating students, with a focus on South Africa, by way of post-programme feedback from both students and academics who have implemented the Engineering for People Design Challenge in their courses.**

Keywords— global responsibility, design challenge, project-based learning, learning journey.

I. INTRODUCTION

We are living in an era where noticeable and constant changes are taking place. From environmental concerns to diminishing resources, from increasing inequalities between humans to diminishing social cohesion. These are risks to society and our world, and perhaps the best way to overcome these challenges is to change our ideas about sustainability and sustainable development. Engineering plays a critical role in addressing the challenges highlighted above, especially in terms of fulfilling the Sustainable Development Goals (SDGs). Recent studies suggest that current ways of educating engineering students do not adequately prepare them for the challenge of tackling these issues, and that they are hence underprepared for the urgent sustainable development needs of today (Institution of Engineering Technology, 2021; EngineeringUK, 2022). While there are some initiatives to integrate and diversify engineering education, these are still in development and might take some time to become fully adopted by institutions (Bringing life to our Engineering curricula, 2022). The skills gap will become increasingly evident as the need for globally responsible engineers heightens. As such, highlighting the need to adapt engineering education and produce engineers who can tackle these ever growing challenges.

II. BACKGROUND

A. Engineering Educaiton

Alexa, et al., (2020) states "Engineering educators around the world have simultaneously witnessed a significant shift in societal expectations of the engineering profession...As a result, "sustainable engineering" has become part of the larger Sustainable Development conversation.". However, to deliver on the SDGs and sustainable development, engineers have a role to address immediate and longer-term global challenges (Desha et al., 2009) and need the critical knowledge, skills and mindsets alongside technical skills. For example, critical thinking, navigating complexity, creativity, social responsibility, sustainability awareness, ethical consequences, innovation, creativity, project management, communication, collaboration, and teamwork have been recognised as crucial competencies to deliver on the sustainable development agenda (World Economic Forum, 2020; Beagon, et al., 2022). These multidisciplinary and interdisciplinary skills are key when devising and delivering a curriculum which will cater to the changes facing in the world.

University engineering curricula does not train engineers adequately on firstly designing for and with different communities, and secondly to be "globally responsible". South Africa has one of the most inequitable societies in the world, yet the curriculum still focuses heavily on traditional engineering problems like "design a machine for a factory". Even where the curriculum does focus on under-served communities, it struggles with exposing students to the real- world needs, desires, constraints and strengths of communities. This is particularly the case with large university classes; in the first and second years there are often several hundred students, making it too large to ask students to interact with communities. It is this short-coming that we address with the Engineering for People Design Challenge.

Institutions readily acknowledge this challenge and often try different interventions, yet continue to struggle with finding effective programmes and the resources to develop them. Given that universities continue to face tightening resource constraints, and the difficulty of curriculum-level collaboration between universities, the Engineering for People Design Challenge provides an innovative solution to the problem of better training engineers to work with under- served communities. The Engineering for People Design Challenge is a response to educational challenges highlighted above and was devised to inspire and equip learners with the many skills needed to tackle an ever increasing demand for globally responsible engineers.

B. Engineering for People Design Challenge

The Engineering for People Design Challenge is an educational program which is integrated into the undergraduate curriculum at participating universities. It seeks to inspire students to become globally responsible engineers, and engender the following qualities: Responsible, Purposeful, Inclusive and Regenerative (Engineers Without Borders UK, 2021a). Using the pedagogy of project-based learning, multi-disciplinary students broaden their awareness of the impact of engineers in the domains of social, environmental, economic and ethical domains, while also developing their technical engineering skills (Engineers Without Borders UK, 2021b).

The Engineering for People Design Challenge places a real community at the center of the program, whereby Engineers Without Borders partners with a local organization, usually a community project or NGO, to create an open-ended Design Brief. This brief highlights real-world problems that people in that country or community face. A working group collaborates and communicates with the chosen community, affording students the simulation of an in-depth experience of consulting with a community to find a possible engineering solution, but with none of the risks or practical constraints. Allowing students the opportunity to respond to this design brief, they develop skills and a stronger understanding of their responsibilities in their future role as engineers, and the ethical and practical challenges of adapting creatively to disruption.

After implementation in modules in undergraduate courses, the top teams from each university are nominated to take part in the competition arm of the challenge, where Grand Finals are held nationally. Students submit their design ideas to the competition where these ideas are reviewed by a review panel of international industry expert reviewers. The Grand Finals culminates in an exciting event where the finalists are able to showcase their design ideas, an inspiring keynote speech is made and winners and runners up are announced.

The Engineering for People Design Challenge is designed and delivered collaboratively in partnership with Engineers Without Borders South Africa and Engineers Without Borders UK. It has been delivered to over 60,000 students in the UK and Ireland since its inception in 2011, and in South Africa since 2019, in Cameroon since 2022 and may soon be joined by students from Somalia in 2023. The Design Challenge is based on the EWB Challenge which was first devised and implemented by Engineers Without Borders Australia.

III. APPROACH

In order to constantly improve the design and delivery of the Design Challenge, our working group collects data from students and academics throughout the implementation process. Monitoring and evaluation of the program, and the subsequent analysis and learnings are taken from the data. This study looks at the Design Challenge, and some of the learning affordances it offers to undergraduate engineering students.

This study explores the feedback received from both students and educators who have taken part in the Engineering for People Design Challenge. The data collected comes from both base-line and end-line surveys which are voluntarily filled out by students before and after they have completed the Engineering for People Design Challenge. The data in this study comes predominantly from the 2020 and 2021 end-line surveys in both the UK and South Africa. (At the time of writing, the Engineering for People Design Challenge was still in progress in 2022).

Note that the equation is centered using a center tab stop. Be sure that the symbols in your equation have been defined before or immediately following the equation. Use "(1)", not "Eq. (1)" or "equation (1)", except at the beginning of a sentence: "Equation (1) is . . ."

IV. FINDINGS

After the text edit has been completed, the paper is ready for the template. Duplicate the template file by using the Save As command, and use the naming convention prescribed by your conference for the name of your paper. In this newly created file, highlight all of the contents and import your prepared text file. You are now ready to style your paper; use the scroll down window on the left of the MS Word Formatting toolbar.

A. Participation in the Engineering for People Design Challenge

Table 1 presents the number of universities and students which have taken part in the Engineering for People Design Challenge from 2019-2022. Despite the COVID-19 pandemic and the associated challenges with delivering a large-scale program, the Design Challenge continued to scale up. There was significant growth in the number of participating universities and number of students participating in the Engineering for People Design Challenge.

TABLE 1: *Overview*

Year	Overall Challenge Participation	
	No. of Universities[a]	Total Students
2021-22	47	11,297
2020-21	44	10,349
2019-20	37	7,494
2018-19[b]	30	5,991

a. Responses can include multiple sign ups from the same university.

b. Responses include participating universities from the UK only

B. Reflections form educators

Feedback from educators in both South Africa and the UK, reflect that the program was not only effective because of the immense trust our partner-educators had in the program, but also that they perceived a relative benefit from the program.

- *"The Design Challenge builds technical as well as non-technical skills. It gives students an opportunity to be creative, and also to express their desire to be involved in their communities. Increasingly I find that students have a strong interest in wanting to give back to communities, especially the communities from which they may come. This challenge gives them an opportunity to practice that."*: University of Johannesburg, South Africa.

- *"It is one of the most valuable opportunities that our students will encounter in their entire degree! A creative and exciting challenge which tests the skills of engineering students to innovate, think, research, design, and refine real-life, plausible solutions for open-ended problems. Essentially, a small version of true engineering; a necessary experience for engineering students."*: University of Witwatersrand, South Africa.

- *"[The Engineering for People Design Challenge] links well with our teaching of the design process, the grand challenges of civil engineering, the UN SDGs and especially sustainability - for me the best part is the focus on people"* University of Liverpool, UK

Not only did educators value the learning experience through participation in the Engineering for People Design Challenge for their students, we also found that professional volunteer judges spoke favorably of the experience during their participation in the Grand Finals.

- *"It was an honour to judge the Grand Finals of the Engineers without Borders design challenge and inspiring to see so many university students fully engaged and responding to real world challenges; something that will be a key part of career growth development."* Grand Finals, UK, 2022

These quotes highlight how the Design Challenge was perceived by educators to have a positive effect on the learning experiences of participating students.

C. Reflections from students in South Afrca

Findings from Interrogating the South African end line data identified that students largely found the Engineering for People Design Challenge to be a beneficial endeavor. Approximately 93% of students would recommend the Engineering for People Design Challenge to a friend or colleague, hence showing their enjoyment of the program, and 81% of students reflected that the Engineering for People Design Challenge changed their mindset about engineering for people and communities.

Notably, 100% of students reported improvement in at least one skill needed in the engineering field and 100% of students reported improvement in at least one knowledge area related to engineering.

- *"I learnt and developed the skills of working through a structured design process to produce unique and clever solutions. I also learnt valuable teamwork and time management skills, as I was lucky to have a very competent and hardworking team."*

- "I am now more confident in my ability to adapt to a change of circumstance; working through the design challenge has taught me that hindrances that arise in various stages of the engineering design process are not to be met with fear as these problems can be solved by making appropriate alterations that enhance the project. Prior to dealing with these issues I was under the misconception that changes would diminish all the work I had done before."

The end line survey questioned if the students' intentions may have changed after taking part in the Engineering for People Design Challenge. Reflecting on their plans post- graduation, many students commented on designing to specifically better a community's experience of their environment.

- *"My intentions are to use my qualifications to come up with new and innovative ideas to make Africa, and even the world a better place."*

- *"My intentions are to work hard enough to be able to raise my voice loud enough to be heard so that I can bring awareness on some of the pressing issues that other South African residents deal with daily. No, it has enlightened me on these issues and through working on the [Engineering for People] Design Challenge, I have been able to raise a few solutions to these problems."*

- *"My intentions are to develop systems and solutions to combat key issues in our country and the [Engineering for People] Design Challenge has made me want to do this in a diverse group of people."*

Further to the above discourse, students also recounted how the Engineering for People Design Challenge taught them new skills and inspired their journey to design for people in mind, as well as tackle the challenges of resources, economic factors and sustainable solutions.

- *"I gained a lot of knowledge because this design challenge taught me how to communicate with others and come up a new design. This also helped me learn how to use computers - something that was hard for me because I never used a computer before."*

- *"This project has opened my eyes to new possibilities in engineering. I loved every moment of this inspirational and educational journey."*

- *"Never allow the limitations of resources, time or finances of a project stop you from changing someone's life, rather see these limitations as an opportunity for you as an engineer to create a better, innovative and sustainable future."*

V. IMPLICATIONS AND FINAL REMARKS

In this paper, we discuss how providing globally-relevant, real-world, project-based learning opportunities is key in preparing future engineers for their careers. We aimed to understand how students viewed their own role as future engineers in addressing global environmental and societal challenges. Overall, Students and educators have both expressed value and excitement with the project, and our academic partners are especially keen to continue with the project's implementation in 2023.

The team from Engineers without Borders South Africa have done research and hence have ascertained that there is no similar initiative to the Engineering for People Design Challenge. There is no programme that does all of the following: a) bring a real-world, under-served community into the engineering classroom, b) deliver this at scale for students in their initial years of study, c) and provide the rich level of detail about this community. There are of course some efforts in isolated courses at different South African universities to encourage students to work with a variety of communities, however these remain largely theoretical. By implementing the Engineering for People Design Challenge at first and second year level, we capture an important window of influence. Students are afforded richly detailed exposure to real-world communities during their formative years, without the risks of learning to do so in a high-stakes environment. There was a strong evidence base that this type of initiative is a model that is both globally-relevant and viable in providing meaningful education at scale.

There is strong evidence to show that the Engineering for People Design Challenge can provide a meaningful and effective, globally-relevant educational experience to engineering students in many different locations worldwide. The 2020-21 end-line surveys suggest that students have both been upskilled as well as inspired to contribute to sustainable and responsible engineering in their future careers as engineers, through their critical reflections through participating in the Engineering for People Design Challenge. Skills, such as "developing creative solutions", "communication", "project management", "working in teams", "working in uncertain environments" and "decision making" are discussed and the development of these skills are observed.

Finally, the Engineering for People Design Challenge seeks to instill a sense of responsibility in students about their role in the world as future engineers. Incorporating global responsibility into engineering education is necessary to prepare students to address global challenges.

- *"Sustainability is more than a word or concept, it is actually a culture, and if we aim to see it mirrored in the near future, what better way exists than that of planting it in the young hearts of today knowing they are the leaders of the tomorrow we are not guaranteed of? It is possible."* 2020-21 Student Participant

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REFERENCES

[1] Alexa, L., Maier, V., Şerban, A. and Craciunescu, R. 2020. Engineers Changing the World: Education for Sustainability in Romanian Technical Universities—An Empirical Web-Based Content Analysis. Sustainability, 12(5), 1983.

[2] Beagon, U., Kövesib, K., Tabasb. B, Nørgaardc, B, Lehtinend, R., Bowe, B., Gillet, C. and Monrad Spliid, C. 2022, Preparing engineering students for the challenges of the SDGs: what competences are required?. European Journal of Engineering Education, 1-23

[3] Bringing Life to our Engineering Curricula, 2022. https://iecurricula.co.za/

[4] Desha, C.J.; Hargroves, K.; Smith, M.H. 2009. Addressing the time lag dilemma in curriculum renewal towards engineering education for sustainable development. Int. J. Sustain. High. Educ. 2009, 10, 184– 199.

[5] EngineeringUK, 2022. Net zero workforce: An analysis of existing research, Url: https://www.engineeringuk.com/research/briefings/net- zero-workforce/.

[6] Engineers Without Borders UK, 2021a. Reaching the tipping point for globally responsible engineering. Our Strategy 2021-2030., Url: https://www.ewb-uk.org/wp- content/uploads/2021/05/Engineers_Without_Borders_UK_Strategy_2021_2030.pdf

[7] Engineers Without Borders UK, 2021b. Engineering for People Design Challenge, Url: https://www.ewb-uk.org/upskill/design-challenges/engineering-for-people-designchallenge/

[8] Institution of Engineering Technology, 2021. 93% of industry without skills to meet 2050 climate targets, Url: https://www.theiet.org/media/press-releases/press-releases-2021/2-february-2021-93-of-industrywithout-skills-to-meet-2050-climate- targets/

[9] Truslove, J. and Crichton, E. and Whitehead, T. and Clark, R.; (2022) Pedagogical approaches to project-based learning : meeting the education needs of the globally responsible engineering workforce. In: Proceedings of the 8th International Symposium for Engineering Education. University of Strathclyde, Glasgow. ISBN 9781914241208

[10] World Economic Forum, 2020. The Future of Jobs Report 2020, World Economic Forum, Switzerland. Url: https://www3.weforum.org/docs/WEF_Future_of_Jobs_2020.pdfG. Eason, B. Noble, and I. N. Sneddon, "On certain integrals of Lipschitz- Hankel type involving products of Bessel functions," Phil. Trans. Roy. Soc. London, vol. A247, pp. 529–551, April 1955. (references)

Technical papers

Ethics and professional role to the society: A proposal to promote ethical attitudes in engineering students

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Abstract — **In the last decades, considerations regarding the role of engineers in their decision-making process have highlighted the importance of dealing with ethics in the teaching-learning process. Consequently, questions about how to design pedagogical strategies to promote an ethical and moral attitude and behavior in engineering students have emerged in a context where engineers must present the financial and ethical consequences of their projects' decisions.**

With this context in mind, this paper presents a brief review of the literature about ethics in engineering education. In particular, we want to describe some challenges that have been identified such as the frequent disconnection between ethics and engineering practice, the absence of positive measurable changes in students' ethical attitudes, the unsystematic implementation of ethics in engineering curricula, the low familiarity with the topic, among others. In addition, we intend to establish an "ought to" mode of engineering curricula related to ethics, considering some educational frameworks for curricular design such as CDIO (conceive, design, implement, operate) or international accreditation quality standards like ABET. Both frameworks make explicit reference to the promotion of ethics, social responsibility, equity and diversity, professional behavior, and making informed judgments in engineering decisions.

These challenges introduce the proposal of a pedagogical strategy to promote ethical attitudes in engineering students in a School of Engineering in South America. This strategy is based on the developmental approach of moral conscience and the reflections on students' values and projects' implications related to engineering decisions and actions in global, economic, environmental, and societal contexts. It involves several landmarks: a systematic chart to approach ethics issues throughout the curriculum, in particular, in classes with a high practical component through projects, voluntary workshops to explore and identify students' values, exploratory tests to identify students' approaches to ethical dilemmas (with their correspondence reflections), among others. An interdisciplinary team of lecturers from different academic backgrounds in ethics, philosophy, and engineering designed the proposal. This strategy has been implemented, and some preliminary results with their corresponding reflections are also presented.

Keywords — pedagogical strategy, ethics in engineering, moral conscience, value clarification, ethical engineering design

I. INTRODUCTION

In recent years, questions about the role of engineering in society for its ethical and moral implications have been increasing. Several local and international news has shown the relevance of engineers' professional and ethical responsibilities. For instance, they inform about the falling of infrastructure, the use of artificial intelligence and big data to elaborate customers' profiles that invade their personal lives, algorithms of facial recognition that cannot recognize people from specific social racial groups, and changes in the software that measures control of emissions to evade economic sanctions. Furthermore, in their classrooms, engineering students have the challenge of learning to acknowledge intellectual property and honor their knowledge without cheating. On the other hand, professors have the challenge to teach respectfully, with appropriate use of their power, and be meticulous in their classes [1]. In this context, the necessity of approaching ethical and moral issues in engineering education is becoming a priority in Latin American engineering curricula.

Considering this context, the School of Engineering at the Pontificia Universidad Javeriana (PUJ) in Bogota, Colombia, has reflected on including, in an explicit way, ethics and morals in engineering curricula. In doing so, international frameworks such as CDIO and ABET have been revised. The CDIO Initiative is an innovative educational framework for producing engineers. The framework provides students with an education stressing engineering fundamentals set in the context of Conceiving — Designing — Implementing — Operating (CDIO) real-world systems and products [2]. ABET accreditation framework is used to consider student outcomes to measure and evaluate the improvement of a wide range of knowledge, skills, and attitudes students should learn during their engineering program's trajectory [3]. Consequently, we redesigned engineering programs curricula from content-based models of curriculum design to competency-based models. Hence, the ability to recognize the ethical and professional responsibilities in the engineering context and make informed judgments considering global, economic, environmental, and societal backgrounds became relevant for students learning process.

II. ETHICS IN ENGINEERING CURRICULA

The field of ethics and morals is broad [4] and includes similarities considering both terms deal with the notion of right or wrong, where ethics seems to be related to social and cultural standards, and morals seem to be related to individual beliefs, intentions, and actions. Therefore, it is possible to understand ethics as a result of morals. Moreover, morals theory is related to two main milestones. In the first place, deontological theory refers to the evaluation of actions based on specific rules. Secondly, the teleological theory is associated with the actions evaluation based on their consequences. Other theories are related to virtues or dispositions to think, act, and feel in a certain way, making a person be considered bad or good. In addition, the relativeness that involves moral thoughts and actions has also been studied. Some people believe there are no manners to establish universal rules of morality, whereas other people think that at least one way is potentially achievable. Likewise, ethics and morals have been studied using theories about how people develop their reasoning. For instance, Skinner focuses on punishment and rewards; to Freud, desires move a person's behavior; Piaget's factors are related to individual socio- cognitive and socio-emotional factors, and Kohlberg proposes a developmental construction of morals [5].

This complexity in the field needs to be fully understood to enhance the teaching-learning process in engineering classes. Diverse models and theories have influenced engineering education. In recent research, Martin et al. [6] point out that 12 major categories can group the goals for engineering ethics education. Six of those categories relate to the development of moral sensibility, analysis, creativity, judgment, decision- making, and argumentation. For these purposes, the more used in engineering curricula is to expose students to ethical dilemmas to refine their moral judgment. They begin by identifying the values; then, they make and adjust their discernment. This way, students can improve their analysis. Other objectives relate to moral knowledge, design, agency, situatedness, emotional development, and character and virtue development. These approaches consider values, not just economic profit, in engineering design and evaluation. Another approach is related to the agency and designing of technology by considering engineering practice as a collective responsibility. A less explored proposal is virtue development: to train students to develop particular character attributes to deal with the context where engineering practice occurs. Despite all of these approaches, it is little known how specific learning goals might convey to students the understanding of their professional responsibility.

Another connected aspect of considering ethics and morals in engineering education is the unbalanced way the engineering curriculum approaches ethics. Technical training is prioritized instead of social or personal skills [7]. This issue is associated with another challenge: the lack of expertise to teach these themes in an engineering subject. Likewise, it is challenging the disinterest shown by students for the lack of their emotional engagement with ethics issues [8] [9]. At the same time, this issue is critical because of the unsystematic and non-systemic implementation throughout curricula, including the lack of instruments to measure the attributes that students need to enhance [6] [7].

Among other conflicting issues in teaching ethics in engineering is the traditional focus on preventing either harm to the public or professional misconduct. For this reason, some curricula only focus on explaining ethics and professional codes. The innovative focus could be a positive orientation to encourage future engineers to do their best professional work for human welfare. Furthermore, there is also a conflict between reflections on professional ethics and personal morality. Hence, although it is crucial to begin reflecting on the people (students) who face ethical decisions, this should be a bridge to reflect on their professional responsibility and, consequently, possible contradictions between them and how they could be overcome [10].

The aforementioned concerns bring the question of how to design a pedagogical strategy to integrate better ethics into engineering curricula.

III. THE ETHICS IN PUJ ENGINEERING CURRICULA PROPOSAL - METHODOLOGY

Considering the mentioned challenges, a pedagogic curricular strategy was proposed, building on several high points throughout engineering curricula in PUJ. This strategy aims to prepare students to engage in their professional context, beginning with moral analysis and judgment and following values of engineering design and evaluation. The strategy presents a systematic "roadmap" to approach ethics foundation issues in the program. Figure 1 represents this roadmap as a summary of the methodology designed to implement the proposal.

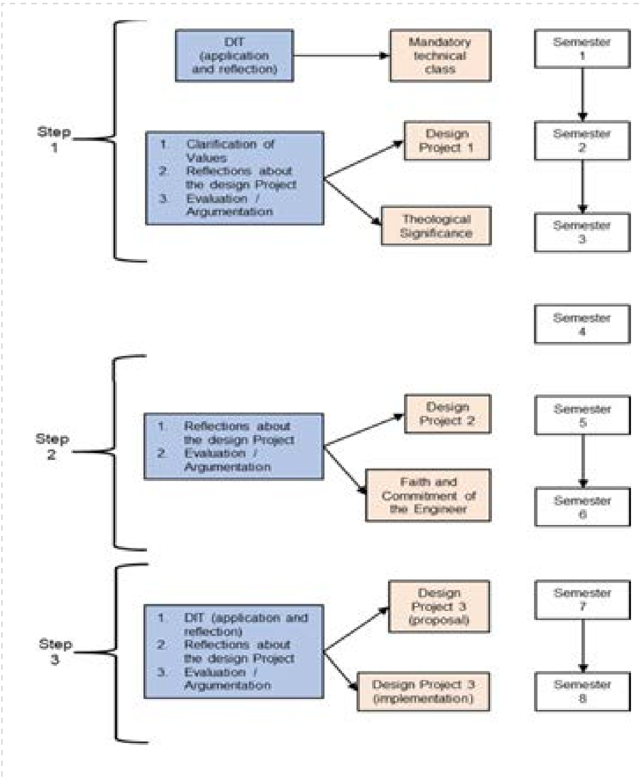

FIGURE 1: Pedagogical Strategy Proposal to Promote Ethics in Engineering Curricula.

The strategy involves various courses and semesters: It starts with a mandatory class in each engineering program curriculum where technical knowledge is taught in the first semester. In this class, students take a test (Defining Issues Test – DIT) related to moral dilemmas associated with the theory of moral development (about moral judgments) proposed by Kohlberg [11]. The overall results are socialized to reflect on the first-year students' decision-making process [12]. Results allow mapping students' thoughts and behaviors for subsequent comparison at the end of the program.

In the second semester, in an engineering design class, where students from all of the engineering programs gather in groups to solve real problems bearing in mind one of the SDG (Sustainable Development Goals), we established a workshop called "Manifiesto Javeriano" (manifesto Javeriano). The manifesto explores students' values as a community willing to behave in an honoring way according to their identified and selected values [13]. Students enrolled in the class clarify their values by fulfilling a personal anonymous survey where they have to prioritize and make a self-aware analysis of those values that rule their present life. Then, they share their selection with peers to formulate a class manifesto, which shows the consensus about what values are relevant for that particular social group.

In addition, another workshop is presented in the middle of the semester to discuss the social, economic, ethical, moral, and environmental impacts of the solutions they are designing. Using the scapegoat theory from Rene Girard as a conceptual framework [14], the students play a group role-plays game to eliminate the opposite group with some constraints and privileges for each group. While playing, this game makes them discuss issues about group decisions, analysis of social situations, trust building, leadership, and consensus design, among others.

Following that activity, students must work with beneficiaries of their design to consider their interests, personal experiences, needs, and emotions. Then, they co-design the solution to their problems. Finally, at the end of the semester, students present their solutions. Professors will inquire about how they decide the relevance of their technical designs according to previous ethical considerations. This way, it is promoted reflections related to improving students' moral development.

Continuing these reflections, there is a third-semester class named "Theological Significance"; there, students and professors from the Center of Theological Formation discuss how their technical solutions should be considered in a systemic and broad sense, using the framework of six hats to think from Edward De Bono [15].

After these activities, other interventions were defined. In the second crucial moment of "Engineering Design" (in the fifth semester) and the class of "Faith and Commitment of the Engineer" (in the sixth semester), a similar scheme is presented between an ethical and technical focus of engineering design. This step of the map route focuses on the design of engineering solutions for vulnerable communities or non-profit organizations.

At the end of the engineering curricula, in the final design project (capstone project), additional intervention is being developed to evaluate how future engineers can face ethical issues in their professional careers. This intervention includes a new application of the DIT (post-test) and the assessment of the ethical impacts of their engineering solutions in students' projects. This assessment is associated with the applied test at the beginning of the program to identify students' improvement in moral development.

A relevant aspect is that specialized faculty in the topic of ethics and faculty of engineering co-design and co-lead these activities in the classroom to prevent students from separating, in their minds, the disciplinary work from the ethical and moral reflections.

This pedagogical strategy aims to build reflections on engineering decisions and ethical impacts on the professional lives of our students. In doing so, the aim is to overcome those challenges previously presented about the need to work with experts, design measures, formulate a systematic way to teach this topic, allow students to discuss this topic in technical classes, and promote several learning objectives.

IV. DATA COLLECTION

Considering the roadmap mentioned in the methodology, data gets collected from students, particularly from three tests and two workshops. Table I represents a summary of those tests and workshops and the number of students that participated in applying them.

TABLE 1: *Data collection*

Test	What does it present?	What is the result?	Who did apply the test?
DIT	Six moral dilemmas	The level of moral judgment: "preconventional", "conventional", or "postconventional".	131 first semester's students
Personal Values Clarification	A set of 24 different boxes with 5 values such as love, commitment,	A ranking of the values, according to the prioritization of those values within each box.	450 second semester's students
Workshop about context analysis	A role-playing game to explore social issues, engineering design, and teamwork	A list of students' learning issues	30 second semester's students
Workshop about context analysis and ideation	A role-playing game to explore social issues, engineering design, and teamwork	A list of students' learning issues	30 third semester's students
Rubric to evaluate the design project	A list of criteria: Context analysis, Performance, Functionality, Sustainability, and Standards.	A grade between 0 and 5 marks students' work.	420 second semester's students

The first test is the DIT [11] [12], which consists of six dilemmas; for instance, should Heinz steal a drug from an inventor in town to save his wife, who is dying and needs that drug? Or should a minority member be hired for a job when the community is biased? Students must prioritize the four most important issues they consider (out of 12) in each dilemma. Then, a result is obtained based on that selection and refers to three states of moral development: A "preconventional" state, that is, they evaluate situations and make decisions avoiding rewards or harm to people and properties, or following their immediate interest. The "conventional" state is where students obey because they defend rules aligned with their thoughts or do not cause conflict with others ones. Also, students bow to satisfy interpersonal values such as trust, loyalty, respect, or gratitude. Finally, in the "postconventional" state, people make decisions considering that some rules are framed socially as social contracts and respecting principles beyond local regulations. It is necessary to highlight that reflections on the complexity and difficulty of achieving this "postconventional" level do not deny the possibility of learning to be an autonomous person capable of making ethical decisions.

The second test called "Personal Values Clarification" [13] presents a list of 24 values that students must prioritize in 24 different boxes that contain 5 of those values. After that, a ranking is generated based on the values with higher points. Then, they have to share those values to establish the class common values.

The third test is the assessment made at the end of the second semester about the project design. It consists of a rubric with the following criteria: context analysis, that is, if students considered beneficiaries' perspectives in their designs; performance, which measures if the proposal achieves the design's purpose; functionality issues, which measure if the proposal accomplishes the technical requirements; sustainability, that is, if students considered social and environmental aspects; and standards issues, that is, if students considered quality and safety standards.

Regarding the workshops, both of them are related to the use of role-playing game to explore social issues, engineering design, and teamwork in two classes. The former is Design Project 1 and the latter is Theological Significance. The main expected results are a list of issues students can identify to approach an engineering design considering beneficiaries perspectives.

V. PRELIMINARY RESULTS

The strategy proposed has been implemented in its first step in the first semester of 2022. Regarding the first class where students present the DIT test, of 131 students, 14,5% are in the "preconventional" state of moral judgment. The other 85,5% of students are in the "conventional" state. Besides, none of the students could be located in the "postconventional" state. This first result was discussed in a technical class of Industrial Engineering called Organizational Systems (structure and behavior) and in a Civil Engineering class named Sustainable Building. During those classes, students were encouraged to think about their individual decisions and how they can influence or be influenced by their engineering studies.

In the second phase of this strategy, 450 students applied a pilot of the Manifesto Javeriano. Through a series of meetings in groups of 5 or 6 members, students presented their agreements about those values that frame their decisions and rule their actions as a community: love (with 23 groups ranking this value as number 1), service (28), commitment (25), wisdom (18), and creativity (1). This result was followed by a reflection about honoring and appreciating those values, beyond rules, as principles to guide decisions in that particular community. Moreover, the invitation was also to contribute to the project bearing those values in mind.

In addition, the workshop about the scapegoat theory was conducted to explain how social issues are related to engineering and teamwork in the class of Design Project 1 in a pilot group of 30 students. The most crucial reflection in this pilot was that communities try to find, most of the time, someone to blame, and the weakest member is the chosen one. Therefore, to overcome this issue, it is necessary to build an ethic of care and trust.

Additionally, in the class named Theological Significance, an ideation activity was implemented in a pilot group of 30 students. Some topics thought and discussed in this activity were the importance of context analysis and the impact of the proposed solutions, the commitment needed to execute plans for a better society, the need to think using logic, feelings, and rules, and the relevance of group decisions and leadership to improve social situations.

Finally, during the last week of the semester, 420 students from Design Project 1 presented their designs. Eight interdisciplinary professors evaluated their proposals based on the rubric designed. Overall, students achieved a grade of 4,2/5,0 in this rubric. Reflections presented by professors show that students can support their decisions considering context elements beyond economic factors; however, they cannot develop a fluid argument to back them yet. Therefore, it seems that more work regarding the purpose of moral and ethics argumentation is needed to promote a better and an explicit way to express their technical decisions.

VI. FINAL REFLECTIONS

This pedagogical strategy aimed to build reflections about engineering decisions and ethical impacts on the professional lives of our students, considering the challenges previously reported in the literature. Concerning this purpose, we work with interdisciplinary experts, design some measures to track students' attitudes and reflections, formulate a systematic way to teach this topic with several milestones throughout the curriculum, allow students to discuss this topic in technical classes, and promote several learning objectives, from moral sensibility, decision-making, and argumentation, to design and virtue development.

Preliminary results have shown, on the one hand, a diagnosis about how students face ethical issues in their daily lives. It is influenced by rewards, the use of rules, and the context as causal factors of their day-to-day situations and decisions. This behavior implies that the development of students' moral judgments gets built while they are taking their semesters at the university. Therefore, curriculum designers and professors have a critical role in contributing to that development.

On the other hand, we explore positive reflections about the implications of students' actions as future engineers, particularly in terms of values that they can establish as principles to rule their decisions as engineering students and concerning their analysis when they have to design a project. A relevant aspect of the students' reflections was going beyond norms and building a culture of trust and care to improve social situations.

Furthermore, it seems students need more practical situations to deepen their ethical decisions and attitudes. This reflection is associated with the need for more practice in argumentation to promote an explicit and better way to support their technical and ethical decisions.

For future work, the plan is to continue the implementation during the second semester of 2022, while finishing the design of the second and third steps. In doing so, it is clear that this kind of pedagogical strategy requires more resources in planning, the interaction between professors from different disciplines, hours of student individual and group work, and the delivery of active learning activities to put students in the center of the reflections.

All of these factors become challenges to overcome to keep promoting ethical attitudes in engineering students. Finally, this paper is an invitation to further explore and adapt this strategy to different academic environments.

REFERENCES

[1] G. A. Avelino, L. H. Barrero, M. J. Bermúdez, M. D. Dávila, F. A. Gómez, S. J. Suárez, C. A. Navarro, L. M. Patiño, J. C. Ramírez, L. F. Rosas. "Ethics and its measures of engineering students and professors in the academic and professional formation. La ética y sus métricas de estudiantes y profesores de ingeniería en la formación académica y profesional. EIEI, ACOFI, September, 2022.

[2] CDIO. What is CDIO? Retrieved on May 24th, 2022, http://www.cdio.org/

[3] ABET. Criteria for Accrediting Engineering Programs. Retrieved on: May 24th, 2022, https://www.abet.org/accreditation/accreditation- criteria/criteria-for-accrediting-engineering-programs-2021-2022/

[4] A, Singhapakdi, S. Vitell, O. Leelakulthanit. A Cross-cultural Study of Moral Philosophies, Ethical Perceptions and Judgements: A Comparison of American and Thai Marketers. International Marketing Review, Vol., 11, No. 6, pp. 65-78, 1994.

[5] M. Jambon, J. Smetana. Theories of Moral Development. International Encyclopedia of the Social and Behavioral Sciences, second edition, volume 15, 2015.

[6] D. Martin, E. Conlon, B. Bowe. A Multi-level Review of Engineering Ethics Education: Towards a Socio-technical Orientation of Engineering Education for Ethics. Science and Engineering Ethics, Vol. 27, No. 60, pp. 59-60, 2021.

[7] N. Canney, A. Bielefeldt. A Model for the Development of Personal and Professional Social Responsibility for Engineers. American Society for Engineering Education, 2012.

[8] B. Newberry. The Dilemma of Ethics in Engineering Education. Science and Engineering, Vol. 10, pp. 343-351, 2004.

[9] A. Bielefeldt, N. Canney. Changes in the Social Responsibility Attitudes of Engineering Students over Time. Science and Engineering Ethics, Vol. 22, pp. 1535-1551, 2015.

[10] C. E. Harris, M. S. Pritchard, M. J. Rabins. Engineering Ethics: Concepts and Cases. Fourth Edition. Wadsworth, CA: Cengage Learning, 2009.

[11] L. Kohlberg. The Psychology of Moral Development: The Nature and Validity of Moral Stages, Essays on Moral Development, Vol. 2, 1984.

[12] J. Rest. (1979) Development in Judging Moral Issues. University of Minnesota Press, 1979.

[13] G. Suárez, J. Meza. Pedagogy for the formation in values. Research progress in Ethics and Moral. Pedagogía para la formación en valores. Avance de investigación. Etica y moral, Actualidades pedagógicas, Revista de la Facultad de Educación de la Universidad de la Salle, No. 42, pp. 102-115, november, 2002.

[14] R. Girard. I see to Satan coming falling as a ray of light. Veo venir a satán. Caer como un relámpago. Spain: Anagrama, 2002.

[15] E. De Bono. Six Thinking Hats. Toronto, Ont: Key Porter Books, 1985

Technical papers

Evaluating innovations in teaching about engineering in society

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***Abstract* — An understanding of the social and human dimen- sions of engineering are increasingly recognised as vital for the engineering graduates of the future. However, such skills are challenging to teach and assess.**
One subject at an Australian university has sought to address this, but in recent years has suffered from poor student feedback and declining enrolments. In early 2022, the subject underwent substantial revisions, with changes to the online content, assess- ment, and pedagogical design of the synchronous online classes. In this paper, these changes are briefly described, along with an evaluation. Although student feedback was very positive, there was no compelling evidence for attitudinal shifts in how students perceived the relationship between engineering and society.

Keywords — evaluation, society, socio-human, socio-technical

I. BACKGROUND AND MOTIVATION

The need for engineering curriculum to develop students' skills and abilities in empathising with different stakeholders, understanding the human dimensions of engineering, and big-picture thinking, are increasingly recognised in aspirational documents published by peak bodies in engineering educa- tion and practice (e.g. the Australian Council of Engineering Deans' Engineering Futures Report [1]).

One example of how this need has been operationalised is the subject Interrogating Technology at the University of Tech- nology Sydney. It fulfils an important role in the undergraduate curriculum for engineering and IT students in challenging students to problematise emergent technologies (such as self- driving cars, facial recognition software, artificial intelligence, etc.), consider their social and environmental impacts, and how they relate to diverse stakeholders.

However, in recent semesters it has received consistently poor student feedback (e.g. scoring 2.0 out of 5 on "Overall, I am satisfied with the quality of this subject"), leading to a decline in enrolments and questions about its effectiveness in developing students' understanding of the relationship be- tween the engineering profession, emergent technologies, and society. In the first half of 2022, a review of the subject was undertaken. This has involved developing more interactive online content and more structured assessments, engaging guest speakers from industry, and facilitating collaborative workshops (for example, co-designing the rubric for the final assessment with students). The aim of this study is to evaluate the effects of this change, both in terms of students' under- standing of different dimensions of the relationship between engineering and society, and in their reported experiences through student feedback surveys.

II. CURRICULUM AND INNOVATION

The subject is broadly focused on exploring the interactions and relationships between engineering and society. It is a twelve-week senior undergraduate subject which accounts for one-quarter of a full-time load. Most students are studying engineering and choosing the subject as an elective, while others are majoring in some aspect of Information Technology, of which a minority are required to complete the subject. Key topics include ethics, policy, stakeholder consultation and engagement, and sustainability. For the first five weeks, students complete weekly worksheets which require them to engage with and respond to the weekly topic and materials. The majority of the assessment comes in the latter seven weeks of the semester, in which students form teams to explore particular emergent technologies, such as self-driving cars or facial recognition, in more detail. These case studies are as- sessed in two parts. The first part is a stakeholder consultation, in which student teams have to identify stakeholders in their particular emergent technology, characterise their influence and interest in the technology (i.e. the stakeholders' 'stake'), and develop and describe different strategies that could be used to engage and consult with those particular stakeholders. The second part is an individual assessment, in which students are randomly assigned a different stakeholder for their team's technology, and then have to develop and advocate for some public policy proposals that would serve the interests of their stakeholder in regard to that technology.

In the first semester of 2022, a number of changes were implemented with the aim of improving the student learning experience. These fall into three categories: online content, assessment, teaching approaches.

A. Online content

Online modules were developed in the Learning Manage- ment System (LMS), Canvas, to support learning in the first half of the semester. These were structured as "before class" and "after class" activities, involving reading, videos, and interactive exercises, to complement the activities and content covered in the weekly workshops.

Native Canvas tools, as well as additional h5p tools, offer a variety of opportunities for asynchronous interaction and exercises. These range from anonymous polls, fill-in-the- blanks, pile-sorts, and more (see Figures 1-3). In each module, students were invited to respond to such exercises to compare their views with others in the class, and as a vehicle to engage with the content.

FIGURE 1: Example of anonymous polling

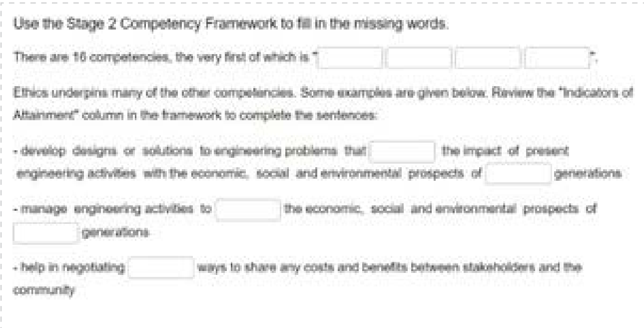

FIGURE 2: Sample fill-in-the-blanks exercise

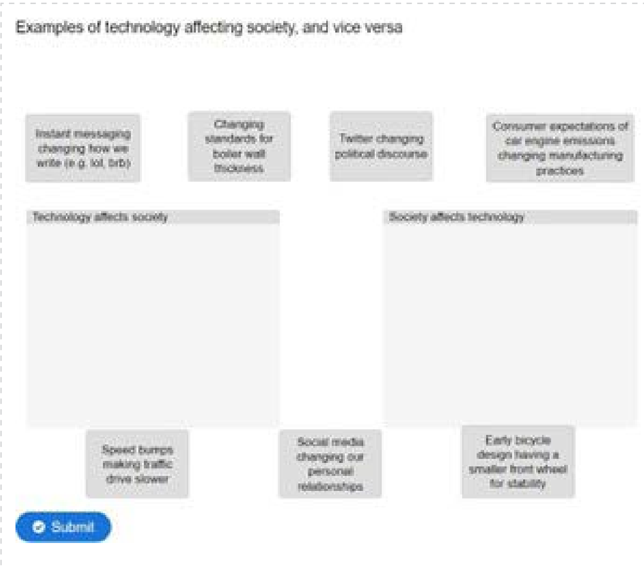

FIGURE 3: Sample pile-sort exercise

B. Assessment

Previous student feedback had identified a lack of clarity around assessment expectations and quality criteria. In re- sponse, detailed templates were developed for each assessment task with accompanying instructions. Rubrics were also devel- oped for first two assessments, in consultation with an experi- enced tutor. The rubrics included several separate aspects, and were articulated at three levels of quality. Classroom exercises to highlight these criteria and in particular the distinctions between different quality levels were conducted (see Figure4).

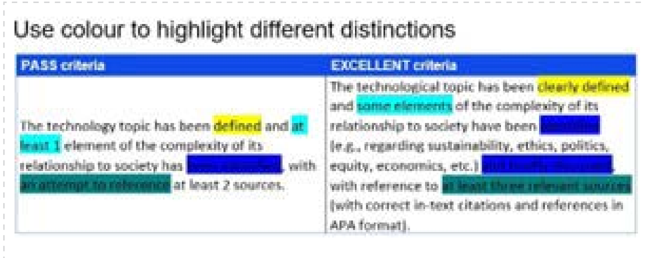

FIGURE 4: Student exercise in contrasting rubric criteria

With the third, most weighty, assessment, the rubric was co-designed with students. This was explained as being justified because one of the central tenets of the subject is stakeholder engagement, and that with students being key stakeholders in their learning the subject material, they should play a role in determining how their learning is assessed. This took place through both classes joining together online and then being lead through a review of the assessment template and instructions, before being broken up into small teams to develop ”pass” and ”excellent” criteria for the 5 different sections. These were then shared and consolidated in plenary. As a follow-up, four students volunteered to meet with me to finalise this consolidation process and also develop inter- mediary ”good” criteria. This was shared with students on the LMS for further commentary, before being published and subsequently used for assessment.

On top of critiquing past assessment exemplars, students had opportunities to get peer feedback on their draft assessments through presenting their ideas to the class and collecting comments and questions on a shared electronic whiteboard, as well as through structured pair-wise peer feedback.

C. Teaching approaches

In class a range of strategies were used to engage students. Icebreakers were a key precursor for creating psychological safety, along with changed student groups for each of the first 5 weeks, which also contributed to building social capital. This capital could then be drawn on in any sensitive discussions, such as in expressing conflicting views about an ethical dilemma, or giving peer feedback on assessment drafts.

Online polling software was used to review key points from pre-work, and to anonymously engage students in expressing their views on Likert-scale type questions used to prompt discussion. Bespoke online electronic whiteboards (e.g. Mural) were used to facilitate discussion and offer interactive activi- ties, and collaborative PowerPoint slide decks were used for break-out groups to focus on a topic, such as their analysis of different ethical dilemmas, and then report back to the class. The intention of having students report back to the class was to challenge them to synthesise their analysis, practice their communication skills, and give students an opportunity to learn from each other by seeing different instances and applications of the theory they had been learning together. Fi- nally, a number of guest speakers from industry and elsewhere were invited to the class, to speak about their professional experience with some of the concepts we covered.

III. EVALUATION

The changes were evaluated using two mechanisms: formal student feedback surveys, and pre-/post- comparisons on a short in-class attitudinal survey.

A. Formal student feedback

The university has 5 standard questions that students are asked to respond to at the end of each semester. Across all five questions, there were dramatic improvements (see Table I). Across the 120 total responses to these five statements in 2022, there were only 2 'Strongly Disagree' responses. Conversely, in 2021 across the 35 total responses to these statements, there were 16 'Strongly Disagree' responses. In the 2022 feedback survey an additional statement was included: "The assessment tasks in this subject were directly related to the subject." This statement had an average score of 4.54, with 16 'Strongly Agree's, rating higher than any other statement, indicative of a coherent alignment between curriculum and assessment.

Many of the open-ended responses support this positive quantitative data. For example:

- *The course content is extremely well planned - in such a way that it is (highly) entertaining, compelling and rele- vant to both assessment tasks and personal/professional development in general.*

- *The entire aim and structure of the subject is brilliant. I loved the collaborative discussion format that made up the most of the classes... It was so refreshing and interesting to have conversations about ethics, policy, and decision making beyond technical calculations, and I think it is hugely valuable as a part of becoming a good engineer / good and useful person in the world.*

B. Pre-/post- attitudinal survey

A short survey gauging attitudes to different aspects of the relationships between engineering, technology, and society was administered in the first and last class of semester, and used to prompt discussion and reflection. In the first class, this survey also included questions about which major the students were enrolled in, where they were dialling in from (classes at this time were still conducted online because of COVID), and other questions designed so that students could better understand the diversity in the room and how they related to it. There were five attitudinal statements or questions that students were invited to respond to in both Weeks 1 and 12. These were all on a scale of 0 to 10 and are summarised in Table II. Each statement was posed as a Likert-scale response where 0 corresponded to 'Strongly Disagree' and 10 to 'Strongly Agree', except for items 1 and 4. Item 1 about the importance of social versus technical had 0 corresponding to "Only the social is important" and 10 as "Only technical is important". Item 4 about the importance of ethics had 0 as "Not at all important" and 10 as "Extremely important".

TABLE 1: *Comparing student feedback before and after curriculum changes*

Feedback survey statement	2021 N=7/21	2022 N=24/98
The learning opportunities provided helped me meet the stated objectives of this subject.	2.57	4.42
I made the most of my opportunities to learn in this subject.	2.86	4.46
Overall, I am satisfied with the quality of this subject.	2.00	4.29
This subject provided practical learning activities to develop new skills and knowledge I may need in the work- place.	2.57	4.33
This subject has developed my understanding of my intended profession.	2.57	4.33

There were no clear trends in comparing the pre- and post- responses. For example, although there was a slightly higher average rating for item 3, about the role of engineers in public policy, there were lower average ratings for items 4 and 5 (about ethics and social responsibility, respectively).

There are a few caveats to keep in mind with the analysis of this data. First, not all of the statements have a clear 'expert' response. For example, with item 1 about the relative importance of social and technical dimensions in engineering work, it is surely defensible to claim that engineering is not solely technical, nor solely social, but there may not be expert consensus around how to respond to this question. That is, is a purely balanced response (5 on the scale) the 'expert' response? Likewise with item 2, the neutrality, or otherwise, of technology with regard to morals and values remains contested. While these statements in my classroom experience proved a valuable prompt to stimulate discussion, the data is difficult to analyse in terms of the development of expertise, while expert views remain contested or unclear. A potential avenue of future research could be to ascertain to what extent there is expert consensus around responding to these statements, or if instead there are alternative wordings (or other established instruments) that could probe such attitudes with greater confidence in their validity.

The other caveats are around the size of the sample, and the fact that the responses were not matched across the semester. In the Week 1 data set, the number of responses varied but was around the 45% mark, while for the Week 12 data set the response rate was around 16 %. The enrolment decreased over the semester but was around 100 students. Further, in keeping with the ethics protocol, responses were not identified and therefore not matched. Knowing how particular individuals changed (or did not change) their responses over the semester could offer greater insight into the effects of the learning experience, but was not possible in this instance.

TABLE 2: *Comparing attitudinal survey responses*

Survey statement	Week 1 (~ 45%)	Week 12 (16%)
1. The social and technical are equally important in engineering and IT work.	5.9	5.9
2. Technology is neutral with regard to morals and values (e.g. a gun can be used to hurt other people, is a gun inherently bad?).	5.8	5.3
3. Engineering and IT professionals have an important role to play in public policy.	7.7	8.5
4. How important is ethics in engineering and IT work?	8.9	8.3
5. Engineering and IT professionals have a responsibility to society.	9.0	7.7

IV. DISCUSSION AND CONCLUSION

Although the student feedback was encouraging, such measures are known to be flawed and prone to many biases [2]. Less encouraging, however, were the attitudinal survey data which showed no compelling evidence of any shift. Other studies of students' development of related competencies, such as socio-technical thinking, suggest that one semester may be insufficient to discern any noticeable changes [3]. Instead, social dimensions of engineering must be made visible and incorporated throughout the curriculum across all year levels [4], to ensure students recognise these dimensions as central to engineering and have a coherent trajectory along which to develop expertise.

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REFERENCES

[1] C. Crosthwaite, "Engineering futures 2035 engineering education pro- grams, priorities & pedagogies," Australian Council of Engineering Deans, Report, 2021.

[2] T. Heffernan, "Sexism, racism, prejudice, and bias: a literature review and synthesis of research surrounding student evaluations of courses and teaching," Assessment & Evaluation in Higher Education, pp. 1–11, 2021.

[3] A. Mazzurco, S. Daniel, and J. Smith, "Development of socio-technical and co-design expertise in engineering students," in Research in Engineer- ing Education Symposium; Research in Engineering Education Network: Cape Town, South Africa, 2019.

[4] J. A. Leydens and J. C. Lucena, Engineering justice : transforming engineering education and practice. Hoboken, NJ : Piscataway, NJ: Hoboken, NJ : John Wiley Sons ; Piscataway, NJ : IEEE Press, 2018.

Technical papers

Change and future of engineering education in the field of transport, analyzed by the state of research in freight rail automation

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***Abstract* — Transportation systems are confronted with a vari- ety of social, economic, ecological and technological challenges. Rail-bound freight transport provides low-emission transport capacities. However, a majority of rail-bound freight transport still relies on inefficient manual processing and lacks digitization, especially when it comes to shunting and train composition. In order to solve the engineering task of smart shunting automation, inter-disciplinary knowledge is required. This includes electri- cal and control engineering, radio communication, localization, smart infrastructure design as well as embedded system pro- gramming. The arising heterogeneity needs to also be reflected in modern engineering education. Therefore, this contribution aims at providing a structured overview of all involved and related education disciplines in designing and implementing Intelligent Transportation Systems and how they need to be considered in research oriented education. Furthermore, the shifted requirements for engineering students in the light of more complex and interdependent systems are outlined. Based on this, several tools and teaching approaches to compensate the shifted requirements are presented. Finally, the approach is illustrated by a current teaching example in the engineering education in the field of smart shunting.**

Keywords — Transportation Engineering, Project-oriented learning, Research-oriented education, Problem-based learning, Experience-based learning, Automated Shunting

I. INTRODUCTION

Mobility and associated processes are of fundamental im- portance in all humans daily lives. Next to individual mobility needs, the freight transportation sector is imperatively required in a global world. However, it also faces the challenges associated with increasing emissions and its effects on climate. Therefore, mobility demands need to be met with a minimum of traffic volume in addition to efficient mode of traffic selection. In order to provide measures targeted to increase the efficiency of transportation systems, the use of digitiza- tion, information- and communication, as well as automation technologies is rapidly emerging in modern mobility systems. Generally, intelligent transportation systems (ITS) aim to provide technology-enabled state monitoring, networking and control of transportation components [1]. As those allow for a more efficient use of transport resources and infrastructure, the development and deployment of ITS will increase steadily over the next years.

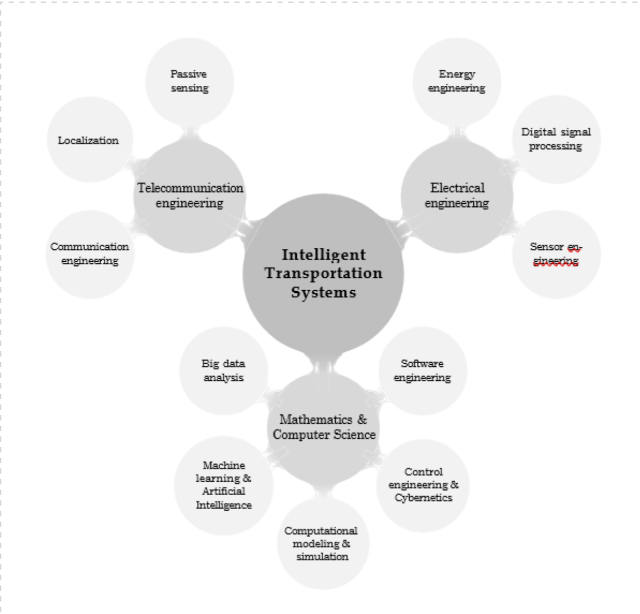

FIGURE 1: *ITS and their educational aspects.*

In unison with these technical and technological develop- ments, the heterogeneity of the required scientific disciplines in order to design and implement these complex systems constantly increases [2]. This transformation ranges from stand-alone, manual transportation over increasing automation of vehicles towards intelligent networking vehicles [3].

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Vice versa, for ITS engineering education, these disciplines and accompanying skill sets for students need to be addressed holistically and with respect to technological evolution steps [4]. Similar to other engineering disciplines, transportation en- gineering is rapidly growing into a multi- and inter-disciplinary research and education field. This is further highlighted in Figure 1, which presents ITS engineering as a cross section of different scientific and engineering disciplines. In addi- tion, discipline-related specializations are further mentioned, required to successfully develop an ITS. This heterogene- ity further underlines the increasing complexity and inter- disciplinarity of transportation engineering. The increase of multi- and inter-disciplinary research and development in modern ITS and their effects on engineering education also poses the main hypothesis this paper will focus on. In order to assess this proposition, the paper will empirically discuss the research topic of automated freight rail shunting and logistics as well as its technological and corresponding research disciplines as well as their effects on modern engineering education. Additionally, we discuss adapted education approaches both in terms of content and learning forms in order to provide engineering students holistic problem solving skills.

II. FREIGHT RAIL ENGINEERING AND ITS EVOLUTION OVER TIME

A. Evolution of freight rail logistics

Beginning with the first railway systems in the 19th century, freight transportation was one of main rail applications. Since then, technology has shifted in a tremendous way. This is foremost visible in change of the drivetrain technology, which shifted from steam engine over diesel engine to electric powered operation. In parallel, the underlying logistics have changed, from a single piece goods centered logistic to con- tainer cargo operations. In contradiction, bulk good transport remained almost constant from a technological point of view. Another big change can be seen in the technology applied in freight wagons. For a long time, those could be seen as passive, “dumb” rollingstock without any active components except pneumatic breaks. The only interconnection to the residual train is given by mechanical couplings and the train pipe. In contrast, the installation of active electronic components, e.g. a smart telematic unit, allows for a variety of applications:

- Localization in shunting yards for automated shunting
- Goods tracking
- Digital freight billing
- Monitoring of mechanical condition of the wagon for predictive maintenance
- Communication link between wagons for train integrity

To implement these functionalities, an active telematic component needs to contain hardware and software solutions for data storage, localization, communication, rollingstock hard- ware condition monitoring and a power supply. Furthermore, the area of application imposes constraints on physical rugged- ness, rail certification and international standardization. There- fore, the hardware solution needs to be as simple, energy- economic, rugged, easy-to-deploy and easy-to-maintain while still providing accurate and powerful solutions to the afore- mentioned applications. From this arises the engineering task of multi-criteria optimization of such a solution, causing an increased amount of complexity. It is not self-evident that such a decentralized system solution with an active component on each freight wagon outperforms a centralized solution with passive freight wagons.

However, the opportunities arising by implementation of smart hardware comes at the cost of higher complexity of the whole system. Assessing both advantages and disadvantages of the proposed solution and taking into account that rail freight system capacity urgently needs to be extended as a result of shifting transport to more climate-friendly modes of transportation. Therefore, we identify the necessity for future engineers involved in designing and working with rail freight systems to be able to deal with and enhance intelligent and automated solutions.

With these in mind, we will now continue with the deduc- tion of necessary skills to fulfill future engineering tasks and explain how engineering education needs to adapt to these changes.

B. Modern requirement profiles for railway engineers

Based on the increasingly complex processes of shunting and the composition of train compositions, a multitude of new knowledge is required from current and future railway engineers. As shown in Figure 2, new engineering disciplines became pertinent for freight transport. It is important to note, that this process resembles a broadening of the field of required knowledge, as the traditional disciplines (e.g. mechanical engineering) still continue to be the foundation of freight train engineering.

Furthermore, a key factor is to understand the deep inter- dependecies between the several disciplines. As an example, long term sensor data acquisition and evaluation for predictive maintenance of wheel sets of freight wagons can be examined. To predict an imminent failure, it is necessary to understand how mechanical intricacies generate oscillations (mechanical engineering), how these propagate through the wagon (solid body physics), how this depends on the current velocity (vehicle dynamics), how sensor signals need to be interpreted accordingly (sensor technology and data analysis) and finally how this incident can be reported to a central authority (communications engineering). This deep integration makes it necessary to impart the knowledge in a holistic and integrated way. An important part take case studies to visualize these characteristics. Furthermore, domain-specific properties need to be taken into account, e.g. the very rugged environment, under which all deployed technology still needs to work.

III. MODERN EDUCATION APPROACHES FOR ITS ENGINEERING

In addition to the domain specific requirements of freight rail engineering, there are more general trends and forces at work in engineering education in the field of ITS. These changes are examined in this section.

A. Change in learning requirements

Lead by the technological changes and on-going digitization, the amount and complexity of ITS scenarios is constantly increasing. Classical engineering education relies on teaching mathematical and engineering tools, which are aimed at solving dedicated problems. However, formerly separated research areas become more and more integrated and cross- discipline. As a consequence, methods for interdisciplinary system understanding and modeling become more important. Several trends in the recent scientific history amplify this effect:

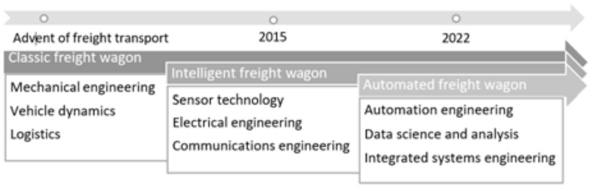

FIGURE 2: *Evolution of rail freight transport and corresponding underlying scientific disciplines.*

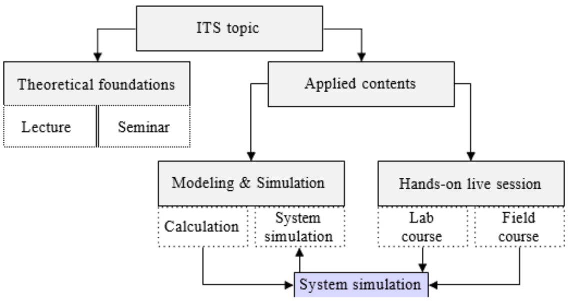

FIGURE 3: *Interconnection of ITS topic at teaching*

1) ***Complexity of application scenarios:*** Complex inter- dependencies between several aspects of a research topic oftentimes can not be described in a comprehensive manner by the means of one traditional research discipline. To understand and design such integrated systems, not only the foundations for radio technology need to be taught, but also how to apply classic localization algorithms within the framework of such integrated systems. This can be illustrated in the scope of ITS by the advances in joint communication and sensing. For this purpose, radio signals are not only used for communication purposes, but also exploited for localization and passive sensing applications.

2) ***Non deterministic systems:*** Another issue arises with the rise of complex statistical models, especially with the advent of deep learning. The deterministic effects within such models can not easily be explained and may be treated as black box models. A common approach to examine the dynamics of such systems is, to observe the statistical behavior over the course of many test runs.

3) ***COVID pandemic:*** In addition to inherently scientific issues, external reasons can restrict classical teaching approaches. The most severe restrictions were posed by the COVID pandemic, which lead to a temporal suspension of presence sessions. As a consequence, online teaching formats emerged rapidly. Further reasons for non-realtime or non in-place learning are time limitations by parallel side jobs, remote studying and family care.

B. Learning process

1) ***Course structure:*** The ensemble of learning content can be grouped in theoretical foundation parts and applied contents based thereon. Traditionally, theoretical knowledge is taught in lectures and self-study oriented seminars (cf. Figure 3). In contradiction, applied contents can be explored by either using modeling tools or doing hands-on sessions in lab or field courses. The integrated combination of both theoretical and applied parts are key to a profound understanding of current research topics and modern transportation systems.

2) ***Learning process:*** The transfer of research results and the methods applied in research to teaching is very important, especially in today's era of networking and digitization. The practiced research-oriented teaching has the following aims [5], [6]:

- Acquisition and consolidation of professional knowledge as well as learning and development of interdisciplinary competences.
- Developing an inquiring attitude: promoting curiosity and the ability to interrogate things as well as to ask questions and explore possible explanations.
- Development of research methodological skills.

ITS education consists of several interconnected parts:
When transferring research results into teaching, students can apply the methods they acquired. Through the experience and the practical relevance, students make their own associations and learning successes are more likely. In this way, students see themselves as part of the project and the gap between theory and practice can be closed. Students are therefore supported in formulating their own research questions and theses.

C. Adaption to changed learning requirements

In order to adapt to the changing learning profile, teaching approaches need to adapt both in structure and in means of knowledge transfer. General trends are:

- Online learning: Live sessions allow for remote learning while allowing interaction. Asynchronous learning material facilitate time management constraints.
- Focus on modeling and implementation skills: Most engineering problems can be approached by implementing a model in a general purpose programming language. Implementing a research issue from scratch require and foster system understanding.
- System simulation: Simulation of complex systems allow for deep exploration of such systems and scenarios which are not accessible in field or lab sessions.

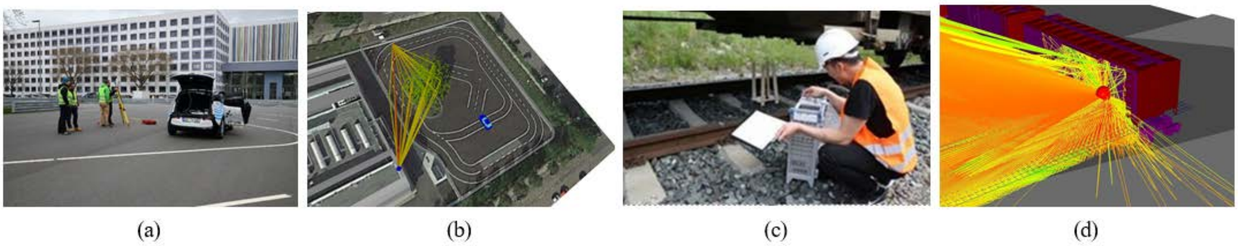

FIGURE 4: Learning environments for ITS engineering: (a, c) Field course for localization and communication systems; (b, d) ITS resp. smart rail infrastructure system simulation for radio propagation.

IV. CASE STUDY: RESEARCH-ORIENTED TEACHING ON THE EXAMPLE OF AUTOMATED FREIGHT TRAIN SHUNTING

A. Problem formulation and research background

One key property of rail freight logistics is the fact that it is necessary to assemble train formations at the transport source and then to disband them again in the sink [7]. Simply put, no trains can run without shunting, because every train is created by the shunting process. These activities take place in shunting yards or train formation facilities and are usually personnel-, cost- and time-intensive. This has a detrimental effect on the economic efficiency of the entire rail-bound logistics value chain. Through a largely automated shunting process, it is possible to make this process more efficient and, above all, with less risk for the personnel [8]. The research project "Automatic Train Shunting in Freight Transport", AZubiG for short, is addressing these challenges of rail freight transport [9]. The aim is to develop an integrated system for the automated shunting processes in train formation facilities using autonomous shunting vehicles and with highly available positioning and communication of the freight wagons. AZubiG will lay the foundation for electro-mobile logistics in rail freight transport. AZubiG also enables automatic and highly flexible round-the-clock shunting and rail operations. This will make the last mile on the railways, and thus the entire railway system, competitive again and able to exploit its ecological and economic advantages.

B. Project related teaching content

In order to understand the project-specific learning requirements, the steps undertaken in AZubiG to achieve the goal of an automated shunting yard need to outlined in more detail:

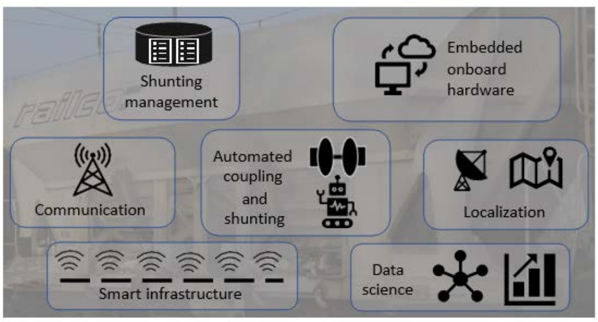

FIGURE 5: Overview of ITS-related teaching and learning forms.

The overall approach is to use a two-way (rail and ground) shunting vehicle, which automatically drives to the wagon to move, uses an automated coupling to attach the wagon, shunt it to the position where the final train is to be composed and finally decouple. This task involves several subtasks to solve, which are shown in Figure 5. In order to control the shunting vehicle's trajectory, precise localization and low- latency communication are necessary, which in turn rely on robust embedded onboard hardware and smart infrastructure sensing components. System properties of certain components therefore are determined by the performance requirements of other components, which requires highly interdependent engineering solutions.

C. Adaptions in curriculum and teaching methods

Traditionally, the Diploma-granting course "Transport Engineering" at Technische Universita¨t Dresden is offered as a mix of foundations of traditional engineering disciplines (mechanical, electrical and process engineering as well) and a specialization, which is chosen after four semesters. In the past, the use of sensors and communication technology in various modes of transport was examined in the field of traffic telematics.

The foundations for this were laid in the basic lectures. In order to develop a full comprehension of complex processes such as automatic shunting, further components must be included in the design of the curriculum. This is because in addition to the use and operation of software components for the management of freight wagons and shunting processes, knowledge of the evaluation of measurement data or as well as a deeper understanding of communication and localization processes are also important skills for an ITS engineer.

Figure 6 shows the adaptation of new teaching content to the existing curriculum using the example of freight railway automation. The new topics are marked in bold. For example, the Traffic Sensors lecture has now been redesigned and the focus is now increasingly on part of data science.

In teaching and knowledge transfer, the focus is increasingly on methods of experienced-based learning and project-based learning. [10], [11] . The students apply the knowledge they have acquired, for example from the basic lectures, to the field of automatic shunting. In addition to face-to-face teaching, some parts of the new learning content were prepared within the context of flipped classroom concepts. [12] A large number of learning videos and materials are made available to the students digitally.

Technical papers

Reducing cyber crime in Africa through education

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***Abstract* — Technology needs and uses are expanding in Africa. Cybersecurity challenges faced daily are: child pornography, stolen money, data breaches, denial of service, online extortion, cred-it-card fraud, identify theft, network takeovers via botnets, fake news and emails, ransomware, and more. Since the Internet is ubiquitous, any security improvement in one location benefits all. This paper postulates that such security achievements can be attained through high- quality engineering education in cybersecurity. ABET is the recognized world leader in accrediting programmes in engineering and computing. In their 2022-23 Criteria for Accrediting Computing Programs, ABET published criteria for accrediting two-year programmes in cybersecurity. The novel research question we examine is what it would take to spawn an ABET-accreditable, two-year degree in cybersecurity from a typical African Bachelor of Science in Computer Science. As experts with a combined 35+ years' experience with ABET accreditation, we use a systematic methodology to evaluate and analyse a programme in a de-tailed, step-by-step, easy-to- understand manner and show exactly what needs to be done to build a two-year cybersecurity programme. Our approach is straightforward, comprehensive, and replicable. Two-year programmes are a step toward developing a cybersecurity workforce in Africa, where there are few programmes dedicated to cybersecurity. It is our hope that this work inspires and shows educational institutions a way to spawn two-year programmes in cybersecurity from their existing programmes. The rationale and significance of this work is that it leads the way to develop educational pro-grammes in cybersecurity in Africa. The cadre of workers that could be added to Africa's workforce from this research is relevant and critical to Africa's development and online security. Without having the personnel and tools to fight cyber-crime properly, the continent falls behind on the international stage and is unable to compete successfully for international businesses. News reports of increasing incidents of cyber-crimes originating from particular regions and countries, badly damage their reputations as locations for healthy places to conduct business. This work combats cybercrime through engineering education.**

Keywords — Accreditation, cybersecurity, and engineering curriculum development.

I. INTRODUCTION

ABET, Inc. is the recognized world leader in accrediting programmes in engineering and computing; ABET is no longer used as an acronym. As of this writing, ABET ac- credits 4,361 programmes at 850 institutions in 41 countries [1]. Every year 175,000+ students graduate from ABET- accredited programmes. To become accredited, pro-grammes must meet the quality standards of their professions so graduates are prepared to enter and succeed in the workforce. In [2] ABET published Program Criteria (PrCr) for accrediting associate-degree programmes in cybersecurity (CSec). These are two-year programmes—equivalent to diplomas in some countries in Africa. For a specific field, PrCr are informed by the most knowledgeable people who have the latest and best curriculum information. ABET's PrCr themselves influence how curriculums evolve at institutions. To become ABET accredited, a programme must meet ABET's curriculum requirements. It is true that if one examines programmes throughout the world, their curriculums do conform to a certain core set of topics, as specified in their corresponding ABET PrCr. The ABET curriculum becomes a guiding model, at least for those starting new programmes, as well as a standard for those having or seeking ABET accreditation. For these reasons, we adopt ABET's two-year model for CSec programmes.

Cybercrimes in Africa are a growing daily occurrence: both in terms of frequency and significance of loss [3], [4], [5], and [6]. Due to the lack of educational programmes in CSec, the continent is unable to meet workforce demands. This paucity of workers contributes to cybercriminals being successful in Africa. There are many well-established, four-year programmes in computer science (CS) throughout the continent (see [7] South Africa; [8] Ethiopia; [9] Kenya; [10] Nigeria; [11] Zimbabwe; and [12] Tanzania for representative examples). Of the 21 institutions in the USA who have ABET accreditation for their four-year CSec programmes [13], a majority evolved from CS. It is natural to look to CS as a genesis for CSec programmes. By examining how a two-year programme in CSec could be spawned from an existing four- year CS programme, we demonstrate how African nations can build their needed CSec workforces. The need for CSec programmes has been demonstrated [14], and the curriculum for CSec has evolved [15]. The two-year CSec curriculum is stable and accepted.

We have compared the CS curriculums in a dozen African countries with that at the University of Namibia (UNAM) [16]. They are relatively close in their course offerings and requirements. As we are most familiar with UNAM's curriculum, it is used as a representative CS curriculum from which to develop a two-year CSec programme. Although this work is entirely new and original, of interest to readers may be related research literature and background information. In [17], [18], and [19], early groundwork was laid for the curriculum of computing programmes. The curriculum evolution continued in [20], [21], and [22]. A recent curriculum model is presented in [23]. In [24] and [25] foundations for the accreditation standards of computing programmes were presented and their history outlined. In [26], they discuss how to interpret ABET's CS Criteria using competencies. ABET has a four-year PrCr for cybersecurity engineering [27], but has no such two-year program. CSec programmes primarily emerged from CS programmes.

This work solves the innovative and relevant research problem of taking a representative CS programme in computing in Africa and seeing what it would take to produce a two-year CSec programme that is ABET accreditable. The research is of interest to administrators, deans, department heads, faculty members, lecturers, and government officials who are motivated to improve their programmes, develop engineering/computing programmes in CSec, help satisfy a workforce demand, and follow the best practices engineering and computing. The relevance and importance of this problem to engineering education is clear. The methodology is to bring to bear 35+ years of experience with ABET, including helping to develop the four-year CSec PrCr for ABET for both computing and engineering, and 50+ years of experience with curriculum development to evaluate and analyse a typical four-year CS programme and morph it into a two-year CSec programme. Although this paper describes how to make such a programme ABET-accreditable, institutions do not have to seek accreditation for this work to applicable. They can offer a two-year CSec programme that has a state-of-the-art curriculum, but does not meet the remaining GC requirements. This is still valuable and of critical importance to Africa's educational and economic development. For programmes that follow through, a roadmap is provided, and the hurdles to be cleared and the resources required are discussed.

This work chose to focus on ABET, as they are the world leader in accrediting programmes in engineering and computing. They are supported by 35+ professional and technical member societies [1]. Over 40+ international groups related to accreditation also recognize ABET. Examples include the British Computer Society, China Association for Science and Technology, European Society for Engineering Education, and the Australian Computer Society. The goal of this paper is not to compare or evaluate accrediting agencies, as that would entail another different paper. The Seoul Accord, which one of the authors helped develop, was "established in 2009 with ABET as a founding signatory. It is the multi-lateral Mutual Recognition Agreement (MRA) for computing. Current members include ABET, the Accreditation Board for Engineering Education of Korea (ABEEK), the Australian Computer Society (ACS), the British Computer Society (BCS), the Canadian Information Processing Society (CIPS), the Hong Kong Institute of Engineers (HKIE), the Institution of Engineering Education Taiwan (IEET), and the Japan Accreditation Board for Engineering Education (JABEE)" [28]. ABET is leading the way in CSec accreditation and most of the other accrediting agencies mentioned do not accredit CSec programmes yet, never mind two-year programmes.

II. ABET'S CRITERIA FOR AN ASSOCIATE CYBERSECURITY

Programmes become ABET accredited by satisfying General Criteria (GC) and a specific Program Criteria (PrCr). The GC (see Table 1) consists of eight items: Students, Program Educational Objectives (PEOs), Student Outcomes (SOs), Continuous Improvement (CI), Curriculum, Faculty, Facilities, and Institutional Support (InS). The PrCr typically focus on SOs and curriculum, with the bulk of the requirements being in the latter area. The Associate CSec PrCr is unusual, even for ABET, in that the PrCr elements for Criterion 3, SOs, and Criterion 5, Curriculum, actually replace these two elements in the GC rather than become additional requirements. The essentials of each are covered next.

The SO requirements for CSec come from the PrCr, and reads as follows [2]:

1. Analyse a broadly defined security problem and apply principles of CSec to the design and implementation of solutions.
2. Apply security principles and practices to maintain operations in the presence of risks and threats.
3. Communicate effectively in a variety of professional contexts.
4. Recognize professional responsibilities and make informed judgments in CSec practice based on legal and ethical principles.
5. Function effectively as a member of a team engaged in CSec activities.

TABLE 1: *GC for all programmes accredited by an abet commission [2].*

Criteria	Description
Students	Policies for accepting new and transfer students; awarding appropriate academic credit for courses completed earlier, including at other institutions; and enforcement of procedures to ensure graduates meet requirements.
PEOs	Broad statements describing what graduates are expected to attain within a few years of graduation.
SOs	Material and activities students are expected to know and do by the time of graduation.
CI	Processes for assessing/evaluating the attainment of SOs.
Curriculum	Technical, professional, and general education (GE) components associated with the programme.
Faculty	Sufficiency and competency of faculty members.
Facilities	Adequacy of facilities to support attainment of the SOs.
Institutional support	Institutional support and leadership to ensure the quality and continuity of the programme.

The CI Criterion requires programmes have a robust system in place that is used regularly to determine the extent to which the SOs are being attained. The system should lead to improvements. Explicit curriculum requirements come from the PrCr. They are shown in Table 2 [2].

TABLE 2: *ABET'S CSEC PRCR curriculum requirements.*

Part	Component	Description
A	Requirements	Aligned to SOs and consistent with PEOs.
B	Curriculum	Technical, professional, and GE components.
C	Credit Hours	Min. 30 semester hours, covering up-to-date material on specified cybersecurity topics.
D	Math Skills	To meet the SOs and PEOs.

Expanding on Table 2C: the material includes "1. Application of techniques, skills, and tools necessary for the CSec practice. 2. Application of the crosscutting concepts (CCs) of confidentiality, integrity, availability, risk, adversarial thinking, and systems thinking. 3. CSec topics from each of the following areas: a) Data Security, b) Software Security, c) Component Security, d) Connection Security, e) System Security, f) Human Security, g) Organizational Security, and h) Societal Security. 4. Programming or scripting skills. 5. Advanced CSec topics building on the CCs and CSec topics" [2].

III. UNAM'S COMPUTER SCIENCE PROGRAMME

First-year students take the following ABET-relevant, computing/CSec-related courses: Programming Fundamentals I (PF I), Introduction to Digital Electronics, Fundamentals of Information Technology I (FIT I), Programming Fundamentals II (PF II), Fundamentals of Information Technology II (FIT II), and Introduction to Statistics [16]. At UNAM, one contact hour is equivalent to one lecture period. Semesters have 14 weeks of instruction. A full-semester course is 16 credits, has four contact hours per week, and totals 56 contact hours. There are also half-semester courses.

Second-year students take: Introduction to Database Systems, Object Oriented Programming I (OOP I), Discrete Mathematics Concepts, Computer Networks I, Advanced Databases, Object Oriented Programming II (OOP II), Telecommunications, and Computer Networks II. Third-year students take: Advanced Computer Networks, Software Engineering, Information Security, Systems Administration and Maintenance, Internet Technologies and Applications, Human Computer Interaction (HCI), Research Methodology, and Platform Technologies. Final-year students take: Research Project for 32 credits, Network System Security which is a half-semester course, Wireless and Mobile Computing which is a half-semester course, and IT Project Management. Final-year students choose two of the following elective courses: Distributed Systems, Artificial Intelligence, and Entrepreneurship and Management of IT Systems. Final- year students also choose two of the following elective courses: Expert Systems, Real Time Multimedia, and Cloud Computing.

IV. SPAWNING AN ASSOCIATE CYBERSECURITY

The authors studied UNAM's courses and analysed them systematically with respect to ABET's requirements for the PrCr Associate CSec. Table 3 shows the courses selected to satisfy the bulk of curriculum requirements. Although UNAM's programme requires many other CS courses, many are at an advanced level and require pre-requisites for courses not included in Table 3. This table was constructed by making judicious choices. The selected courses give the greatest coverage of the curriculum requirements in the PrCr Associate CSec. The table shows a total of ten computing courses (40 credits), one math course (4 credits), and three GE half courses (6 credits), for an overall total of 50 credits. A typical two-year programme has 60–65 credits, and a value in that range is desirable. The 10 to 15 credits not yet specified give wiggle room to add curriculum elements not yet covered.

When there is a shortcoming, meaning a part of the Criteria is not yet met, it is indicated by a Si, where 'i' is a number representing the shortcoming's number. After processing requirements, each shortcoming is discussed. As shown in Table 2A, "Program requirements must be consistent with its PEOs and so SOs can be attained" [2]. UNAM's programme has not defined ABET-style PEOs (S1), which is natural because the programme design did not use ABET's standards, and they have not sought accreditation. ABET's CSec PrCr SOs all focus specifically on CSec, so the CS programme's curriculum does not specifically address the CSec PrCr SOs yet (S2). The courses listed in Table 3 provide natural places where the necessary CSec material can be inserted. We explain how this can be accomplished later (see Table 4). Table 2B specifies that the curriculum needs to combine technical, professional, and GE components. The courses in Table 3 provide technical and professional components to prepare students for a career and lifelong professional development in CSec. The other piece of B, as shown in Table 2, is that students receive an appropriate GE. There are only six credits dedicated to GE and most are in English. UNAM offers many GE courses, we opted to devote four of the available credits to one. Roughly 15% of the programme is dedicated to GE. This eliminates a potential shortcoming.

TABLE 3: *UNAM'S CS programme's required courses that can be used in a two-year CSEC programme. in Column 3, C = credits.*

Course	ABET Requirement	C
English Communication	B. GE course.	2
PF I	C4. Programming or scripting skills.	4
Digital Electronics	C1. Techniques, skills, and tools for CSec practice. C3c. Component Security.	4
FIT I	C1. Techniques, skills, and tools for CSec practice.	4
English	B. GE course.	2
Social Issues	B. GE course.	2
PF II	C3b. Software Security. C4. Programming or scripting skills.	4
FIT II	C1. Techniques, skills, and tools for CSec practice.	4
Database	C1. Techniques, skills, and tools for CSec practice. C2. Confidentiality, integrity, and availability. C3a. Data Security.	4
Math for CS	D. Math skills.	4

Course	ABET Requirement	C
Networks I	C1. Techniques, skills, and tools for CSec practice. C2. Availability. C3cd. Component and Connection Securities.	4
Architecture	C1. Techniques, skills, and tools for CSec practice. C2. Availability and systems thinking. C3cde. Component, Connection, and System Securities. C5. Advanced topics.	4
HCI	C1. Techniques, skills, and tools for CSec practice. C3afh. Data, Human, and Societal Securities. C5. Advanced topics.	4
Emerging Technologies	C1. Techniques, skills, and tools for CSec practice. C3be. Software and System Securities. C5. Advanced topics.	4
Total		**50**

When there is a shortcoming, meaning a part of the Criteria is not yet met, it is indicated by a Si, where 'i' is a number representing the shortcoming's number. After processing requirements, each shortcoming is discussed. As shown in Table 2A, "Program requirements must be consistent with its PEOs and so SOs can be attained" [2]. UNAM's programme has not defined ABET-style PEOs (S1), which is natural because the programme design did not use ABET's standards, and they have not sought accreditation. ABET's CSec PrCr SOs all focus specifically on CSec, so the CS programme's curriculum does not specifically address the CSec PrCr SOs yet (S2). The courses listed in Table 3 provide natural places where the necessary CSec material can be inserted. We explain how this can be accomplished later (see Table 4). Table 2B specifies that the curriculum needs to combine technical, professional, and GE components. The courses in Table 3 provide technical and professional components to prepare students for a career and lifelong professional development in CSec. The other piece of B, as shown in Table 2, is that students receive an appropriate GE. There are only six credits dedicated to GE and most are in English. UNAM offers many GE courses, we opted to devote four of the available credits to one. Roughly 15% of the programme is dedicated to GE. This eliminates a potential shortcoming.

Table 2C specifies that at least 30 hours of CSec-related topics are included in the programme. Table 3 shows 40 hours (items marked C1 in Table 3) that contain up-to-date materials on the specified topics. All these courses focus on the application of techniques, skills, and tools necessary for the CS practice. They apply to CSec too. It is required that the CCs of confidentiality, integrity, availability, risk (S3), adversarial thinking (S4), and systems thinking (S5) be applied. See items in Table 3 marked with a C2. The third requirement of Part C (items marked with a C3 in Table 3) necessitates inclusion of CSec topics from each of the following areas: a) Data Security (covered in Database and HCI), b) Software Security (PF 2 and Emerging Technologies), c) Component Security (Digital Electronics, Networks I, and Architecture), d) Connection Security (Networks I and Architecture), e) System Security (Architecture and Emerging Technologies), f) Human Security (HCI), g) Organizational Security (S6), and h) Societal Security (HCI).

The fourth requirement of Part C (items marked C4 in Table 3) necessitates covering of programming or scripting skills. These items are covered in PF I and II, where programming is taught. The final requirement of Part C (items marked C5 in Table 3) specifies that there must be advanced CSec topics building on the CCs and CSec topics (S7). Table 2D stipulates that math skills must be included in order to meet the SOs and PEOs. Math for CS is a course in discrete math that covers the skills that a CSec student requires. In the next section, the seven shortcomings identified are addressed. Remedies are presented to alleviate them. Table 4 summarizes the shortcomings identified in the curriculum.

TABLE 4: *Shortcomings with respect to ABET'S requirements for the associate CSEC using courses from UNAM.*
G = grade, E = easy, and H = hard.

#	Shortcoming	Fix	G
S1	No PEOs.	Define ABET-style PEOs.	E
S2	SOs not specifically addressed with respect to Csec.	Shift the focus to CSec rather than CS. Add material to address the SOs. Add a team project in the proposed new course Cyberattacks; see item S7. Add a new course Cyber Ethics that covers legal and ethical principles of CSec, and includes individual written & oral presentations. The course should focus on the CCs.	H
S3	Application of the CC of risk.	Include some modules and discussions in Database and HCI.	E
S4	Application of adversarial thinking.	Include some modules and discussions in Architecture and HCI.	E
S5	Application of systems thinking.	Include some modules and discussions in Architecture and Emerging Technologies.	E
S6	No coverage of Organizational Security.	Include some modules and discussions Cyberattacks—the new course to remove S7 (see next row).	E
S7	Need to include advanced CSec topics building on CCs.	Introduce a new advanced course on Cyberattacks. Discuss the CCs and include modules and discussions on Organizational Security. Include a team project. Build on the CCs.	H

S1 is unfair because a programme not seeking accreditation will not have ABET-style PEOs. UNAM's programme has its own goals for graduates. These could be modified into a couple PEOs for Associate CSec graduates. Similarly in S2, programmes will not have adopted ABET's SOs. The two-year programme being proposed would need to shift its focus from CS specifically to CSec. To accommodate ABET's SOs, the programme would need to add teamwork, ethical and legal principles relating to CSec, communication exercises, more material on the CCs, and increase its focus on CSec in general. To fill in these gaps, we propose adding two courses Cyberattacks and Cyber Ethics. As elaborated on in Table 4, the two courses remediate the shortcomings with respect to the SOs. The shortcomings S3, S4, and S5 deal with the CCs. In Table 4, certain courses are indicated where the missing CCs can be incorporated. S6 is related to Organizational Security. In the new course Cyberattacks, a module on Organizational Security is included. To remediate S7, the new course on Cyberattacks builds on fundamental Csec topics and the CCs to incorporate advanced CSec.

Table 5 shows the curriculum in the new two-year programme. The lightly shaded courses require the introduction of new CSec modules. The darker courses are new. Thus, by the introduction of just two new courses and the addition of CSec content in only four other courses, we made a subset of UNAM's CS programme's curriculum compliant with ABET's Associate CSec. The programme contains 62 credits. Next the remaining GC requirements are examined to see what would need to be done to make the programme fully ABET compliant rather than just curriculum compliant.

***TABLE 5:** Complete Two-Year CSEC programme. Lightly shaded courses require some modification. The darkly shaded courses are entirely new.*

Course Name	C
English Communication & Study Skills	2
Programming Fundamentals I	4
Introduction to Digital Electronics	4
Fundamentals of Information Technology I	4
English for Academic Purposes	2
Contemporary Social Issues	2
Programming Fundamentals II	4
Fundamentals of Information Technology II	4
Introduction to Database Systems	4
Mathematics for Computer Science	4
Computer Networks I	4
Computer Organization & Architecture	4
Human Computer Interaction	4
Emerging Technologies	4
General Education Elective	4
Cyberattacks	4
Cyber Ethics	4
Total Credits	**62**

V. MODIFICATIONS REQUIRED FOR ABET COMPLIANCE

The authors analysed each GC item in turn for the programme proposed in Table 5. Due to space limitations, findings are summarized in Table 5I. Note that with a shift in focus toward CSec and with two new courses added, Cyberattacks and Cyber Ethics, the SOs will be enabled.

***TABLE 6:** summary of issues to comply with ABET'S GC, excluding curriculum matters.*

G = grade, E = easy, M = medium, and H = hard.

Issue	Action Required	G
No SOs defined.	Adopt ABET's SOs.	E
No PEOs defined.	Formalize programme goals for graduates. Formalize process for maintaining PEOs and keeping the constituents involved.	H
Publish PEOs and SOs.	Develop PEOs and SOs, make them public. Publish enrollment data.	E
Develop a CI process.	Develop and implement a complete assessment and evaluation process, and use it to improve the programme.	H
Some faculty members are not current in CSec.	Provide professional-development opportunities and funds so faculty members can remain current in CSec.	M
Making sure SOs are attained and PEOs achieved.	Once the programme adopts ABET's SOs and defines PEOs, make sure the SOs can be attained and that they support PEOs.	M
Library/computing labs are outdated.	The library can subscribe to electronic materials. Sufficient funds need budgeted to upgrade equipment.	H
Institutional support.	The leadership needs to support the proposed two-year CSec programme.	M
Paying ABET's fees.	Budget for ABET's annual dues and fees. These are significant costs for UNAM.	H

VI. SUMMARY AND CONCLUSIONS

To address the rapidly increasing number and severity of cybercrimes in Africa, there is a critical need to expand the workforce in the CSec domain. Rather than consider a minor in Csec for CS majors in four-year programmes, a two-year standalone programme allows for fast-tracking graduates for entry into the workforce. In the USA, roughly half of undergraduate students are enrolled in two-year programmes. The cost is less per year and so far less than half overall. From a typical four-year CS programme in Africa, we forged a two- year CSec programme that meets ABET's PrCr for the Associate CSec. The relevance and importance of such programmes from an engineering educational, economic, and societal point of view are huge. The curriculum modifications were relatively minor:

1. Increase the coverage of the ABET's CCs in CSec. They are confidentiality, integrity, availability, risk, adversarial thinking, and systems thinking.
2. Add discussion and modules to four existing courses in order to cover missing security topics.
3. Introduce a new course, Cyberattacks, which includes advanced CSec topics, coverage of Organizational Security, and a team project.
4. Introduce a new course, Cyber Ethics, which covers legal and ethical principles of CSec, and includes individual written and oral presentations. The course also focuses on students applying the CCs.

Only two new courses need developed and the content of just four existing courses shifted to a focus more on CSec. With these relatively minor changes, CS programmes can quickly evolve two-year CSec programmes. Once such programmes are implemented, new graduates will be ready to enter the workforce in two years. The costs of developing such programmes are minimal. The rewards and benefits are great. If such programmes decide to pursue ABET accreditation, they will need to ensure there is an appropriate institutional support for the CSec programme and sufficient budget to cover ABET's fees.

This research shows a way forward for a typical African CS programme to develop a solid ABET-accreditable two- year

CSec programme. Programmes throughout the world can make use of this analysis as well. They too can build viable CSec curriculums from their CS programmes, with perhaps only a few modifications and additions. With a few dedicated faculty, a supportive administration, and a knowledgeable consultant, the dream of expanding the CSec workforce in Africa can be realized in a relatively short time.

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REFERENCES

[1] ABET, "Setting the Standard Worldwide: ABET," 24 February 2022. [Online]. Available: https://www.abet.org/accreditation/.

[2] ABET, "Criteria for Accrediting Computing Programs, 2022-23," Computing Accreditation Commission, ABET, 2022.

[3] J. Haworth, "Africa sees increase in ransomware, botnet attacks – but online scams still pose biggest threat", The Daily Swig | Cybersecurity news and views, 2022.

[4] N. Allen, "Africa's Evolving Cyber Threats," African Center for Strategic Studies, 2021.

[5] S. Ikela, "Cyber threats - anyone can be a victim", News Era Live, 2019.

[6] F. Olivier, "Cybercrime in Namibia," The Namibian, 2017.

[7] "BSc in Computer Science - University of Pretoria," 15 03 2022. [Online]. Available: universityofpretoria-international.com/program- mes/bsc-computer-science/.

[8] Bahirdar University, "Computer Science Program National Level Harmonized Modular Curriculum. Ethiopia," 16 03 2022. [Online]. Available: nanopdf.com/download/14-course-handbook_pdf.

[9] University of Nairobi, "Bachelor of Science in Computer Science.," 16 03 2022. [Online]. Available: somo.co.ke/program-computer-science- sm1-429#a_program.

[10] Osun State University of Nigeria, "Curriculum for B.Sc. Degree in Computer Science," 17 03 2022. [Online]. Available: uniosun.edu.ng/Curriculum/SET/ICT/CSC.pdf.

[11] University of Zimbabwe, "Bachelor of Business Studies & Computing Science Degree," 20 03 2022. [Online]. Available: www.uz.ac.zw/index.php/staff-political/206-faculty-of.

[12] University of Dar es Salaam, "Bachelor of Science in Computer Science," 21 03 2022. [Online]. Available: cse.udsm.ac.tz/programs/program-details/bsc-in-computer-science-%28bsc-cs%29.

[13] "Accredited programs in cybersecurity," [Online]. Available: ABET.org/accreditation. [Accessed 15 September 2022].

[14] R. K. Raj, C. Tang, D. Gibson, L. Jones and C. O'Brien, "The Need for ABET Accreditation of Associate's Cybersecurity Programs," in ASEE Annual Conference, 2021.

[15] "NCC Webcast: Cyber2yr2020: ACM Curriculum Guidance for Associate Degree Programs in Cyber-security," [Online]. Available: youtube.com/watch?v=u8G34Oc7PTQ. [Accessed 24 March 2022].

[16] UNAM, "School of Science Prospectus," 16 3 2022. [Online].

[17] J. W. F. Atchison, S. D. Conte, J. W. Hamblen, T. E. Hull, T. A. Keenan, W. B. Kehl and D. M. Young, "Curriculum 68: Reommendations for Academic Programs in Computer Science: A Report of the ACM Curriculum Committee on Computer Science," Communications of the ACM, vol. 11, no. 3, pp. 151-197, 1968.

[18] R. H. Austing, B. H. Barnes, D. T. Bonnette, G. L. Engel and G. & Stokes, "Curriculum '78: Recommendations for the Undergraduate Program in Computer Science—A Report of the ACM Curriculum Committee on Computer Science," Communications of the ACM, pp. 147-166, 1979.

[19] A. B. Tucker and B. H. & Barnes, "Computing Curricula 1991–Report of the ACM/IEE-CS Joint Curriculum Task Force," ACM Press, NY NY and 1EEE Computer Society Press, Los Alamitos CA, 1, 1990.

[20] L. Cassel, A. Clements, G. Davies, M. Guzdial, R. McCauley, A. McGettrick, B. Sloan, L. Snyder, P. Tymann and B. W. Weide, Computer science curriculum 2008: An interim revision of CS 2001, ACM, 2008.

[21] The Joint Task Force on Computing Curricula, "Computing curricula 2001," Journal on Educational Resources in Computing (JERIC), vol. 1, no. 3es, pp. 1-3es, 2001.

[22] ACM/IEEE-CS Joint Task Force on Computing Curricula, "Computer Science Curricula 2013 (CS2013)," ACM Press and IEEE Computer Society Press, 2013.

[23] A. Clear, A. Parrish, P. Ciancarini, S. Frezza, J. Gal-Ezer, J. Impagliazzo, A. Pears, S. Takada, H. Topi, G. van der Veer and others, "Computing Curricula 2020 (CC2020): Paradigms for Future Computing Curricula," ACM/IEEE Computer Society, NY, 2020.

[24] M. Besterfield-Sacre, L. J. Shuman, H. Wolfe, C. J. Atman, J. McGourty, R. L. Miller, B. M. Olds and G. M. Rogers, "Defining the outcomes: A framework for EC-2000," IEEE Transactions on education, pp. 100-110, 2000.

[25] G. Engel, J. Impagliazzo and P. LaMalva, "A Brief History of the Computing Sciences Accreditation Board (CSAB): Promoting Quality Education in the Computing Fields," in 2009 IEEE Conference on the History of Technical Societies, 2009.

[26] R. K. Raj, A. N. Kumar, M. Sabin and J. Impagliazzo, "Interpreting the ABET Computer Science Criteria Using Competencies," in 53rd ACM Technical Symposium on Computer Science Education, Providence RI, USA, 2022.

[27] ABET, "Criteria for Accrediting Engineering Programs, 2022-23,"Engineering Commission, ABET, 2022.

[28] M. Mulligan., "ABET's Global Engagement," 16 May 2022. [Online]. Available: peer.asee.org/abet-s-global-engagement.

Technical papers

YouTube's social media analytics as an evaluation of educational teaching videos

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Abstract — **During the COVID-19 lockdowns in South Africa undergraduate laboratory sessions were forbidden, in turn, video- based tutorials were proposed as a tentative solution to address the lack of in-person practical demonstration sessions. Five videos were filmed on electrical engineering topics, uploaded, and then publicly shared on YouTube. An investigation was then conducted as to whether videos may be useful for the teaching of practical engineering content in the university context. This article is a report back on the findings of using YouTube as a platform for sharing and evaluating engineering educational practical tutorial videos. The gaol of this article is to introduce YouTube's social media analytics as a tool for educators to evaluate their educational videos. The findings suggest that educators may consider evaluating their videos using social media analytics, but these analytics should be reviewed critically and should comprise of several metrics measured temporally. Understanding YouTube's recommender system and its influence on the platform is also an important factor in evaluating one's video content.**

Keywords — YouTube, social media analytics, digital pedagogy, video quality, recommender system

I. INTRODUCTION

Videos provide educators with a mode of providing a lot of information and rapid explanations as compared to only verbal or written forms [1]. Videos have been found to have a positive effect on learner performance, knowledge acquisition, and improve the learning process [2] [3] [4]. Videos also seem to increase learner satisfaction [5] [6]. Educational videos have thus become a key resource for content delivery in flipped, blended, and online classes [7].

During the recent COVID-19 lockdowns in South Africa, undergraduate laboratory sessions were forbidden. Owing to this challenge, video-based tutorials were proposed as a tentative solution to address the lack of in-person practical demonstrations. An investigation was then conducted as to whether videos may be useful for the teaching of engineering practicals in the university context and whether such videos could provide positive outcomes for a module that relies on hand skills. In addressing such questions, YouTube was proposed as an online platform and a series of professional videos were created to supplement the module called Workshop Skills in the Bachelor of Engineering Technology at the University of Johannesburg. The videos were uploaded and publicly shared on YouTube in 2020. This article is a report back on the findings emanating from using YouTube as a platform for the sharing of educational videos and for evaluating these videos. The gaol of this article is to introduce social media analytics (SMA) as a tool for educators to evaluate their educational videos.

A. Why YouTube?

1. Analytics data

Many universities utilize a web-based system to support online learning which educators use for their curriculum delivery, including the uploading of videos. While these platforms may be provided by third parties, they are generally closed to the public; thus, the video content uploaded by educators for their courses would only be viewed by the enrolled students. A downside to keeping this content private is that some lecturers abused this practice and have simply dumped low quality videos on the university platforms in place of their in- person teaching. What exacerbates this problem is that the content uploaded onto the universities' online platforms are often unmonitored and unreviewed. However, videos, like any other academic content, needs to be of high quality and this is particularly true for videos pertaining to engineering praxis. If, however, the educator's videos are publicly shared on well- established social media platforms, educators can obtain performance data for each of their videos as these platforms provide analytics. These analytics can be used by educators to determine how people are experiencing the content. Obtaining feedback about one's teaching and educational output is an important part of teaching excellence—a goal in many universities. The university platforms, however, do not readily provide performance data about one's media content, and thus social media platforms are proposed as a suitable vehicle for this purpose.

2. Wide Audience

Social media platforms often have an initial spike in popularity and then go out of fashion or change their focus, such as MySpace, Friendster, Google+, Vine, and Ello. However, even though YouTube was launched in 2005 and has been active for many years, it has still shown exponential growth in viewership in the last few years. It seems YouTube has something important to offer as YouTube already reached one billion daily views in 2010 [8]. It is estimated that in 2022, almost five billion views take place each day on this platform, making YouTube the largest media sharing platform [9] and the second largest social media network[1]. While it is common

1 https://www.statista.com; https://fortunelords.com/youtube-statistics/

knowledge that Google is the most popular search engine, YouTube processes over four billion search queries each day[2], putting YouTube in second place. Thus, if an educator would like to reach a large audience, YouTube is a worthwhile platform.

YouTube is popular across various age ranges including the adult demographic. For example, according to a Pew Research survey of over 1500 adult Americans, 81% of adults who were surveyed use YouTube as a resource [10]. Within this demographic, YouTube was also found to be the most popular social media platform with over 50% of respondents acknowledging that they visit YouTube daily. It is thus unsurprising that YouTube has become a popular resource for even high-level educational content since the platform seems to appeal to adults. According to the Oxford Economics' survey of higher education in the United States, over 65% of adult students who use YouTube, reported that YouTube supports their assignments or personal study [11, p. 36]. At least 70% of educators noted that YouTube is helpful when incorporated into the classroom, and educators also cited that it makes classroom learning more fun [11, p. 26].

3. Oranised and Free Online Repository

YouTube is the largest repository of multimedia content. It is estimated that there are over 800 million videos on YouTube. This tremendous volume necessitates a well-developed set of algorithms to classify and rank the video content to provide the user with suitable options following a search query, or what YouTube engineers term "search and goal-oriented browse" [8, p. 293]. If YouTube is unable to match a search query to a set of high quality, useful, and relevant results, users will watch fewer YouTube videos and may search other websites instead. Since of YouTube's goals is to maximise a viewer's watch time on the platform [12], the top video search results should be good matches for each search query. To achieve this goal, YouTube needs to know how viewers are experiencing the videos they watch so that YouTube can determine what viewers prefer; thus, YouTube algorithms provide search results that should be the best matches based on aggregated viewer behaviours [13]. For example, a user may input a search query of "how to wire a house" and YouTube may have 30 videos with this exact title, and 1000 videos with different titles but still on the same topic. YouTube's algorithms would need to learn which videos are the best matches for this search query, as well as variations of the search query which still address the same topic. One might find that the top result for the search query is actually a video with a completely different title, since having the same title does not mean the video is the right match. YouTube must be able to organise and rank videos with what it computes as best options otherwise users will have to watch hundreds of videos before finding a few that are relevant to their needs.

4. The Recommender System

A feature that has a significant influence on users' activity on YouTube is called the recommender system [14]. When a user is watching a video (seed video), YouTube's recommender system computes what would be the best set of options for that user. This process relies on a map of video pairings that are continuously updated based on both the individual's preferences as well as the aggregated behaviour of all users across the platform. This automated system aims to provide "related" videos that may be of interest to the user [8, p. 293] [15]. The recommender system accounts for about 60% of all videos watched on YouTube [8]. If 60% of all videos watched are from

YouTube recommending videos to viewers, it can be assumed that this system must be good at aiming certain content at certain audiences. Similarly, it also implies that YouTube can sift through content to prioritise content that will be watched, content that is likable, and content that will keep the audience on the platform for longer. These algorithms not only recommend content that is similar to the seed video (video currently being watched), but also suggests videos that are on different topics but possibly still within the user's interests [13]. Obviously there are exceptions and some recommended videos do not interest users; however, there are over 800 million videos on the platform which means there would be extensive machine learning, analysis, and filtering that must take place. To perform this task, the recommendations, as well as the search engine's ranked results following a search query, both use "video quality signals" to compile suggestions and search results for the user. These video quality signals are based on social media analytics (SMA) [8, p. 295] [16].

II. YOUTUBE'S SOCIAL MEDIA ANALYTICS

When a user attempts to watch a video on YouTube, data points are created across several categories. For example, a user may enter a direct search query to which YouTube then provides a list of ranked results. The user then sees the results and then say for example is attracted to the thumbnail artwork of the fourth video in the list of results. The user selects this video but unfortunately does not enjoy this video and therefore only watches 5% of it. The user in turn rates the video negatively with a thumbs down and posts a negative comment. This user then goes back to the original list of results, browses along the list again, but this time hovers their mouse over each video to get an impression of the video before making a final selection. This user now selects the second video in the list and watches it. The user enjoys this video and even rewatches certain parts but does skip through other parts. Collectively the user watches 70% of this second video, gives the video a thumbs up, posts a positive comment, and shares the video with two friends. All this activity is tracked by YouTube, including the rewatching of certain sections of a video as well as the hovering over the thumbnail. Thus, from this one user, extensive video quality signals are created, which according to YouTube engineers, includes the number of times the video has been watched, the videos ratings (likes and dislikes), whether the video was shared, the comments accrued, and the upload date [8]. YouTube tracks user behaviour to determine the quality signals for the videos across the platform while also learning

2 Ranked according to number of monthly active users: https://fortunelords.com/youtube-statistics/

topic frequencies from user feedback [13]. Video quality signals thus assists YouTube in ranking and recommending videos.

Video quality signals are created irrespective of whether the user performs explicit or implicit actions. Explicit actions include liking or disliking a video, sharing a video, or commenting on a video. Implicit actions include the user's demographics (age, location, gender), viewing history, hovering over thumbnails, amongst other activity. A user also implicitly shows their interest in a video by how long they stay tuned to that video—measured as a percentage of the video that is viewed (higher percentage indicates more interest in the video). When the aggregated percentage viewed for many users are computed against the search query, YouTube is able to continually rank and pair certain videos to certain queries by tallying which videos had a higher watch time percentage, indicating a better match to a search query under that topic cluster. Much of these quality signals that accrue for each video are also presented to the content creator (people who upload content to the platform). The clustering and presentation of these different data sets is called SMA and can be described as being "concerned with developing and evaluating informatics tools and frameworks to collect, monitor, analyse, summarize, and visualize social media data … with the aim of extracting useful patterns and intelligence..." [17, p. 14]. SMA are thus powerful tools, used not only for YouTube's algorithms to provide search results and recommendations, but are also available to the educator to understand how well their educational content is being utilised.

If an educator would like to get feedback about their classroom teaching, they usually request a module evaluation (survey) which is usually aimed at evaluating the whole module. However, if a lecturer wanted to get feedback about each one of their topics, they would need to perform a survey for each topic. With SMA, as presented in this article, both qualitative and quantitative data are available to the educator for each of their videos and thus apart from surveys and interviews, SMA provides different methods to generate insight, including trend analysis and sentiment analysis [18]. A further benefit is that SMA allows for phenomena to be studied dynamically [19]. It is thus proposed that educators relying on video content as part of their curriculum delivery may use SMA as a form of teaching evaluation.

III. USING YOUTUBE'S SOCIAL MEDIA ANALYTICS TO EVALUATE EDUCATIONAL VIDEOS: AN EXPERIMENTAL STUDY

The aim of this experiment was to use SMA to evaluate five educational engineering videos. The videos are specifically aimed at South Africans owing to the use of the South African wiring standard SANS 10142:2020. The videos, which range from two minutes to 19 minutes, are meant to be step-by-step high-resolution tutorials showing technical steps that include narrations and captioning. Topics include the wiring of plugs and plug outlets, the wiring of a stove isolator, and the wiring of distribution boards. The videos would first be evaluated in a traditional manner (student surveys and staff peer review), and then by using YouTube's SMA.

A. Method

The course leader for the Workshop Skills module approached the writer to create videos. Filming took place in August of 2020. Four videos were filmed at the University of Johannesburg's Doornfontein campus and the fifth video was filmed in the writer's studio. All videos are tutorial based and relate to practical electrical wiring. The videos were filmed and edited in 4k resolution with semi-professional videography gear. The reason for using a 4k resolution was based on the need for high quality imagery that should clearly show parts as small as wire strands, labels of the circuit breakers, or even just a nick in a wire. At least ten hours of footage was needed for the five videos which were then edited using Vegas Pro software. The videoing collectively took three days; the editing was completed over two weeks. The videos were reviewed by the course leader and an electrician prior to being made public on YouTube. Figure 1 shows an example of the videography setup.

FIGURE 1: *Videography equipment for a video about electrical wiring.*

After the first group of students used the videos, the course leader then prescribed the videos owing to their favourable impact. Since the videos are in the public domain and were available prior to the class starting, it may seem like a flipped class, but the lecturer and lab instructor first explained the theory and then advised the students to watch the videos. The videos could be watched/downloaded freely on the university's WIFI; thus, students did not need to use their own data.

B. Traditional Evaluation of Educational Videos: Students and Peer Review

The videos were used for two semesters with anonymous student evaluations taking place. The module evaluations were favourable. The standout feature was students personally contacting the course leader expressing their gratitude for the videos; thus, students notably commented on the importance of the videos. Students also contacted the presenter of the video and stated that the videos are beneficial. The lab technician who assists the students with the practicals noted that the videos have become an important part of the students' preparation for the module. The videos have "improved the student's ability and speed in performing their practicals". The lab technician also reported that students often hold their phones in hand watching one of the videos while practising the practical steps. They listen to the presenter using earphones with the aim of using the video as a guide in order to practice their practical work. Since the students can pause, speed up, or slow down the video, they can go at their own pace and skip parts that they are already proficient in. Students have noted that the videos show the steps in a close-up view which they say is helpful. The module's pass rate comprises of more than the five topics on offer in the five videos and thus does not reflect only the videoed sections; however, the videos have improved the students' skills and practical performance. It seems that if videos are well made and explanatory, they are of great use to students and students do show their appreciation for such videos. Reference [20], who used YouTube for their physics lectures, also experienced high levels of appreciation from their engineering students who actively watched their videos.

The student and peer evaluations are positive; however, the purpose of this article is to show that SMA can assist in evaluating one's educational videos which means the SMA from YouTube must be analysed. If the uploaded videos were shared only with the students (closed to the public), then the educator can only get the analytics derived from the enrolled students. For example, educators may use analytics to monitor only their group of students to see how many views took place and how much of the video was watched—student viewing patterns [20] [21]. Students, while incredibly important, are too narrow a group to achieve an evaluation of one's educational content. SMA are thus proposed as a viable tool for this task; however, this should be undertaken publicly which means that educational videos should be publicly shared. Since the five videos were openly shared at publication date, extensive SMA have accrued.

For the remainder of this article, only one video will be evaluated to simplify the analysis. The video evaluated is titled "How to wire a single phase distribution board and load circuits – tutorial[3]". The evaluation which follows in the next section reflects the performance from video publication (28 Aug 2020) until the time of writing (July 2022).

C. Evaluation Using YouTube's Social Media Analytics

YouTube provides at least 60 metrics which can be used to analyse a video's performance. The data is derived from both explicit and implicit user activity. In this article only the following metrics will be used for the evaluation: comments, likes and dislikes, number of views and their source, subscribers, watch time, and shares. Each of these metrics will be discussed in the sub sections which follows. Table 1, which is at the end of this whole section, shows a summary of the performance for each metric under review. Since YouTube does not provide baselines for these metrics, determining what is considered a "good" result does depend on the context and purpose of the video, amongst other factors. For example, a pop music video may garner millions of views every week, but an educational video on a niche topic may only get 1000 views in a month but still be considered good. Thus, when comparing metrics of different videos, one should compare videos on the same topics set off against the video category[4], since a measure such as number of views alone, for example, is insufficient to determine quality. Common sense also plays a role, for instance, a video that gets more dislikes than likes is obviously not well received.

An important qualifier in determining likability and quality is YouTube's ranking and recommendation system. If YouTube does not recommend the educator's videos or does not list the educator's video high in the search results following a topic search (even after months), then it is probable that the content has not made a significant impact with viewers. This statement does assume that YouTube's algorithms can differentiate likable content from poor content. While this may be a contentious issue for controversial topics, engineering educational videos are assumed to be ranked based on aggregated user behaviours, that is, what users experienced as best matches for their search query (see [8]). For example, if a user performs a search for how to fix a kettle, it is highly likely that the results will be very good examples of this activity, which is one reason why people use YouTube as an information resource. Personal experience also plays a role in analysing the metrics. The writer has over 900 videos on YouTube, over 80 000 subscribers, and over 30 million views on one of his channels.

1. Qualitative evaluation: comments

The distribution board video has accrued 128 comments in the last 23 months since publication (excluding replies to comments). To qualitatively evaluate the comments, one could perform a sentiment analysis to determine if the comments are mostly positive or negative by defining associative words [22]. For this video there was only one negative comment and two comments that had both positive and negative themes. The remaining 125 comments were all positive. The most common words and phrases were: thank you, awesome, very clear, enjoyed, excellent, best, great, nice, teacher, informative, helpful, amazing. From the qualitative comments, it is evident that this video was well received. The four other videos have also achieved a high positive sentiment.

Comments often introduce subtopics which can be analysed and modelled [22][23]. A subtopic word frequency can be performed when there are many subtopics. In the case of the distribution board video, there were only a few. The most common subtopics were "three-phase", "troubleshooting" and "plug outlets". Users are asking for videos that deal with these related topics. Educators can review the comments to get ideas about future content that they may upload to their channel. While this video had overwhelmingly positive comments, negative or critical comments can also be helpful to the educator. In the case of a critical comment, the educator could check if there were any replies posted from other users to see if other users agree or disagree with the critical comment. In some cases, critical comments are unwarranted, but members of the public moderate one another. For example, if a negative comment is made and it accrues thumbs downs and negative replies, it means other viewers do not agree with the critique. However, if a negative comment gets support from other users, it is likely that the educator has made an error in the video and should fix the video.

3 https://youtu.be/6O90pFfHuOo

4 YouTube has 15 video categories. Examples include sports, education, gaming, news & politics, entertainment, and autos & vehicles.

One may argue that the viewers on YouTube are not specialists and thus their comments do not provide high level analysis. The users on YouTube span diverse people and that includes highly specialised individuals. In the case of engineering videos, many viewers are experienced artisans who often provide critical and helpful comments. One should not assume that since the videos are aimed at students that only students are watching. On the contrary, a wide range of people watch educational videos. With regards to electrical videos, the writer was contacted by the company who manufacture the circuit breakers as well as the person who holds one of the patents for the plug tops.

2. Quantitative evaluation

a) Likes, dislikes, and the likes to dislike ratio

The distribution board video accrued 3423 likes and 182 dislikes. Using only the number of likes is insufficient to evaluate whether the video is well received or not since some videos attract large audiences or have been on the platform for many years. A video titled "How does electricity work" may appeal to a wide audience and accrue thousands of likes while a video that explains how to calculate the size of a surge arrestor would have a much narrower audience. A video that has 1000 likes but the total views exceed 1 million, is less impressive than a video that only has 10 000 views but 1000 likes, as the latter has a much higher likes to views ratio. The distribution board video achieves an average of 11 likes per 1000 views. Another important metric is the likes to dislikes ratio. If the video is well liked, the ratio is higher. The distribution board video achieved a like to dislike ratio of over 94%.

3) Number of views and traffic source

The metric that gives the most bragging rights is the number of views. The distribution board video accrued 310 059 views in just under two years, although most views accrued in the second year. Figure 2 shows two graphs of the video's performance. The top graph is the daily views from the time of publication until the time of writing. The bottom graph shows the composition of views based on the traffic source. The traffic source distinguishes how the video is being located—different for every video. The two traffic sources with the highest associated views are the "Suggested videos" and the "YouTube search". YouTube search represents the views originating from users typing in a search query in the search bar—direct search. However, for this video, a lot of views originate from the video being recommended by YouTube as shown as the blue waveform in the bottom graph of Figure 2. On average 48% of all the views for this video are from YouTube suggesting the distribution board video after the user has watched another video (seed video). This means that the distribution board video has been paired to other videos. YouTube provides the educator with a spreadsheet of the co-viewed videos—a list of other content creators' videos that lead to the educator's own video being watched. While this list is out of the scope of this article, educators may review this list to compare the paired content to get ideas as to what other topics one may work on in future to grow one's channel. What is significant in Figure 2 is that the growth and decay in the number of daily views matches the composition of the views from the recommender system as shown in the traffic source graph. The recommender system has a significant influence on users' activity on YouTube [14] and in turn can influence one's popularity on the platform.

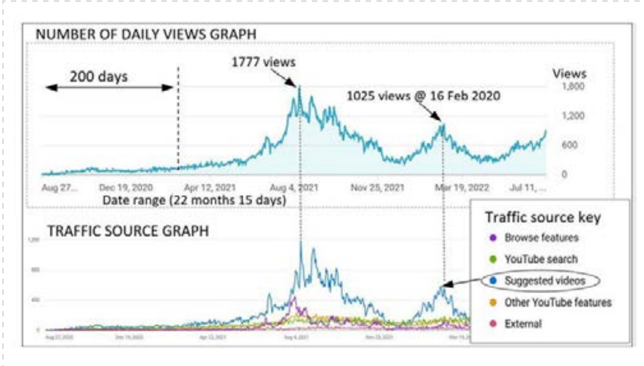

FIGURE 2: *Graphs showing the daily views and the traffic source for the distribution board video along its lifespan.*

a) Subscribers

Over 5800 people subscribed to the channel from watching the distribution board video. On average between five and 20 people subscribe daily. When analysing the number of subscribers, like all metric data, this number also needs to be evaluated relative to other factors. Similarly to the likes per views, subscribers per views is a better measure. Table 1 shows the number of subscribers per 1000 views which was calculated as 19. Since a content creator can compare each of their videos, they can get an idea as to what their top performing videos are when comparing the metrics and ratios. The subscription growth for the distribution board video is considered high but that is only based on the writer's experience and from hearing of the experiences from other content creators.

b) Watch time and average view duration

The total watch time accrued for the video is 28 156 hours. The total watch time is less important than the aggregated percentage viewed, which for this video is 29%. This percentage does not seem high though. Comparing this percentage viewed with the other four videos in the series, this video has a lower percentage but is also the longest video. From experience, the percentage viewed is generally lower for longer videos and the distribution board video is almost 19 minutes long. Reference [24] also found that their longest YouTube video had the lowest percentage viewed. Apart from the length of a video, there are numerous reasons for watch times being quite low. One reason is that a user may have set their YouTube session to automatically play the next video to which the user cancels the video as it begins. Another reason is that many viewers are from other countries and when they see the components used in the video differs from their local standards, they stop watching. Since the distribution board video uses the SAMITE size circuit breakers (specific to South Africa), the audience specificity is high and thus viewers might stop watching. A follow-up video on the same topic using a more common circuit breaker size (DIN rail as per IEC 60715) has a higher percentage viewed than the video using the SAMITE rail. Lastly, the video is a tutorial video that is explanatory and aimed at students. Some viewers would prefer a video that goes at a faster pace and just shows the technique without the tutorial and tips.

To critically evaluate the percentage viewed, one should review how much the percentage drops (or increases) over the video playback time. Figure 3 shows the average percentage viewed for the distribution board video. There is an initial sharp drop in viewer retention immediately as the video starts which is common on YouTube. At about two minutes, 45% of viewers are still watching, then from this point the decay is slower. If the percentage viewed dropped off at the rate shown by the dotted line (a), then this would signal a poor video. What is important though is that 17% of viewers watch the whole video. Even though the average viewed is not very high, the graph shows that viewers who do watch, watch most of the video.

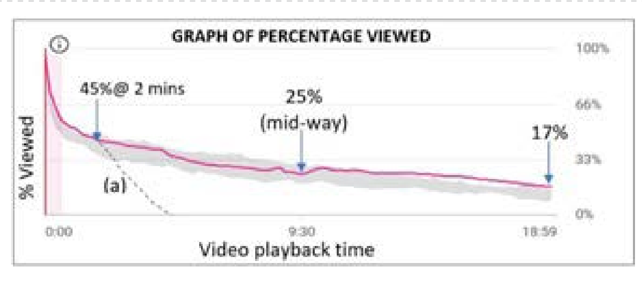

FIGURE 3: Percentage viewed for the tutorial video along the video length.

c) Shares

When a user views a video and decides to share it with someone else by using the share button, this is tracked by YouTube. The distribution board video was shared 2845 times. A higher number of shares for an educational video signifies a better video. The distribution board video achieves about nine shares for every 1000 views.

TABLE 1: Summary of key social media analytics.

Metric	Value
Upload date	28 August 2020
Months active	23
Video duration	18 min 59 sec
Total comments	128
Percentage positive	98%
Total likes	3423
Likes per 1000 views	11
Likes vs dislikes	94,7% positive
Total number of views	310 059
Average daily views	±440
Main traffic source	Suggestions: 48%
Subscribers accrued from video	>5800
Subscribers per 1000 views	19
Total watch time	28 156 hours
Average percentage viewed	29%
Shares	2845
Shares per 1000 views	9
Audience	29% traffic from South Africa

IV. CRITICAL DISCUSSION

With the growing popularity of videos used as part of courses, educators should evaluate their videos and provide evidence of their evaluations. While educators may opt to only share their videos with their students, this may be too small of a pool to understand the impact and quality of one's educational content. In this study the videos were publicly shared and thus accrued extensive SMA from a wide audience. The video used in this study achieved a high likes to dislike ratio of over 94% which shows that the video is well liked. The video has also grown it its average daily views, which in the last year averages about 680 views per day (Figure 2). This growth shows that the video is still relevant and seems to be popular. One may argue that the views are influenced by the fact that the video is a prescribed video for the university students. However, there are less than 150 students per year, and they only use the videos for about three weeks, yet the video averages over 20 000 views per month and the peaks in the graph shown in Figure 2 do not correlate with the students' timetable. Thus, the students' activity is considered to be insignificant in the SMA that accrued. The SMA that accrued from the public for the video correlated with the positive student evaluations. The public comments had a predominately positive sentiment, and the videos are well liked with many requests for more content to be made. The traditional evaluations (student evaluations and peer review) supported the videos to such a degree that a second round of videos were uploaded in the following year which received a similar reception, including support for funding of additional videography equipment.

A. Social Media Analytics as a Measure of Pragmatics

If viewers like a video, they may subscribe to the channel and thus there should be some subscriber activity for educational videos. The distribution board video gets at least 10 new subscribers each day. However, the number 10 does not indicate how good a video is. Similarly, 3423 likes or 310 059 views, while seemingly high numbers for this type of video, still does not mean a video is good or good quality. What then is a "good quality video" if that sentence uses two ambiguous words and could take a whole journal article to address? While the term "good" may be used loosely, defining what a good video is can be a slippery slope. The phrase "good quality video" spans across multiple domains. For example, the term "quality video" to the videographer refers to the resolution, colour, lighting, audio, imagery, and the editing of the video. The manner in which the video is delivered could also be evaluated against a long list of discipline specific criteria including communication skills, clarity, coherence, flow, ability to captivate an audience, technical language, teaching skills, and humour. Then there are the digital media skills, including use of software, simulations, animation, captioning. Lastly and most importantly, the information that is on offer in the video must also be evaluated. Thus, a good video or a quality video can be measured across different rubrics.

While there are numerous publications on ascertaining the quality of educational videos on YouTube, particularly videos that pertain to medical information, the evaluations are based on the researchers' criteria to measure the quality of the content by a panel of experts [25] [26] [27]. This type of evaluation of quality relies on specialists in the field to review the video's content, such as certified clinicians, doctors, surgeons, etc. who provide a type of peer review of the videos. From these specialist reviews the researcher arrives at a conclusion as to whether the selected YouTube video has accurate information, which is often described by using the word "quality". Specialist peer review is important, however, this is not what I am proposing since a video may be reviewed as technically correct and accurate but may be impractical, of limited use, or not well received. Similarly, a teacher in a classroom may present content that is technically correct but may deliver the content in a dull and unengaging manner, resulting in poor student evaluations. This example implies that impact and likability should be features in discerning what a quality educational video is. Hence, I am proposing that the SMA, which are already provided by YouTube, may be used to assist in evaluating video quality based on the qualitative and quantitative data that accrues from the aggregated user behaviours. For the tutorial (teaching) video used in this experimental study, the quality is thus also a measure of the usefulness, likability, and user engagement that is attributed to the video.

What is clear from the SMA for the distribution board video is that there is a steady stream of positive signals for this video. The likes continue to increase, the like to dislike ratio remains high every month, subscriber count grows daily, users are sharing the video, and positive comments are frequently posted. Thus, the video does seem to positively generate what Google engineers term video quality signals [8, p. 295] [16]. If the analytics performance data as shown in Table 1 and the graphs from Figure 2 are evaluated collectively, while taking into consideration the video category (educational), and the narrow target audience, one may justify a conclusion that the video is probably good quality or a good resource. This conclusion rests on the premise that "good" in this case also relates to pragmatics, since the video is a practical engineering tutorial that is specific to a certain context (Table 1 shows that almost 30% of the viewers are located in South Africa). The conclusion also relies on a temporal requirement. If the video did not provide practical usefulness and had inaccurate information, it is unlikely that viewers would watch the whole video, or subscribe, or share it. If, for example, users had followed the instructions in the video and it resulted in a poor outcome for them, they could report the video, unsubscribe, or return to the video's homepage to post harsh comments. These unfavourable actions do not happen for this video and the video is almost two years old.

If YouTube uses video quality signals to organise content on the platform [8], and if the quality signals for the distribution board video are good, then it stands to reason that the video should be recommended frequently. If one analyses the traffic source metric for this video, it shows that it has received almost 50% of the total views from recommendations and that it continues to be recommended. Since one of YouTube's goals is to keep people on the platform [12], it seems obvious that YouTube would suggest content that users would like.

B. Rankings

What if a user performs a direct search query for the phrase: "how to wire a distribution board?" If the distribution board video from the this study is a good resource for this search query, the video should be ranked quite high in the list of results. The video is ranked first and has been top for the last 12 months, occasionally dropping to second place then moving back to first place. To maintain top spot should mean the video is generally accepted as one of the correct results for the search query. If it was a poor result, users would rate it negatively by their explicit and implicit actions, which when aggregated and learned by YouTube's algorithms, would drop the video in the rankings. Since the distribution board video maintains its rankings, the public must be providing positive video quality signals. When comparing this video to other videos on the results page, there are some older videos on the same topic but are lower in the rankings, however, these other videos do have significantly more views than the video in question. This underscores the point that view count alone is insufficient to evaluate how good a video is as older videos have more time to accrue views.

If in the above example, the search query is changed to "how to wire a house"—which relates to the same topic, but the phrase differs—the distribution board video is ranked in third place even with the different phrase used in the search. After adjusting the phrase used in the search query several times, including "how to wire a switch board"; "how to wire circuit breakers"; or just "db wiring", the video still ranks either first or on the first page. This means that YouTube has linked the video to the different topic clusters by learning the users' behaviours following search queries. This also implies that YouTube's algorithms have categorised the distribution board video as a viable option since there are hundreds of videos on these topics which do not make it onto the first page of results. Expanding this test, if other search engines are used, namely Google web search, Bing, and DuckDuckGo, they all rank the distribution board video as a top result. The purpose is not to brag, the point is that if one's video is a good resource, and in this case a practical tutorial, it should be ranked quite high in search results. It thus stands to reason that the video is useful.

C. Benefits of Using a Video

Close-up demonstrations that take place in person with many students are challenging and time consuming as much of the technique needs to be shown on a one-to-one basis. Even with a small group of students, not all students get within 50 cm of the demonstration which is problematic, particularly when demonstrations include hand skills and small movements. A feature of these tutorial videos is that they offer close viewing angles. Students have noted that showing the parts and actions in a zoomed view is helpful. The use of high-resolution imagery assists in showing the students intricate steps. Additional benefits include the students being able to vary the rate at which the video plays while also skipping parts and rewatching other parts. This type of control is unavailable in classroom demonstrations. Two additional findings were that the students were able to perform the practical work faster with improved skills. Since students tend to be better prepared owing to watching the videos, the lab technician can cater for more students, reducing the repetitive in-person teaching time and catering for more question-and-answer time.

D. Community Service

The public nature of online video sharing brings with it additional societal benefits. Judging by the popularity of the five videos and the continuous requests for more videos, it could be argued that there is a need for tutorial-based engineering education that is freely available to the community. One may argue that there are some possible risks associated with publicly sharing video demonstrations which could be potentially dangerous for the user to perform. If this logic is followed, then a library with books on electrical engineering topics should be restricted as well.

Public universities should have an aim to educate the masses, and while not every person needs to do a professional degree, sharing of knowledge is in the service of humanity. This also means that educators are performing a community service. The community too are providing the educator with a service as they provide social media data in the form of video quality signals that can be useful to evaluate one's educational content.

E. In Closing

Engineering tutorial videos were proposed to address the lack of in-person practical demonstrations during lockdowns. These videos were initially proposed as only a tentative solution but owing to their success, are now status quo. Using YouTube's SMA to evaluate the videos was helpful and supportive to the educator. With the assumption that digital pedagogy will be increasingly popular post pandemic, public video sharing and SMA may be useful for several reasons. Firstly, for the evaluation of an educator's videos. Secondly, as evidence of impact and community service. Thirdly, as a source of possible revenue. Lastly, as a publication route in the scholarship of teaching and learning by publishing one's teaching praxis as the publication, which may have been what Ernest Boyer's Scholarship Reconsidered originally meant [28].

V. LIMITATIONS

The production of professional videos can be costly [29]; however, since the video content can be reused, the expense can be justified [30]. Universities often have a department that deals with audio and video and these resources could be utilised by educators. Additionally, with the improvements in smart phones, most medium to high end phones can record at a high resolution. However, not all educational videos need a video camera as many videos are recorded using screen recording software, including the popular and free Open Broadcaster Software (OBS).

Creating videos and editing is time consuming. Reference [24] noted that it took their team approximately 40–60 hours to create one short psychology video of about five minutes. Similarly, in this study, recording and editing were time consuming and one also needs to factor in the preparation time.

YouTube provides 63 different metrics as part of its analytics. Only a few metrics were presented in this article.

REFERENCES

[1] E. Bravo, B. Amante, P. Simo, M. Enache and V. Fernandez, "Video as a new teaching tool to increase student motivation," 2011 IEEE Global Engineering Education Conference (EDUCON), 2011, pp. 638-642, doi: 10.1109/EDUCON.2011.5773205.

[2] A. W. Armstrong, N. Z. Idriss, and R. H. Kim, "Effects of video-based, online education on behavioral and knowledge outcomes in sunscreen use: A randomized controlled trial," Patient Education and Counseling, vol. 83, no. 2, pp. 273–277, May 2011, doi: 10.1016/j.pec.2010.04.033

[3] S. Muniyandy et al., "Influence of YouTube videos on the learning of tablet- and capsule-formulation by Malaysian pharmacy students: A pilot study," Pharmacy Education, vol. 15, Oct. 2015, Accessed: Oct. 08, 2022. [Online]. Available: https://pharmacyeducation.fip.org/pharmacyeducation/article/view/396 2015

[4] H. Forbes et al., "Use of videos to support teaching and learning of clinical skills in nursing education: A review," Nurse Education Today, vol. 42, no. 42, pp. 53–56, Jul. 2016, doi: 10.1016/j.nedt.2016.04.010.

[5] D. Zhang, L. Zhou, R. O. Briggs, and J. F. Nunamaker, "Instructional video in e-learning: Assessing the impact of interactive video on learning effectiveness," Information & Management, vol. 43, no. 1, pp. 15–27, Jan. 2006, doi: 10.1016/j.im.2005.01.004

[6] P. Nikopoulou-Smyrni and C. Nikopoulos, "Evaluating the impact of video-based versus traditional lectures on student learning," bura.brunel.ac.uk, 2010, Accessed: Oct. 08, 2022. [Online]. Available: https://bura.brunel.ac.uk/handle/2438/4652

[7] C. J. Brame, "Effective Educational Videos: Principles and Guidelines for Maximizing Student Learning from Video Content," CBE—Life Sciences Education, vol. 15, no. 4, Dec. 2016, doi: 10.1187/cbe.16-03- 0125.

[8] J. Davidson et al., "The YouTube video recommendation system," Proceedings of the fourth ACM conference on Recommender systems - RecSys '10, 2010, doi: 10.1145/1864708.1864770.

[9] J. Arthurs, S. Drakopoulou, and A. Gandini, "Researching YouTube," Convergence: The International Journal of Research into New Media Technologies, vol. 24, no. 1, pp. 3–15, Jan. 2018, doi: 10.1177/1354856517737222.

[10] B. Auxier and M. Anderson, "Social Media Use in 2021," Pew Research Center, Apr. 2021. [Online]. Available: https://www.pewresearch.org/internet/wp- content/uploads/sites/9/2021/04/PI_2021.04.07_Social-Media-Use_FINAL.pdf

[11] Oxford Economics. The state of the creator economy. assessing the economic, societal, and cultural impact of YouTube in the us in 2020. Oxford Economics Ltd. Oxford UK, 2021

[12] P. Covington, J. Adams, and E. Sargin, "Deep Neural Networks for YouTube Recommendations," Proceedings of the 10th ACM Conference on Recommender Systems - RecSys '16, 2016, doi: 10.1145/2959100.2959190.

[13] M. Bendersky, L. Garcia-Pueyo, J. Harmsen, V. Josifovski, and D. Lepikhin, "Up next," Proceedings of the 20th ACM SIGKDD international conference on Knowledge discovery and data mining, Aug. 2014, doi: 10.1145/2623330.2623344.

[14] R. Zhou, S. Khemmarat, and L. Gao, "The impact of YouTube recommendation system on video views," Proceedings of the 10th annual conference on Internet measurement - IMC '10, 2010, doi: 10.1145/1879141.1879193.

[15] S. Baluja et al., "Video suggestion and discovery for youtube," Proceeding of the 17th international conference on World Wide Web - WWW '08, 2008, doi: 10.1145/1367497.1367618.

[16] B. Liebald et al., "Recommendations based on topic clusters." U.S. Patent No. 8,589,434. Nov 19, 2013

[17] D. Zeng, H. Chen, R. Lusch, and S.-H. Li, "Social Media Analytics and Intelligence," IEEE Intelligent Systems, vol. 25, no. 6, pp. 13–16, Nov. 2010, doi: 10.1109/mis.2010.151.

[18] W. Fan and M. D. Gordon, "The power of social media analytics," Communications of the ACM, vol. 57, no. 6, pp. 74–81, Jun. 2014, doi: 10.1145/2602574.

[19] A. Edwards, W. Housley, M. Williams, L. Sloan, and M. Williams, "Digital social research, social media and the sociological imagination: surrogacy, augmentation and re-orientation," International Journal of Social Research Methodology, vol. 16, no. 3, pp. 245–260, May 2013, doi: 10.1080/13645579.2013.774185.

[20] G. Schiltz. "Video Analytics: when and how do students use tutorial videos." In Proc. 23rd Int. Conf. on Computers in Education ICCE (pp. 774-776), 2015

[21] O'Brien et al. "Using YouTube Analytics to Investigate Instructional Video Viewing Patterns" Proceedings of the 18 th Europea n conference on E-learning, Copenhagen, Denmark, pp. 428-436. 2019

[22] M. Thelwall, "Social media analytics for YouTube comments: potential and limitations," International Journal of Social Research Methodology, vol. 21, no. 3, pp. 303–316, Sep. 2017, doi: 10.1080/13645579.2017.1381821.

[23] D. Blei, B. Edu, A. Ng, M. Jordan, and J. Edu, "Latent Dirichlet Allocation," Journal of Machine Learning Research, vol. 3, pp. 993– 1022, 2003, [Online]. Available: https://www.jmlr.org/papers/volume3/blei03a/blei03a.pdf?ref=https://githubhelp.com

[24] S. Langworthy, "Do You YouTube? The Power of Brief Educational Videos for Extension," The Journal of Extension, vol. 55, no. 2, Apr. 2017,[Online]. Available: https://tigerprints.clemson.edu/joe/vol55/iss2/24/

[25] B. Karic, V. Moino, A. Nolin, A. Andrews, and P. Brisson, "Evaluation of surgical educational videos available for third year medical students," Medical Education Online, vol. 25, no. 1, p. 1714197, Jan. 2020, doi: 10.1080/10872981.2020.1714197.

[26] A. Derakhshan, L. Lee, P. Bhama, E. Barbarite, and D. Shaye, "Assessing the educational quality of 'YouTube' videos for facelifts," American Journal of Otolaryngology, vol. 40, no. 2, pp. 156–159, Mar. 2019, doi: 10.1016/j.amjoto.2019.01.001.

[27] O. Zengin and M. E. Onder, "Educational quality of YouTube videos on musculoskeletal ultrasound," Clinical Rheumatology, vol. 40, no. 10, pp. 4243–4251, May 2021, doi: 10.1007/s10067-021-05793-6.

[28] E. L. Boyer, Scholarship Reconsidered: Priorities of the Professoriate. Princeton University Press, 3175 Princeton Pike, Lawrenceville, NJ 08648., 1990. [Online]. Available: https://eric.ed.gov/?id=ED326149

[29] J. Köster, Video in the Age of Digital Learning. Cham: Springer International Publishing, 2018. doi: 10.1007/978-3-319-93937-7.

[30] Y. Delaviz and S. D. Ramsay, "Student usage of short online single-topic videos in a first-year engineering chemistry class," Proceedings of the Canadian Engineering Education Association (CEEA), Dec. 2018, doi: 10.24908/pceea.v0i0.13083.

Technical papers

Developing technical talents as future engineers through humanoid robot as a learning tool in a participative approach

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***Abstract* — Future engineers face fundamental challenges, such as digital transformation and the integration of sustainable goals into industrial processes, which require problem solving skills and deep knowledge applied to new context and constraints. This contribution introduces and discusses a project-oriented and scenario-based learning concept employing humanoid robots to motivate and develop technical talents as future engineers, focusing particularly on integrating gender and diverse perspectives into the technical field. Humanoid robotic platforms cannot only motivate to gain complex knowledge, but also provide multiple competence development including criteria such as sustainability and creativity. In this contribution these correlations are discussed and integrated into a study course design for human-machine interaction that is revised for better supporting the competence development of technical talents as future engineers by not only integrating gender and diversity aspects but also taking sustainable goals into account. The revised approach may lead to innovative and creative technical solutions for future challenges.**

Keywords — humanoid robots, human-machine interaction, project-orientation, scenario-based learning

I. INTRODUCTION

"Engineers are building bridges into the future" [1], their knowledge and skills not only contribute to future technological developments but also will have an essential impact on socio-economic constraints. Therefore, engineering education, in particular engineering pedagogy, must aim at the development of multiple competence, based on scientific methods and fundamental knowledge [2]. The development of technical skills and competencies combined with analytical and creative thinking is not only depending on personal learning strategies but inevitable combined with the supported learning processes and correlated methods using innovative learning technologies. Here "adaptive and personalized learning technologies" play an important role as well as "open educational resources and practices" and "robotics in the classroom". The use of the robotic technologies varies by geographical regions, thus it is mostly used in North America (21,1 %) and Africa (20,4 %), less in Europe (11,6 %). The use is preferred especially in the disciplines of Telecommunication Engineering (22,7 %) and Electrical and Computer Engineering (20, 2 %) whereas the "social interest" in robotics for education varies from 70,29 % to 78,89 % and 77,37 % in the years of 2016 to 2018, showing the discrepancy between actual and potential use as a learning tool [3].

In engineering disciplines e. g. the gender or diverse perspective is still missing and mostly needs to be re-invented through "Gender Impact Assessment" or Engineering Innovation" reflecting "Past Innovation Practices" [4, 5]. Thus, the overall aim should be that future engineers not only have to be conscious of their own capabilities and expertise, but also being able to create innovative solutions regarding social needs and defend their concepts in order to manage multiple challenges. These new challenges can only be solved when gender and diversity aspects are integrated into engineering education and especially into a study course design [6].

Developing innovative technical solutions with respect to gender, age or individual disabilities is partly missing in engineering education. In order to regard such aspects learning processes require integrating a participative approach into teaching and learning in order to make visible such informal constraints and to give technical problem processes a broad and diverse perspective [7, 8]. The teaching and learning processes, especially of technical subjects, require a structured knowledge base of complex technical subjects, active learning methods, such as project-oriented and scenario-based learning methods, and last but not least motivating learning tools, such as humanoid robots. By designing learning scenarios that represent authentic tasks in real-world context and considering different perspectives, students are enabled to acquire complex knowledge in a self-determined and learner- centric way [9]. The design of an interactive humanoid robot depicts a motivating learning tool with a wide field of application, which motivates for future challenges that correlates to the Sustainable Development Goals [10], especially the fourth goal of Quality Education with respect to Gender Equality (5th goal) and Reduced Inequalities (10th goal). Thus, integrating these aspects into a study course design the research questions are as follows:

- How must a study course be designed to meet the requirements for developing technical talents as engineers being prepared for future challenges?
- Which elements are necessary to fulfill the multiple requirements, supporting technical talents as future engineers in order to develop multiple competence?

- What kind of role can humanoid robot play in this context and is it appropriate to fulfill multiple requirements of a study course?
- How can the competence development be supported in a study course for the development of innovative, creative technical problem-solving skills including gender, diversity and sustainability aspects?

II. CONCEPTUAL APPROACH

A. Basic considerations

Solving technical problems through engineering disciplines requires complex knowledge and scientific background, also practical experience, e. g. laboratory work. Here the use of humanoid robots as a learning tool provides a great variety of tasks and subjects that can be realized in different application and learning scenarios [11]. A humanoid robotic platform can be used for learning complex knowledge, such as kinematics, sensor technology, but also supports the integration of social aspects regarding the design of human-machine interaction. If the humanoid robot is e. g. used as an assistive system the application and learning scenario also demands the implementation of the user's requirements.

The development of innovative solutions must not only be assessed by functionality or technical design but also must face sustainable constraints, such as resource efficiency and energy consumption not only in the developmental process but also in the whole lifecycle of technical devices. Also the complexity of highly integrated technical devices not only requires complex constructive knowledge but also multidisciplinary proficiency such as electrical engineering or technical computer science. Different solutions have to be evaluated through multiple criteria for these processes as future engineers have to be enabled to evaluate complex design in a reflective manner [12, 13]. This has to be integrated in a study course concept.

B. Humanoid Robot

Humanoid robots as a learning tool have several advantages. Due to functionality, the robot application design can be totally different, from programming to construction. For the conceptual design of project-oriented study course, two types of humanoid robots are applicable that are presented in the following (see Figure 1).

__FIGURE 1.__ Outer appearence of used humanoid robots [14, 15]

1) ***Humanoid NAO Robot:*** the size is about 58 cm, it has 25 degrees of freedom (2 in the head, 5 in each arm, 1 in each hand, 5 in each leg and 1 in the pelvis), consists of a 1,91 GHz Processor Atom, quad core, 4 GB DDR3 RAM, 32 GB SSD, 4 omindirectional microphones, 2 loudspeakers, two 5 megapixels camera systems, sonar, eight force sensitive resistors in the feet, an inertial system consisting of gyroscope and accelerator sensory system and connectivity through bluetooth, ethernet-wifi. The camera system enables face detection and object recognition, the robot also provides interactive concepts like the basic channel, basic awareness, autonomous life, language processing including speech recognition, supporting more than 20 languages. Some artificial components are also implemented such as a semantic engine, whereby the robot is able to make some simple assertion through the dialogue system [14, 16].

2) ***Humanoid Robotis OP2:*** consists of 20 actuators, its size is about 46 cm with 20 degrees of freedom, six degrees of freedom per leg, three per arm and two for head movement, the motor system enables gait velocity of 24 cm/s. The robot has a 1,6 GHz Dual Core Intel Atom N 2600 microprocessor with 4 GB RAM, a Webcam mounted in the head for computer vision, an inertial sensor system of a 3-axes- gyroscope and accelerator sensor for movement control, a microphone for speech processing and the Lithium-Polymer- Accumulator (1,8 Ah) enables about 30 minutes movement and intensive work [15, 17].

C. Methods

1) ***Participatory Design:*** for the design of application scenarios the knowing of the user's requirements are inevitable and difficult to estimate. Ignoring the requirements lead to inefffficient and cost-intensive technical solutions and the developed technical device or designed application will not be accepted [18]. Due to the fact that actual assistive humanoid robotic systems are not robust enough for every- day life use, application scenarios using humanoid robots can only be realized as use cases in research context. Nevertheless, realistic engineering tasks, e. g. a conceptual approach as assistive system for elder or disabled persons can help analysing future perspectives and oppurtunities. A basic task is the realization of robotic application in the context of human-machine interaction based on the functionalities of the used humanoid robot. In the design task it is essential to considerate gender and diverse aspect in the interaction design [19]. In order to integrate these aspects it is necessary to implement them in a participative approach as follows:

- What is the target group and what are the user's requirements and how can the target groups be involved in development processes?
- Which are the interdependencies between the functionality of the humanoid robot and how can the architecture of the robot be used in order to fulfill the user's requirements?
- Which different solutions can be provided and which is the best solution in the chosen context?
- Which resources are needed and how can the design influence the efficient use of resources?

2) ***Project-orientation and scenario-based learning:*** Project works enables the development of problem-solving skills and prepare for future work in the engineering field. Therefore, the project work should be placed in a real world scenario [20, 21]. The students have to work in teams coordinating the project work and making documentation of the progress in the project using different methods and tools of project management. First of all, they have to define smart goals for their project work, estimating the work load, making a project plan and defining milestones to be reached in definite time segment. Afterwards they have to distribute the work load equally on all team members and control the progress. As project work never performs as planned, conflicts in group processes have also to be solved, in order to guarantee that all team members contribute to the project work as defined.

Using humanoid robots is a challenging task for project work as most team members don't have any experience in programming or construction of humanoid robotic systems. Here the definition of smart goals and estimation of work packages is difficult to manage. Therefore, a short introduction in the functionality of the humanoid robot is mandatory. Also the project work needs high quality support in individual learning processes of all group members due to the specific task to be solved in group work. Here, the students have to design an application scenario by choosing a subject or task to solve, modelling body movement, such as grasping objects, using sensor and camera system, evolving autonomous or reactive behaviour and variable dialogue design. Personalization of the application using face recognition is optional. With these constraints the basis for competence development should be guaranteed [22].

D. Criteria for Competence Development

The introduced elements require a motivating learning strategy strengthening the self-efficacy, integrating multiple methods and a reflective assessment of the involved competencies. This may be realized in a holistic approach of the shaping competence, providing active learning methods in the field of vocational didactics [23, 24], being adapted to engineering pedagogy. The new concept of shaping competence enables holistic project work in a reflective manner providing competence development with respect to the following criteria:

- Functionality: is the solution appropriate to the user's requirements, are there alternative solutions and is the solution possible to realize?
- Technical Design: are there possibilities to adapt the robot's components or features in order to generate a new solution for the defined tasks?
- Efficiency: is the estimation of work load for reaching the project goals realistic and are all project resources applied in an efficient way?
- Process Orientation: are all project tasks and results gained in structured working processes and are all necessary information provided to all group members at the right time for efficient work?
- Gender & Diversity Aspects: are all gender and diversity aspects implemented in the presented solution?
- Technological Impact Assessment: what are the impacts of the used technology and the provided solution for society?
- Sustainability Aspects: what are the ecological implications of the used technology and the provided solution?
- Creativity: are the opportunities and possibilities for shaping and designing the application scenario widely used or is an innovative solution realized?

E. Study Course Design

In the following, a conceptual course design for the use of humanoid robots in a project-oriented and scenario-based study course is introduced. As a first approach, the study course is designed for students of mechanical engineering, as this engineering discipline generates fundamental constructive solutions for great varieties of complex products and production systems. The concept also provides the integration of interdisciplinary group work and is appropriate for students of mechatronics, electrical engineering or technical computer science. The integration of project- orientation with scenario-based learning methods in a participative approach leads to the study course design of "Technology of Human-Machine Interaction".

The different criteria for competence development can be assessed in correlation to the different humanoid robots that can be used in the course concept. Due to the different robotic platforms, the support for competence development is different with respect to the defined criteria and is illustrated in Figure 2.

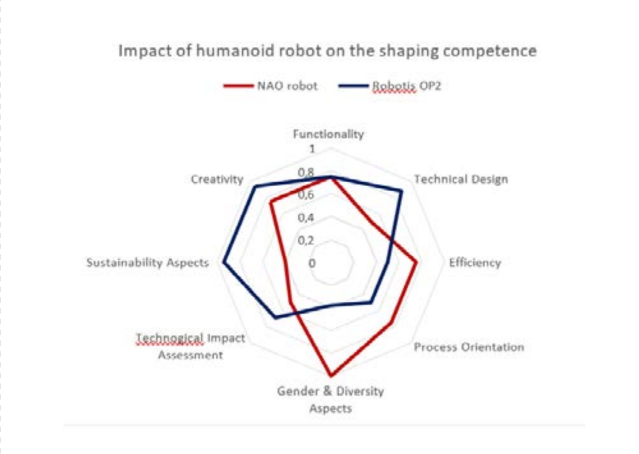

FIGURE 2: *The impact of humanoid robot on the assessmenet of the shaping competence*

Each criteria is assessed due to the correlated knowledge that is involved in the development of assistive scenarios with the different humanoid robotic system. According to Bloom's Revised Taxonomy the knowledge can be categorized into factual, conceptual, procedural and meta-cognitive knowledge [25], the two humanoid robotic platforms support the gain of knowledge differently due to their design and features. The NAO robot strengthens the competence development in functionality, efficiency, process orientation, it is possible to integrate gender and diversity aspects and provides creativity for application development.

The Robotis OP2 is superior in sustainability and supports the competence of technical design, whereas the outer appearance can be shaped using additive manufacturing [26].

In the actual course design students develop innovative solutions for different technical problems using the humanoid NAO robot in a group work [27]. The groups can choose a subject of their own and present their results designing application scenarios using humanoid robots. The study course using humanoid robots is applied since 2017, almost every year in the summer semester with about 20 to 40 students of the fourth or sixth semester of mechanical engineering (Bachelor degree). In the first years also students of computer science participated as well as students of mechatronics, electrical and industrial engineering. Due to pandemic situation, the number of participants is reduced because of limited laboratory space.

III. RESULTS

Due to the conceptual design the results of the study course are presented and reflected. In most application scenarios the humanoid NAO robot is used and permits the analysis and reflection of the actual course concept. Using the humanoid NAO robot the subject categories of the chosen tasks for application scenarios by the students shows Tab. 1.

TABLE 1: *Subject categories*

Subject	No. of choices	
Assistive scenario	6	Learning assistance, pick-and-place-tasks for disables persons
Playing games scenario	4	Bowling, playing dice or cards, selfies
Sport trainer	3	Body fitness, barbells
Robotic system analysis	2	Grab objects, climbing stairs
Total	15	

Most of the groups choose tasks for assistive scenarios, such as humanoid robot as learning assistance, pick-and-place tasks for injured or disabled persons. In the second and third place students developed applications for playing games or sportive activities. The analysis of the robotic system is chosen only by two groups. Here the grabbing of objects is not placed in an interactive scenario with social constraints, that denotes that the analysis of the user's requirements is missing.

As an example, one realized scenario is illustrated in Figure 3, showing the searching and finding of objects for blind people. The object recognition can be supported by NAOMarks helping the robot to easier find objects with computer vision methods through the robot's camera system under changing light constraints.

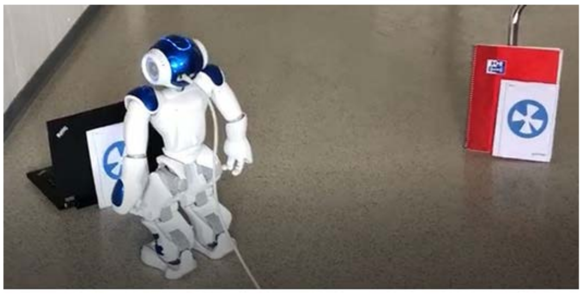

FIGURE 3: *Example of application design using the NAO robot*

This example shows how far an application can be realized and leading to future modification of the course design. In the realized application scenario the assessment of competence development for the criteria "Gender & Diversity" or "Technological Impact Assessment" is well integrated, whereas other competence criteria may be difficult to be rated. Since the NAO robot can't be changed in the construction, here the "Technical Design" or "Sustainability Aspects" can be better realized by using the second robotic platform. Here the robot's outer appearance can be shaped by additive manufacturing processes which also may lead to more creativity and a deeper competence development.

The assessment of the six assistive scenarios application in relation to the to the reachable knowledge-supported criteria of competence development supported by the chosen robotic platform is shown in Figure 5. The realized application scenarios of the different groups are similar in the criteria of "Functionality", "Technical Design" and "Efficiency". The process orientation differs only for one group result due to the group work and the poor progress achieved in the whole project. "Gender & Diversity Aspects" are only implemented in some group results whereas "Technological Impact Assessment" and "Sustainability Aspects" have only poor results. Here the course design should be reflected and needs further development. "Creativity" is achieved by all group work due to the motivating factor of the robotic platform and great variety of features that is provided by the robot's architecture.

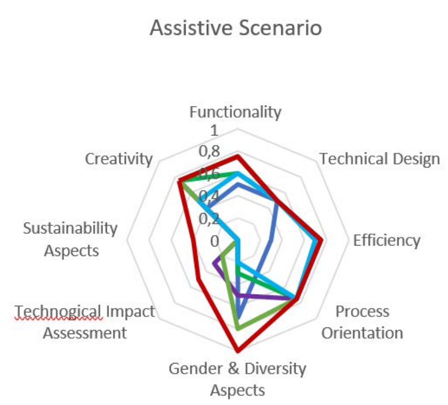

FIGURE 4: *Assessment of assistive scenarios using the humanoid NAO robot*

The presented methodological concept of the course design shows the correlation between the use of humanoid robots for competence development and achievable project results in group work. It also shows that the robotic platform may be a limiting factor for some criteria so in order to be more future-oriented, e. g. integrating sustainability aspects, here the second humanoid robotic platform may be a promising alternative. This may lead to restrictions for efficiency or process orientation whereas the functionality is not best supported as they are on the NAO robot. This shows that the second robotic platform should also be considered for the new course design to meet future constraints and challenges.

IV. FUTURE DEVELOPMENT

The concept is not only based on recent experiences and results such as the study course "Technology of Human-Machine Interaction", but also on development project and study work in bachelor and master theses. All experimental verified application scenarios are developed in a participatory approach as the students choose the subjects on their own due to their individual interests. This motivates not only for the chosen subject and work but also may help for the learning processes of classic subjects such as mechanics, examining e.g. static and dynamic stability using the humanoid robotic platforms.

In order to provide future competence development, a new study course "Project Subject with Project Management" is implemented into study curriculum of mechanical engineering, with a workload 150 h, implemented in the third semester of Bachelor degree. It starts with a seminaristic introduction in project management, followed by project work in groups consisting of 5 to 10 students, being combined by scientific documentation and presentation. The use of the second humanoid robot with more complex technological features can be implemented with respect to sustainability aspects as discussed before.

The new concept of the module has not yet been realized and will start in the next semester. Focus on group size, choice of subject, choice of humanoid robot, the intersection between competence development and robot design, interest in programming or constructive elements should be introduced and analysed. Here, the design of human-machine interaction through programming the shaping of the outer appearance of robots through technical design, the choice of technical components, and using AI in interaction design can be provided. This will lead to more profound engineering knowledge but requires a higher time consumption. This further development may provide the holistic competence development for future engineers facing new challenges and being enabled to realize innovative and responsible technical solutions.

REFERENCES

[1] G. Kammasch, Impulsvortrag, https://www.hrk- nexus.de/material/tagungsdokumentation/erfahrungsaustausch-zum-verhaeltnis-von-fachlickeit-und-beruflichkeit/, last accessed 2021/08/21.

[2] P. Anzenberger, A. Dehing, R. Dreher, J. Hoefele, G. Kammasch, S. Kersten, B. Lübben, T. Schelker, H.-B. Woyand, K.Vesper, V. Ziroff Gut, „Das IPW Curriculum", Kammasch, G., Dehing A., van Dorp, A. (eds.), Referate der 10. Ingenieurpädagogischen Regionaltagung 2015, pp. 247−283, 2015.

[3] S. Martin, E. Lopez-Martin, A. Moreno-Pulido, M. Castro, "The Future of Educational Technologies for Engineering Education", IEEE Transactions on Learning Technologies, pp (99): 1-1, 2021.

[4] L. Schiebinger et al. (eds.), "How Gender Analysis Contributes to Research", Report of the Expert Group "Innovation through Gender", European Commission, 2013.

[5] L. Schiebinger, I. Klinge, H. Y. Paik, I. Sánchez de Madariaga, M. Schraudner, M. Stefanick, (eds.), "Gendered Innovations in Science, Health & Medicine, Engineering, and Environment" (genderedinnovations.stanford.edu), 2011-2020.

[6] E. Godfrey, L. Parker, "Mapping the Cultural Landscape in Engineering Education", Journal of Engineering Education, Vol. 99 (1), pp. 5–22, 2010.

[7] E. Tilley, J. E. Mitchell, "Teaching self-awareness, diversity and reflection to support an integrated engineering curriculum augmented with problem and scenario-based learning", SEFI Annual Conference, Birmingham, 2014.

[8] M. Wolffgramm, T. Tijink, M. Disberg-Van Geloven, S. Corporaal, „A Collaborative Robot in the Classroom: Designing 21st Century Engineering Education Together", Journal of Higher Education Theory and Practice, Vol. 21(16), 2021.

[9] M. Gessler, A. Sebe-Opfermann, "Project-Based Learning in German Vocational Education and Training: a Structured Approach to Developing Self-determined, cooperative Problem-Solving Competence", Senac Journal of Education and Work, Vol. 44, No. 3, 2018.

[10] https://sdgs.un.org, last accessed 2022/07/29.

[11] A. Dederichs-Koch, U. Zwiers, „Der NAO-Roboter als motivierendes Medium zur Unterstützung des gendergerechten Lernens komplexer mathematisch-technischer Sachverhalte", Referate der 9. Ingenieurpädagogischen Regionaltagung, 2014.

[12] N. M. Fonseca Ferreira, A. Araujo, M. S. Couceiro, D. Portugal, "The potential of a robotics summer course On Engineering Education", Teaching Robotics with ROS, Workshop at European Robotics Forum, Tampere, Finland, 2018.

[13] M. L. Cruz, G. N. Saunders-Smits, P. Groen, Evaluation of competency methods in engineering education: a systematic review. European Journal of Engineering Education Vol. 45 (5), pp. 729–757, 2020.

[14] NAO robot, https://developer.softbankrobotics.com/nao6/, last accessed 2021/05/31.

[15] https://www.robotis.us/open-source-robots/, last accessed 2022/05/31.

[16] D. Gouaillier, V. Hugel, P. Blazevic, C. Kilner, J. Monceaux, P. Lafourcade, B. Marnier, J. Serre, B. Maisonnier, "The NAO humanoid: a combination of performance and affordability", Computing Research Repository, 2008.

[17] C. N. Thai, "Exploring Robotics with ROBOTIS System", Springer International Publishing Switzerland, Cham, 2017.

[18] R. M. Siino. P. J. Hinds, "Robots, Gender & Sensemaking: Sex Segregation's Impact On Workers Making Sense Of a Mobile Autonomous Robot, Management Science & Engineering, Stanford University, 2005.

[19] P. Alves-Oliveira, S. Janarthanam, A. Candeias, A. Deshmukh, T. Ribeiro, H. Hastie, A. Paiva, R. Aylett, "Towards dialogue dimensions for a robotic tutor in collaborative learning scenarios", RO-MAN: the 23rd IEEE International conference, 2014.

[20] R. Grit, "Project Management. A Practical Approach." Third Edition. Groningen/Houten,the Netherlands, Nordhoff Uitgevers, 2011.

[21] Q. Xu, J. Ng, O. Tan, Z. Huang, B. Tay, T. Park, "Methodological Issues in Scenario-Based Evaluation of Human–Robot Interaction", Int J of Soc Robotics (International Journal of Social Robotics), Vol. 2, 2015.

[22] A. Dederichs-Koch, U. Zwiers, "Digital Spaces as an Opportunity for Supporting Complex Learning Strategies in Human-Machine Interaction". In: Auer, M. E., Hortsch, H., Michler, O., Köhler, T. (eds.): Mobility for Smart Cities and Regional Development – Challenges for Higher Education. Proceedings of the 24th International Conference on Interactive Collaborative Learning (ICL 2021), Vol. 2, p. 1059-1072. Lecture Notes in Networks and Systems. Vol. 38. Springer Nature, Switzerland, 2021.

[23] F. Rauner, „Competence Diagnostics and Competency Development in Vocational Education and Training", in: McGrath, Mulder et al. (eds.), Handbook of Vocational Education, 2019.

[24] F. Rauner, "Measuring and Developing Professional Competences in COMET – Method Manual". Springer, Singapore, 2021.

[25] D. R. Krathwohl, "A Revision of Bloom's Taxonomy: An Overview. In: Theory into Practice 41 (4), 2002.

[26] A. Dederichs-Koch, U. Zwiers, "Integrating Sustainable Aspects to Robotic Application and its Impact on Course Design in Human- Machine Interaction", Learning in the Age of Digital and Green Transition, Proceedings of the 25th International Conference on Interactive Collaborative Learning (ICL 2022), 2022.

[27] A. Dederichs-Koch, U. Zwiers, R. Dreher, „Kurskonzept „Technik der Mensch-Maschine-Interaktion" am Beispiel humanoider Roboter", Referate der 12. Ingenieurpädagogischen Regionaltagung, 2017.

Technical papers

Evaluating the usefulness of an online participative modelling tool when post-graduate engineers co-model enterprise operations

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***Abstract* — Digital participatory enterprise modelling (PEM) is an emerging knowledge area that may increase collaboration and understanding amongst team members in modelling enterprise operations, especially when team members are geographically dispersed.**

The COVID-19 pandemic emphasised the need to use participatory design practices when in-person face-to-face participation is not possible. Within a tertiary post-graduate engineering education context, this study uses an online approach to demonstrate the use of PEM to students. The main objective is to investigate whether an interactive modelling tool is useful to post-graduate engineering students when they also apply digital PEM within the context of their own enterprise.

Using design science research to further evolve an existing story card method (SCM), we address a key concern that was identified during a previous design iteration of the SCM, namely that the previous modelling tool did not encourage active participation during modelling due to the latency of the tool. Although multiple participative modelling tools are available, we used a list of entry requirements to short-list two tools. We provide a comparative analysis of the two tools, motivating selection of a single tool that was used in combination with the SCM. We involved 36 participants in applying the SCM, of which 25 completed a survey to evaluate whether the tooling encouraged participative design.

Using a demonstration case to illustrate the notion of participative design to the post-graduate participants, using the selected tool in combination with the SCM, we obtained positive feedback about the participative enterprise modelling tool that was used by post-graduate engineering students. The feedback also provides guidance towards our future teaching practices, encouraging participative online co-modelling, especially when post-graduate students conduct their studies remotely.

Keywords — participative enterprise modelling, engineering education, participative modelling software tools.

I. INTRODUCTION

Enterprises need to continuously adapt their existing business models and therefor also their enterprise operations and supporting information systems. When business-oriented software needs to be developed within a scaled context, the story card method (SCM) assists in structuring emerging software requirements within a taxonomy that represents enterprise operation [1]. However, members of an agile software development project, first need to develop a common understanding about enterprise operation. Digital *participatory enterprise modelling* (PEM) is an emerging knowledge area that may increase participation and understanding amongst team members in modelling enterprise operations, especially when team members are geographically dispersed.

The COVID-19 pandemic emphasised the need to use participatory design practices when in-person face-to-face participation is not possible. Digital participation was not only evident in industry. Tertiary education institutions also had to apply digital participation technologies to continue their educational offerings during the pandemic. Initiated by the online engineering education mode of teaching in 2020 at a South African tertiary education institution, post-graduate engineering students indicated in 2022 a need to continue their studies remotely. Post-graduate students believe that online teaching is more inclusive, since students would be able to continue with their studies remotely without disrupting their work commitments within industry.

Since the university offered an opportunity to continue with online teaching for post-graduate modules, an opportunity existed to experiment with online participative design tools in combination with the SCM, answering the primary research question of this study, namely:

RQ: How useful is an interactive modelling tool during participative enterprise modelling, using the SCM, when applied by a group of post-graduate participants?

II. RESEARCH METHODOLOGY

Our study applies a design-based research methodology, called design science research (DSR), to address a deficiency that was highlighted for an existing artefact, called the *story card method* (SCM) [1]. DSR is an appropriate research methodology if an existing problem could possibly be solved by creating or adapting an artefact, where an artefact could for instance be a method or a software application. The SCM, explained in more detail in section III, was initially designed to assist a novel analyst to use story cards to map out enterprise operations as a story or sequence of tasks, i.e. one story card per task, prior to converting the story cards into a graphical representation of the enterprise operations, using a coordination structure diagram (CSD). This study further extends the SCM, using the SCM in combination with a *digital participative enterprise modelling tool* that allows multiple stakeholders, involved in enterprise design, to co-model enterprise operations interactively, using an online software modelling tool. Experimenting with an online software modelling tool, within the engineering education curriculum, not only provided relevant training to students on enterprise modelling, but also prepared students for the post- pandemic workplace, where digital and participative design became a de facto practice.

Peffers et al. [2]. indicate that a DSR research effort may start in many different ways, also "with an already designed version of an artefact" [2]. Our study focuses on one part of the SCM artefact, namely the *software tooling* that is used, addressing the five steps of the DSR cycle (presented in [3]) in the following way: (1) *Identify a problem:* The software tooling, used in combination with the SCM does not encourage participative modelling due to a delay in reflecting updates performed by co-modelers; (2) *Define objectives of the solution:* Select a modelling tool that encourages participative modelling; (3) *Design and development:* Embed the method steps of the SCM within the new software tool to encourage participative modelling; (4) *Demonstration:* Demonstrate to participants how a fictitious case can be applied when the SCM is used in combination with the new software tool; and (5) *Evaluation:* Request that post-graduate engineering students apply the SCM and software tooling within their own industry context to obtain survey feedback about the usefulness of the modelling tool.

III. BACKGROUND

Enterprises are complex entities, multiple enterprise models and perspectives are needed to represent different facets or domains of the enterprise [4, 5]. Multiple modelling languages exist to represent a particular domain, such as the organization design domain, including Petri Nets, BPMN (Business Process Modelling and Notation) and DEMO (Design and Engineering Methodology for Organizations) [6]. The DEMO modelling language is specified using DEMOSL (DEMO Specification Language). DEMO, when compared to other modelling languages, focuses on representing enterprise operation in a *consistent* and *concise* way, also hiding operational complexity in a consistent way [7]. One of the four aspect models, the *cooperation model* (CM) represents the essence of enterprise operation in terms of a cooperation structure diagram (CSD) and a transactor product table (TPT).

Although the CSD is useful as a taxonomy in structuring user stories that emerge during an agile software development project, an additional method, called the story card method (SCM) is required to model a CSD in a participative way [1]. The latest version of the SCM however indicated that the software tool hampered interactive modelling and hence needed further experimentation with alternative tools [1]. Since we wanted to ensure that the new software tool incorporated entry requirements that would encourage and monitor active participation, we investigated the emerging knowledge area, called digital participative enterprise modelling (PEM).

A. Participative Design and Participative Enterprise Modelling

Two knowledge areas developed in parallel, both sharing a participative approach, namely *participative design* and *participative enterprise modelling*.

Participative design (PD) emerged as a method within human-computer interaction (HCI) and software design for more than a decade [8]. The main objective of using participatory design is to make the consumers as end-users, part of the design process, rather than involving the consumers right at the end of the design [9]. According to Simonsen and Roberson [10], participatory design supports mutual learning between multiple participants in collective "reflection-in-action". Since PD is used when designing a new artefact, an entire design cycle may be implied, starting with an existing understanding of a current artefact, process or operating context that needs to be re-designed, also including participation in selecting among different choices for solution areas and solution constructs [11].

Enterprise modelling (EM) is "an integrated and multi-perspective way of capturing and analysing enterprise solutions" [12]. Enterprise models may be created to serve different objectives, also as part of a design cycle to design or redesign a part of the enterprise. When multiple individuals are involved during modelling, EM can be further classified as collaborative or participatory. Fellman et al. [13] indicate that *collaborative* modelling emphasises joining of several experts into a coordinated effort, whereas *participative* enterprise modelling (PEM) also involve *users or enterprise stakeholders*. One of the main objectives of a participative approach for EM is avoiding conceptual misalignment between the stakeholders and their different perspectives [13]. PEM is also aligned with the paradigm of the 2018 B*usiness Information Systems Engineering* conference research note, moving enterprise modelling from an expert discipline towards a more inclusive modelling approach [14].

Highlighting 3 main characteristics, Stirna and Persson [12] indicate that a participative approach: (1) Has a defined way of working in the form of methodological steps to carry out the modelling sessions with explicit principles of stakeholder involvement; (2) Has a group of stakeholders responsible for the knowledge that goes into the model; and (3) Has a modelling facilitator responsible for guiding the discussion among stakeholders and the modelling method used. Before we started with the *design and development* part of our study, embedding the SCM into a PEM software tool to showcase the 3 characteristics identified by Stirna and Persson [12], we had to select a tool that would encourage and enable participative modelling.

B. Tool Selection

We used an iterative process to experiment with two participative modelling tools, namely Miro and MURAL. The main researchers had full administrative rights on the two tools and used an exploratory or inductive approach to identify the main features of the two tools. Two additional participants formed part of the experimentation team and were involved to act as members or visitors on the tooling platforms, with restricted access rights. The experimental process consisted of two main phases: (1) feature exploration, and (2) entry criterion identification.

During the feature exploration phase one of the researchers experimented with two no-cost platforms, developing a SCM template for Miro and MURAL. The two main researchers collaboratively identified entry requirements during this phase as well, i.e. those features that are absolutely necessary, when used in combination with the SCM.

The entry requirements included:

1. ***Interactive modelling:*** There should not be any latency in reflecting updates performed by multiple participants.
2. ***Workspace membership control:*** Full members should be prevented from adding new members if membership numbers are restricted. During the main experiment, the administrators need to ensure that participants of the experiment have "full member" privileges.
3. ***Workspace privilege control:*** Administrators should have control over workspace privileges, e.g. preventing members from adding new rooms. The experiment requires monitoring of activity within the rooms and therefor rooms had to be created by the administrators.
4. ***Board membership control:*** Should provide board membership to selected members (i.e., all participants in the SCM experiment).
5. ***Board access control:*** Should be able to manage the users (members and visitors) per board, also removing users from a board.
6. ***Board access control relating to new memberships:*** Should allow Education members to invite visitors from outside with "edit" abilities on a board without occupying full memberships. The SCM experiment has to allow participants to invite their colleagues to join a SCM board.
7. ***User type access for board access:*** Users that are invited to a board should also allow access to "industry" users with editing access. For the SCM experiment, participants need to invite a colleague from industry to participate/edit on a board.
8. ***Change tracking:*** Should be able to track changes per user that are made for the contents of a board, for the lifetime of a board. For the SCM experiment we would like to keep track of the level of participation in making changes to a board.

Miro and MURAL were compared against the entry requirements, quantifying the level of addressing each of the entry requirements, using 3 values, namely 0, 0.5 and 1, that should be interpreted as *not-addressed, partially addressed* and *fully addressed* respectively. MURAL addresses all of the entry requirements (scoring 8 out of 8), whereas Miro failed to address the entry requirements (scoring 4.5 out of 8).

A third no-cost platform was also discovered later in the study, called FigJam. One of the entry requirements that relate to the feature "User type access for board access", indicate that "Users that are invited to a board should also allow access to "industry" users with editing access." For FigJam, users with editing rights need to be registered students. Since our experiment with the SCM involved both students and non-students, we excluded FigJam as an option.

IV. PARTICIPATIVE MODELLING AND THE SCM

MURAL provides more control over privileges for the free-to-use Education plan than Miro. The researchers, both with administrative privileges, could access the pre-created rooms to observe the board (called murals) created and edited by their industry colleagues. Section A presents the template that was available to participants, whereas Section B illustrates the main deliverables when the SCM is applied via the MURAL template.

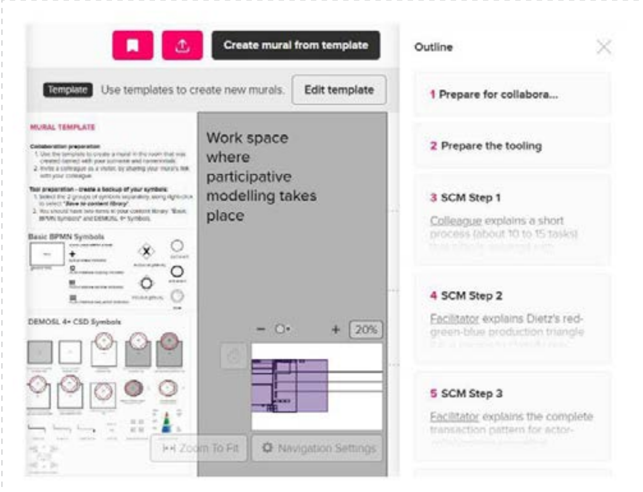

FIGURE 1: *The SCM template*

A. The SCM facilitated in MURAL

Figure 1 provides an illustration of the SCM template that was created for participants to use. On the left-hand side, two groups of symbols are available, namely *Basic BPMN Symbols* and *DEMOSL 4+ CSD Symbols*. The grey-shaded middle part is the working space where multiple users participate during interactive modelling. On the right-hand side, an *Outline* is used to provide methodical guidance in using the SCM, i.e. including 13 steps that form part of the SCM. When a user of this template uses the button *Create mural from template*, a new board (also called a mural) is created within a user-selected room. The user may invite several other users to join the mural and co-model, following the steps that are listed in the *Outline*. Figure 1 only includes 3 of the 13 steps. When a user clicks on a step, e.g. *SCM Step 1*, more detail is shown underneath the heading *SCM Step 1*.

MURAL and the SCM template incorporates the 3 main characteristics defined by [12] for a participative approach, as follows: (1) The template's *Outline* provided a defined *way of working* in the form of methodological steps to carry out the modelling session with explicit principles of stakeholder involvement indicated in detailed descriptions per step; (2) Users as participants of the SCM experiment, need to have *knowledge* about DEMO aspect models and they need to involve a colleague that is *knowledgeable* about a particular operating context at a real-world enterprise; and (3) Users as participants of the SCM experiment, acted as modelling facilitators, responsible for guiding the discussion with their colleagues during a SCM modelling session.

B. The Main Deliverables of the SCM

Post-graduate students received training on DEMO, also receiving a full interactive demonstration of the SCM, using some post-graduate operations of a fictitious tertiary education institution as the operating context. The interactive modelling, when using the SCM, was demonstrated by the two main researchers of this study, where one researcher played the role of *facilitator*, and the other researcher played the role of *industry colleague* for the post-graduate case. Additional examples were also discussed during class, some of which are discussed in further detail in [7]. Documentation for a second demonstration of the SCM for a pet-sitting case, was also provided. Figure 2 and Figure 3 are the main modelling outputs that are produced as a result of applying the SCM.

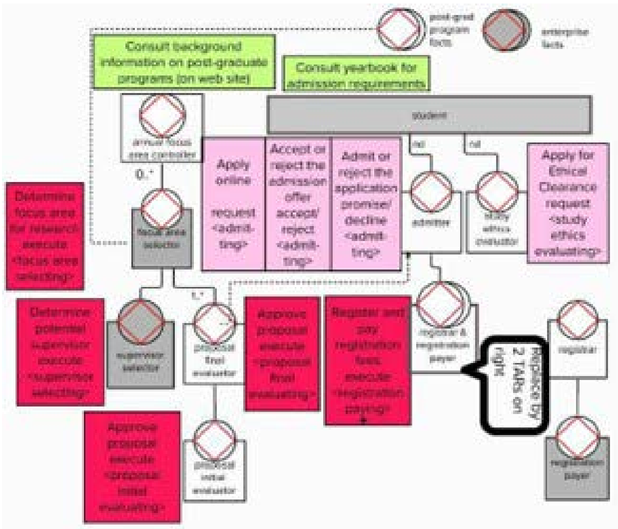

FIGURE 2: Applying Steps 7 to 12 of the SCM

transaction kind	product kind	executor role
focus areas controlling	focus area control for [year] is completed	focus areas controller
focus area selecting	the focus area of [study] is selected	focus area selector

FIGURE 3: A partial Transactor Product Table (TPT)

The SCM steps can be divided into 3 phases:

Phase 1: Applying Steps 1 to Steps 6 facilitates interaction between the modelling facilitator and the colleague to map out some enterprise operations in the form of tasks, also called *story cards*. The purpose is also to classify the tasks, identifying tasks that are called *original* when the tasks produce new production facts versus *informational* when the tasks are used to share facts. Original tasks are color-coded in red or pink to distinguish between production acts versus coordination acts respectively, whereas informational tasks are color-coded in green.

Phase 2: Applying Steps 7 to 12 of the SCM, converts the color-coded story cards into a diagram, called the coordination structure diagram (CSD), illustrated in Figure 2. The guidance provided in Steps 7 to 12 requires discussion and participation to ensure that the enterprise operations are correctly depicted in terms of actor roles that interact with one another in coordinating their actions related to production.

Phase 3: Step 13 produces a transactor product table (TPT), illustrated in Figure 3, with the main purpose of validating the completeness of the CSD by defining a transaction kind (left column of Figure 3) and product kind (middle column of Figure 3) for each transactor role (right column of Figure 3) that appears on the CSD. The participants need to ensure that for each instance of the transaction kind, it is possible to define an original product kind that comes into existence. Taking the first row of Figure 3 as an example, a single instance of *focus area controlling* will produce a unique product kind *focus area control for year 2022 is completed*.

V. FEEDBACK RESULTS

We involved 36 participants in applying the SCM, of which 25 completed a voluntary survey to evaluate whether the tooling encouraged participative design.

Participants had an engineering background that covers multiple disciplines, i.e. industrial engineering (13 out of 25), mining (4 out of 25), metallurgy (3 out of 25), mechanical (2 out of 25), electronic (2 out of 25) and chemical (1 out of 25). Most of the participants (23 out of 25) had experience in using drawing tools or repository-based modelling tools in the past. Some of the participants used more than one tool, which included Visio (16 out of 25), Diagrams.net (9 out of 25), MURAL (2 out of 25), Miro (1 out of 25), Lucidchart (1 out of 25), MagicDraw (1 out of 25), Microsoft PowerPoint (1 out of 25), ARIS (1 out of 25), and Enterprise Architect (1 out of 25). The participants had the freedom to select a tool for verbal communication, some using multiple tools and therefor some of the 25 participants indicated that they used *multiple* tools in combination. Participants used MS Teams (14 out of 27 tools), WhatsApp Calls (7 out of 27 tools), Zoom (3 out of 27 tools), Google Meet (2 out of 27 tools) and a phone call (1 out of 27 tools).

The following reported survey statements (indicated with Q), rendered responses that are summarised in Figure 4:

Q17: From a facilitator perspective, I followed the story-card method, allowing my colleague to co-model, aligned with instructions provided by the story-card method.

Q19: My perspective: MURAL hampered participative modelling and created frustration when applying the story-card method.

Q21: Colleague perspective: MURAL hampered participative modelling and created frustration during modelling.

Q23: From an ease-of-use perspective, if I had to participate with other team members in future, doing online participative modelling, I would recommend that MURAL is used.

Q25: From a facilitator perspective, if I had to use the story-card method in future to facilitate teaching on the CSD, I prefer to use face-to-face facilitation and drawing on a physical whiteboard, rather than using online modelling.

For each of the reported survey questions (Q17, Q19, Q21, Q23, and Q25), probing questions (Q18, Q20, Q22, Q24, and Q26) were used to encourage participants to further motivate if they deviated from a positive opinion. For Q17 (see Figure 4) the participants that disagreed/strongly disagreed indicated that their colleague who co-modelled the operating context was not from an engineering background and had difficulties in understanding the concepts used in the SCM.

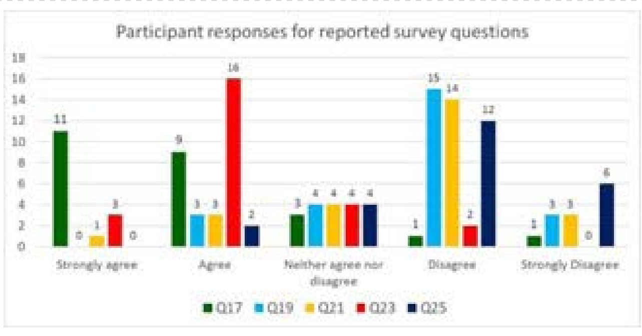

FIGURE 4: Participant responses for reported survey questions

For Q19 (see Figure 4) the 3 participants that agreed, indicated that (1) some functionalities in MURAL (e.g. ctrl-c) did not work; (2) the "undo" function did not always work; and (3) the exports from MURAL are not readable. For Q21 (see Figure 4) we wanted to determine whether the software tool was a barrier during the co-modelling process, rather than an aid. The 3 participants that agreed, indicating that MURAL was indeed a barrier in the participating design effort, provided additional motivation, indicating that (1) the colleague found it challenging to complete the process flow, since MURAL is not as user-friendly as Visio; (2) the colleague did not understand the new concepts and did not appreciate the value of the new modelling language; and (3) MURAL would often refresh automatically causing distraction and time loss. For Q23 (see Figure 4) 1 of the 2 participants that disagreed provided additional motivation, indicating that many companies already have modelling tools that are more self-explanatory than MURAL. For Q25 (see Figure 4) the 2 participants that agreed indicated that (1) people engage better with face-to-face facilitation and the first session should be using a whiteboard followed by more online examples; and (2) zooming in and out on the SCM caused frustrations with navigating.

VI. CONCLUSIONS, LIMITATIONS AND FUTURE RESEARCH

The COVID-19 pandemic emphasised the need to conduct participative modelling within industry, as well as within the tertiary education domain. As a result, this study investigated how well online participative modelling is facilitated by MURAL, a tool specifically designed for digital collaboration. Post-graduate engineering students that participated in this study were mostly positive about MURAL. Few (2 out of 25 participants) still preferred a face-to-face facilitation and drawing on a physical whiteboard, rather than using online modelling. The positive experience from participants, using MURAL for co-modelling enterprise operations, forms the basis to further explore participative online co-modelling within other design-based post-graduate modules.

Project management, an instance of such a post-graduate module, typically requires the modelling of work breakdown structures and network diagrams. Future work is suggested to investigate whether a tool, such as MURAL, encourages students within a project team, to participate online in compiling project-related diagrams.

Since the study only included 25 voluntary participants, and participant background and social desirability may have an effect on the tooling experience during participative design, we also propose a replication of the study for future work, using a larger sample size. Since one of the participants already indicated a preference for using a different tool, Miro, instead of MURAL, a comparative study will also attenuate possible bias, increasing the reliability of the study results.

The SCM only involved two participants, co-modelling the operating context of an enterprise, which may also be a limitation of this study. Since engineering students are also encouraged to work in groups for design-based projects, we believe that further experimentation is required on a larger scale. A larger group of participants within a modelling session may have a different experience regarding the usability and responsiveness of the tool.

Participative modelling tools are still developing, and as indicated by one of the participants, other tools, such as Miro, may be more user-friendly. Due to some of our entry-criteria, focusing on controlling the number of memberships and managing access to the MURAL rooms, features that are available as part of MURAL's Education Plan, we excluded Miro as an option. For future work, this study should be repeated when Miro avails additional features within their Education Plan.

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REFERENCES

[1] M. De Vries, "Adapting and evaluating the Story Card Method," in Lecture Notes in Business Information Processing: Advances in Enterprise Engineering XV. EEWC 2021, D. Aveiro, H. A. Proper, S. Guerreiro, and M. De Vries, Eds. Cham, Switzerland: Springer, 2022.

[2] K. Peffers, T. Tuunanen, and B. Niehaves, "Design science research genres: introduction to the special issue on exemplars and criteria for applicable design science research," European Journal of Information Systems, vol. 27, pp. 129-139, 2018/03/04 2018.

[3] K. Peffers, T. Tuunanen, M. Rothenberger, and S. Chatterjee, "A design science research methodology for information systems research," J. of MIS, vol. 24, pp. 45-77, 2007.

[4] B. Lantow, K. Sandkuhl, and J. Stirna, "Enterprise Modeling with 4EM: Perpsectives and Method," in Domain-specific conceptual modeling: Concepts, methods and ADOxx tools, D. Karagiannis, M. Lee, K. Hinkelman, and W. Utz, Eds. Cham: Springer, 2022, pp. 95-120.

[5] M. De Vries, "Towards consistent demarcation of enterprise design domains," in Advances in Conceptual Modeling, S. De Cesare and U. Frank, Eds. Switzerland: Springer, 2017, pp. 91-100.

[6] D. Karagiannis, M. Lee, K. Hinkelmann, and W. Utz, Domain-Specific Conceptual Modeling: Concepts, Methods and ADOxx Tools. Cham: Springer, 2022.

[7] J. L. G. Dietz and H. B. F. Mulder, Enterprise ontology: A human-centric approach to understanding the essence of organisation: Springer International Publishing AG, 2020.

[8] C. A. Scariot, A. Heemann, and S. Padovani, "Understanding the collaborative-participatory design," Work, vol. 41, pp. 2701-2702, 2012.

[9] P. Hansen, I. Fourie, and A. Meyer, "Third space, information sharing, and participatory design," in Synthesis lectures on information concepts, retrieval, and services, 1947-9468 ; lecture #74, P. Hansen, I. Fourie, and A. Meyer, Eds. San Rafael, California: Morgan and Claypool Publishers, 2021.

[10] J. Simonsen and J. Roberson, Routledge International Handbook of Participatory Design: Routledge, 2012.

[11] T. Bratteteig and I. Wagner, "Unpacking the notion of participation in participatory design," Computer Supported Cooperative Work (CSCW), vol. 25, pp. 425-475, 2016.

[12] J. Stirna and A. Persson, Enterprise Modeling: Facilitating the Process and the People: Springer International Publishing AG, 2018.

[13] M. Fellmann, K. Sandkuhl, A. Gutschmidt, and M. Poppe, "Structuring Participatory Enterprise Modelling Sessions," Jönköping: Jönköping University, JTH, Datateknik och informatik, 2020.

[14] K. Sandkuhl, H. G. Fill, S. Hoppenbrouwers, J. Krogstie, F. Matthes, A. Opdahl, G. Schwabe, Ö. Uludag, and R. Winter, "From expert discipline to common practice: A vision and research agenda for extending the reach of enterprise modeling," Business & Information Systems Engineering, vol. 60, pp. 69-80, 2018.

Technical papers

Methodology of teaching and learning for micro- and nano-electronics during the COVID-19 pandemic using online educational tools

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***Abstract* — Worldwide students are having their education disrupted by the 2019 coronavirus disease (COVID-19) pandemic. Due to this, numerous contact courses have recently been moved to the online format in academic reforms. Microelectronics, Nanoelectronics, Nano-Electro-Mechanical Systems (NEMS) and Micro-Electro-Mechanical Systems (MEMS), in general, become challenging to educate and learn for both lecturers and students, respectively in this pandemic scenario. The epidemic has also offered a stimulus to increase the use of educational tools. The primary goal is to use Project-Based Learning (PBL) to explore conceptual online tools and generate attention in the field of MEMS and NEMS. This research describes a teaching style that combines PBL with NEMS and MEMS online courses for undergraduate students. This research work delves into the principles and ideas of Micro- and Nano-electronic models. Teaching styles develop understanding, skills, and values relative to the subject. The basics of MOSFETs, cantilever beams, biosensors, comb drive, piezoelectric devices, etc. are also examined clearly through assignments. The online platform is designed to develop creative concepts and model devices for future applications. Using the PBL technique, this research work fosters both academics and students' self-learning, resulting in more sophisticated studies on subjects such as NEMS, MEMS, and Bio-MEMS. This work displays its text description as well as numerical simulations. In a controlled experiment, two sets of pre- and post-evaluation analyses have been conducted to look at the impact of PBL utilizing numerical simulation tools on fundamental theory learning. The analytical assessment demonstrates that combining numerical simulation with PBL results in more efficient understanding of fundamental MEMS and NEMS ideas. It will be a potential teaching modality for the development of online courses in this area.**

Keywords — Evaluation, Microelectronics, Fundamental theory, Teaching methodology, Project/Research-based learning.

I. BACKGROUND AND MOTIVATION

The global spread of Coronavirus Disease-2019 (COVID-19) presents a challenge to education across the world. The global spread of COVID-19 has affected schooling everywhere, forcing the almost complete shutdown of educational institutions [1, 2]. Since last year's COVID-19 epidemic, educational institutions have been unable to satisfy the instructional demands of their students. Based on statistics from the UNESCO center, after the historic disruption caused by the COVID-19 epidemic, the majority of schools throughout the world have reopened. However, education is still in recovery mode, analyzing the damage and learning from it [3]. Due to the apparent COVID-19 epidemic, massive in-contact lectures and courses have shifted to online academic reforms since around March 2020. In higher educational institutes, in particular, the Electronics Engineering subject specializing in Micro-Electronics, Nano- Electronics, MEMS, NEMS, and Bio-MEMS become challenging to teach and to learn for both academicians and students, respectively [4, 5].

Moreover, regular academic sessions contain both theoretical and practical classes; here, the practical classes play a significant role in understanding and developing students' hands-on skills. Unfortunately, due to the pandemic situation nowadays, the theoretical classes are conducted online, but practical/project classes are challenging [6, 7]. To make engineering highly attractive and aid in student learning, even more individuals want to adopt teaching strategies that are based on research [8, 9]. To overcome these shortcomings, a few numerical simulator tools were used to conduct the practical/project sessions. The epidemic has also offered an opportunity to increase the use of educational tools.

In response to the growing interest in specialization such as Micro-Electronics, Nano-Electronics, MEMS, NEMS, and Bio-MEMS among graduate students in the sensors and actuator fields, numerous universities have begun to offer online courses [10]. Students pursuing advanced degrees in sensors and actuator fields sometimes find these modules to be hard to understand. Electronic and Mechanical engineering principles have combined the specialization. These two factors are essential to developing electronic devices and cannot be ignored. Graduate students with expertise in sensors and actuators should focus on theoretical studies of Electrical and Mechanical aspects in microstructures, such as computation of electrical characteristics, mechanical deflection, stress, and resonant frequency. However, grasping these MEMS and NEMS foundational notions might be challenging for newcomers. To begin with theoretical classes are notoriously challenging. Students often report feeling bored and unmotivated during online theoretical sessions. Many graduate students, however, would be unfamiliar with the specialization of the specialized course because they were not taught it as undergraduates.

According to the research, students have a harder time focusing solely on theoretical lectures, reducing their effectiveness as a learning environment [11, 12]. The PBL, blended learning, narrative theory teaching, hands-on experiments, and numerical simulation experiments are some of the new methods that have been created to address this issue [6]. However, as online courses are computer-based, numerical simulation trials are a useful alternative for teaching core courses [13].

This paper has been organized as follows. Section II has the objective and research questions for this work. Section III covered the methodology, including technical contents of the Micro-Electronics, Nano-Electronics, MEMS, NEMS, and Bio-MEMS design fundamentals like MOSFET, cantilever beams, biosensors, comb drive, and piezoelectric devices. Materials and methods used for this work. Section IV has findings for the online learning environments, with the surveys in detail. Finally, Section V concludes the work and recommends the future aspects.

II. AIM AND PRAPOSED RESEARCH

Among the many fundamental theories underlying the course are Metal Oxide Semiconductor Field-Effect Transistors (MOSFETs), solid and fluid mechanics, piezoelectric actuation, electrostatic actuation, capacitive and piezoresistive sensors, etc. The mechanical and electrical performance of MEMS and NEMS structures may both be predicted using Finite Element Method (FEM) modeling. Curves, pictures, and animations are all examples of visualization outputs that may be used to present data like displacement, stress, deformation, electrical field, electrostatic force, transducer, etc. The MOSFET, cantilever beams, biosensors, comb-drive, and piezoelectric devices are the most fundamental and fundamentally significant theories modeled in the course.

In this present research work, the authors incorporated the FEM simulation into the online course in an effort to bring the course's theoretical concepts. The impact of numerical simulation on learning theory has been measured by a controlled experiment consisting of pre- and post-evaluation. Analytical assessment using pre- and post-evaluation shows that students better understand fundamental ideas on the topics mentioned earlier when numerical simulation experiments are combined with oral lectures. Positively, this investigates several approaches to education. It's a promising approach to building online courses.

III. METHODOLOGY

This research aims to pique students' interest in specialized topics such as MOSFET, Cantilever beams, biosensors, comb drives, piezoelectric devices, etc. This part exposes the specific important topics discussed during the course.

A. MOSFET

Most digital and analog circuits use a MOSFET transistor [14, 15]. As electronic switches, MOSFETs excel, as they can toggle currents ON and OFF, hundred of times per second. To store and transmit data, transistors are crucial to modern digital computers. P-type and N-type MOSFETs are the two most common varieties. The n-type MOSFET, also known as an NMOS transistor (Figure 1), will be the basis for this modeling tool [16]. An NMOS transistor is one in which electrons, which are negatively charged, play a significant role in the formation of the current. The n-type MOSFETs have negative charge carriers, while p-type MOSFETs would contain positive carriers. There must be a difference between the gate voltage (VG) and the threshold voltage before electrons may flow from the source to the drain (VT). More information on this idea may be found in the subsequent discussion of the MOSFET operation. Figure 1 shows no current flows because the gate voltage is below the threshold value.

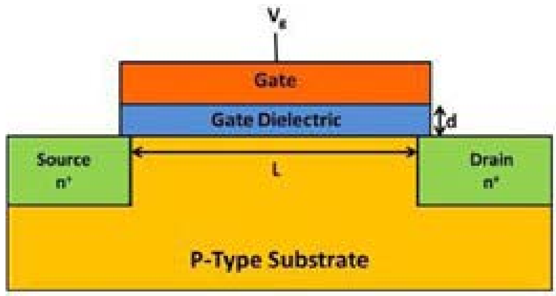

FIGURE 1: *2D model of basic MOSFET [16].*

B. Cantilever Beams

Microbeam research is challenging since making such devices is time-consuming and bulky. The development of this discipline would be tremendously aided by an open- source program to model such beams; However, as nanoelectronics is one of the recent research areas. With no difficult construction required, this device replicates microbeams. This project aims to provide a tool that may be used to analyze, demonstrate, or teach micro-beam structures, a subset of MEMS. A cantilever beam is a beam that is anchored at one end but enables the other end to hang freely [17, 18]. The instrument is made to imitate the behavior of the cantilever beam under varied stresses and moments. The tool may do sweep analysis and static analysis, two distinct simulations.

During the sweep analysis, the cantilever can be subjected up to two parameters (tip force and moments) at user-defined locations. During the static analysis, the cantilever can be subjected to up to four 3D loads (forces and moments) at user-defined locations. The tool produces a graphical representation of the beam's deflection along the three principal axes and the numeric deflection value at the location of interest in tabular format. The cantilever's theoretical and practical models are shown in Figure 2.

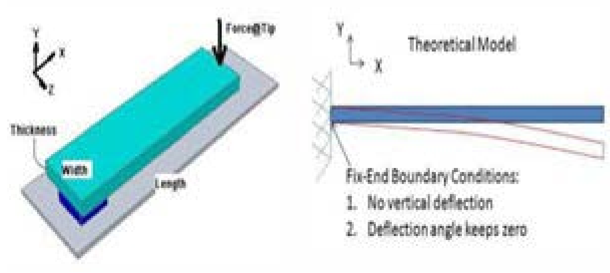

FIGURE 2: *Practical (left) and theoretical (right) model of cantilever [17].*

C. Biosensors

Only sensors that can identify the presence of charged biomolecules close to the sensor surface through electrostatic contact are the focus of BioSensorLab [19]. To avoid parasitic reactions, the surfaces of electronic biosensors like the planar insulated-gate FET are functionalized with receptor molecules (blue symbol in the image) of known identification. For the purpose of chemical identification, a biosensor is a type of analytical equipment that combines a biological component with a physicochemical detector in a single device [20]. Examples include organelles, tissue, bacteria, enzymes, nucleic acids, antibodies, cell receptors, etc. Biological engineering can also be used to produce physiologically sensitive components.

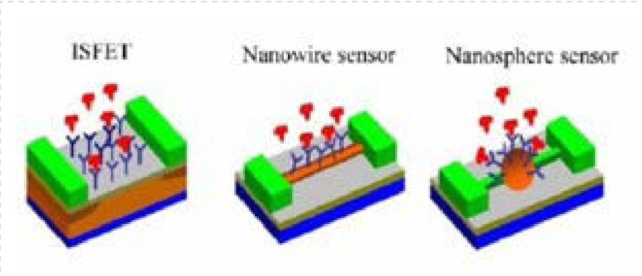

FIGURE 3: Illustrates the planar Insulated Gate FET or ISFET, Nanowire sensor, and Nano sphere sensor structure used in the simulation tool [19].

In most cases, a biosensor is made up of a bio-receptor (such as an enzyme, antibody, cell, nucleic acid, or aptameric), a transducer component (such as a semi- conducting substance or nanomaterial), and an electrical system that comprises a signal amplifier, processor, and display. For instance, electronics and transducers can work together in CMOS-based microsensor systems. The recognition component, also known as a bio-receptor [21], interacts with the target analysis using biomolecules from living things or receptors designed to resemble biological systems. The bio transducer, which generates a quantifiable signal proportional to the concentration of the target analyte in the sample, measures this interaction. The main objective of a biosensor's design is to provide rapid, practical testing at the point of care or concern where the sample was obtained.

D. Comb-drive

Comb-drives are MEMS actuators that employ electrostatic forces between two electrically conducting combs [22, 23]. They are frequently utilized as linear actuators. Typically, comb-drive actuators function at the micro- or nano-scale scale and are made via bulk micromachining or surface micromachining of a Silicon wafer substrate.

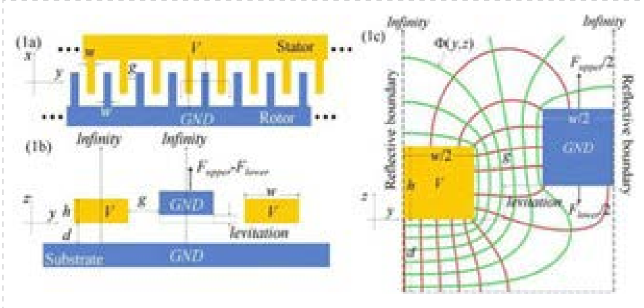

FIGURE 4: Illustrates the comb-drive structure used in the simulation tool.

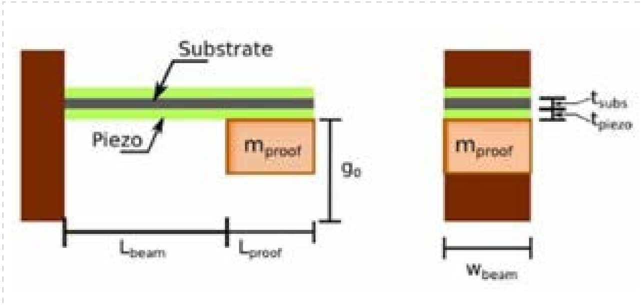

FIGURE 5: Illustrates the piezoelectric structure used in the simulation tool.

In the comb actuator a movable set (rotor) and a stationary set (stator) of comb fingers are engaged. Usually, they operate at the micro- or nano-scale scale. An attractive electrostatic force is generated when a voltage is applied between the stationary and moving combs, bringing them closer. The actuator's output force is proportional to the driving voltage, the number of comb teeth, and the distance between the teeth. It's proportional to the two combs' capacitance. The combs are set up so they don't contract (because there would be no difference in voltage if it happened). It is common practice to configure the teeth so they can slide past one another until each tooth is situated in the slot that corresponds to it on the comb. The addition of springs, levers, and crankshafts can transform the motor's linear action into rotation or other activities.

To study the comb-drive structure simulation in this work, the authors used the nanohub open source simulation software. In nanohub select the tool comb-drive levitation tool. Step by step procedure to simulate the comb-drive structure in nanohub is select the tool and define the parameters in the parameter description such as permittivity, finger width, finger thickness, the gap between fingers, gap between stator finger and substrate, and applied voltage on the stator fingers, then select the button to simulate, it performs the numerical simulation and obtains the output for the defined parameters. Figure 6 shows the step-by-step procedure involved in the comb-drive simulation tool.

E. Piezoelectric Devices

Piezoelectricity is the accumulation of electrical charge caused by mechanical stress in certain solid materials, including crystals, certain ceramics, and biological stuff like bone, DNA, and other proteins [24, 25]. Piezoelectricity is the term for electricity produced by pressure and latent heat. Piezo means to press or squeeze and lektron, which means amber, formerly a source of electrical charge. When a crystalline material's electrical and mechanical states interact linearly without interference, the piezoelectric effect occurs. The reverse piezoelectric effect, which is the internal generation of a mechanical strain as a result of an applied electrical field, is also demonstrated by materials that exhibit the piezoelectric effect.

As an illustration, when the static structure of lead Zirconate Titanate crystals is distorted by just around 0.1 % of the original dimension, a discernible piezoelectric effect is produced. If an external electric field is given to the identical crystals, however, they will expand or contract by around 0.1% in static dimension. Ultrasound waves can be created by employing the inverse piezoelectric effect.

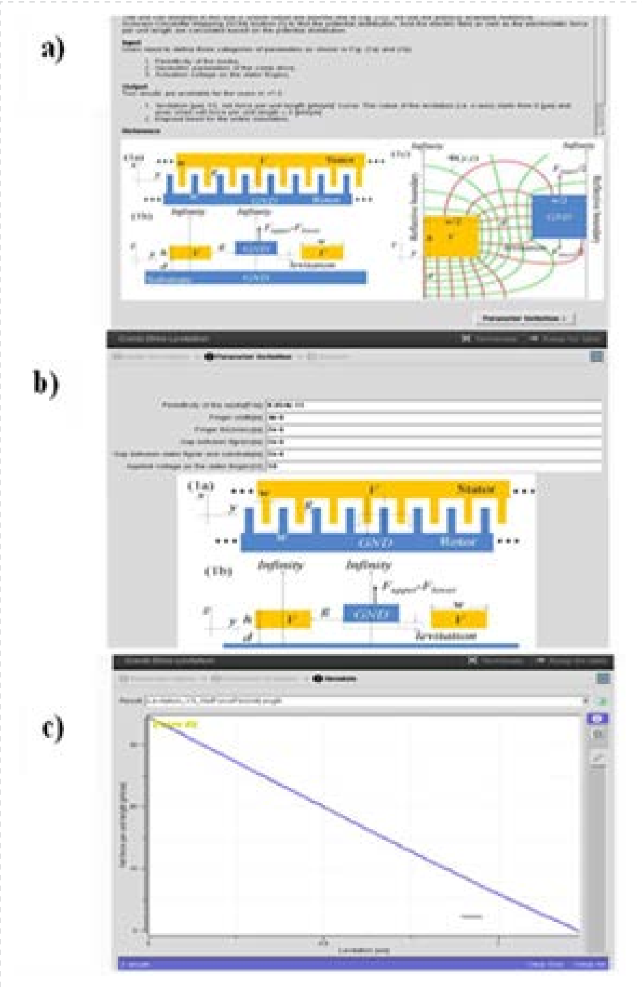

FIGURE 6: Illustrates the step-by-step procedure of comb-drive simulation using the comb-drive levitation tool in nanohub.

IV. FINDINGS FOR THE ONLINE LEARNING ENVIRONMENTS

A. Basic structure of the standard course case

Micro-Electronics, Nano-Electronics, MEMS, NEMS, and Bio-MEMS fundamental course that is designed for graduates of the college/university of sensors and actuator fields who are working toward their Master's in engineering degree. The estimated student effort for this course is 30 hours of class time. Twenty of these hours are devoted to the study of fundamental theory, while the remaining ten hours are devoted to the study of application. Every spring semester, students have the opportunity to take it during the teaching session that lasts for six weeks. It's a three-credit course for M.E (Electronics and Communication, 70-credit degree). This course is an elective subject for the II-year ME/MSc students. Twenty hours are spent on studying the underlying ideas, while the remaining time is spent on learning how to apply such theories in practice. Each year during the spring semester, it is taught for a total of 5.5 weeks.

The study of fundamental MEMS and NEMS theories is divided into various categories, such as solid mechanics, electrostatic actuation, fluid mechanics, piezoelectric actuation, capacitive sensing, and piezoresistive sensing [26- 28]. In this research work, the curriculum for the first portion of the course has been mapped out and constructed. The online theoretical classes that took place during the course of the first session consisted only of lecturing sessions and centered on the extraction of fundamental theoretical equations. In the course that is being taught online in the second half, visual simulation experiments have been incorporated. The same course is taken twice for the same set of students by theoretical and by using numerical simulations.

B. Pre- and Post-Evaluation

When a new method is implemented into education, everyone agrees that evaluation is crucial. This study utilized two sets of pre- and post-assessments as part of a controlled experiment to determine the effect of numerical simulation on the fundamental theory of learning. That's a straightforward approach to determining how students are doing in class. The students are given a static bending and dynamic vibration content pre-test at the beginning of the presentation. The post- test is administered once the first section of the course, solid mechanics, has been completed. The MOSFET principles, cantilever beams under concentrated end loading, cantilever beams under dispersed loading, comb-drive deflection, biosensor sensitivity, composite cantilever beam vibration, and piezoelectric pressure sensing are all covered in the pre- and post-tests. There are two questions for each topic. The maximum possible score on this exam is set for 50 marks.

***TABLE 1:** Pre - and post–evaluation results of students in the course*

S. No.	Pre-evaluation result Marks (out of 50)	Post evaluation result Marks (out of 50)
Student candidate 1	15	30
Student candidate 2	25	32
Student candidate 3	22	19
Student candidate 4	28	37
Student candidate 5	12	18
Student candidate 6	8	5
Student candidate 7	28	40
Student candidate 8	37	46

S. No.	Pre-evaluation result Marks (out of 50)	Post evaluation result Marks (out of 50)
Student candidate 9	45	48
Student candidate 10	5	18
Student candidate 11	17	23
Student candidate 12	22	30
Student candidate 13	27	32
Student candidate 14	48	50
Student candidate 15	26	28
Average Total	24.33	30.40

In the MEMS and NEMS courses, there were 15 students. The pre-and post-test findings are summarized in Table I. The average pre-test score was 24.33 during the first phase (pre-), while the average post-test score was 30.4. It illustrates how using numerical simulation experiments may significantly enhance learning outcomes overall. And the average score was virtually fantastic 30.4. This examination of instructional strategies is advantageous. It offers a potential method for creating online courses for the instruction of MEMS and NEMS core ideas.

V. CONCLUSIONS AND FUTURE RECOMMENDATIONS

Learning fundamental ideas, like microelectronics, MEMS, and NEMS theory, is widely seen as being laborious.

This work was focused on investigating a method to demonstrate the theoretical issues intuitively in an effort to alter this circumstance. Finite element simulation experiments are a useful place to start in MEMS design and theoretical research. This work discussed the MOSFET, cantilever beams, biosensors, comb drive, and piezoelectric devices in relation to micro-electronics, nanoelectronics, MEMS, NEMS and Bio-MEMS. The pre-and post-analytical assessment demonstrates that the integration of numerical simulation experiments might generate higher motivation in the student to acquire essential ideas when compared to solely oral lecture instruction.

It promotes more efficient learning of the core theories of Micro-Electronics, Nano-Electronics, MEMS, NEMS, and Bio-MEMS will be a potential style of instruction for the design of online courses. Microelectronics, MEMS, and NEMS are courses where project-based learning activities are utilized to help students grasp new concepts. The platform is heavily utilized throughout this course. There are now more chances for students and teachers to collaborate on research and professional development projects through classroom activities. Both students and teachers valued the classroom's individualized pace and the opportunity to fully engage with the material.

In the future, the courses have been modeled based on the availability of online resources, which is important for future development of technologies and it has been delivered to the students will create more impact on the learning and it will help for future technology improvement.

REFERENCES

[1] Cathy M. Toquero "Challenges and opportunities for higher education amid the covid-19 pandemic: The Philippine context," Pedagogical Research, vol. 5, no. 4, pp. 1-5, 2020.

[2] Rasheed M. Nassr, Abdulaziz Aborujilah, Danah A. Aldossary, and Alia A. A. Aldossary, "Understanding education difficulty during covid-19 lockdown: Reports on Malaysian university students' experience," IEEE Access, vol. 8, pp. 186939 – 186950, Oct. 2020.

[3] "UNESCO - COVID-19 educational disruption and response." Available at: https://en.unesco.org/covid19/educationresponse.

[4] Lincoln S. Peter and Viranjay M. Srivastava, "High speed and secured network connectivity for higher education institution using software define networks," 19th Int. Conf. of the Applied Stochastic Models and Data Analysis, Athens, Greece, 1-4 June 2021.

[5] Marcus L. George "Effective teaching and examination strategies for undergraduate learning during covid-19 school restrictions," J. of Educational Technology Systems, vol. 49, no. 1, pp. 23–48, Sept. 2020.

[6] A. Kolmos and E. De Graaff, "Problem-based and project-based learning in engineering education: merging models," Cambridge Hand Book on Engineering Education Research, vol. 24, pp. 141– 160, Jan 2015.

[7] Zofia K. Bishop, Thomas Howard, Panagiotis Lazari, Ben Taylor, Peter Trend, and Adam Funnell, "Student experiences of practical activities during the covid-19 pandemic," IEEE Global Engineering Education Conference (GEEC), Vienna, Austria, 21-23 April 2021, pp. 619-623.

[8] Shashi K. Dargar and Viranjay M. Srivastava, "Integration of ICT based methods in higher education teaching of electronic engineering," 10th Int. Conf. of Strategic Research on Scientific Studies and Education (ICOSRSSE), Rome, Italy, 17 – 18 June 2019.

[9] M. M. Larrondo Petrie, L. F. Zapata Rivera, C. Aranzazu Suescun, J. A. Sanchez Viloria, A. E. Molina Pena, and K. S. Santana, "Addressing the need for online engineering labs for developing countries," World Engineering Education Forum/Global Engineering Deans Council (WEEF&GEDC), Madrid, Spain, 15 – 18 Nov. 2021, pp. 387-396.

[10] Shivani Malhotra, Rubina Dutta, Amit K. Daminee, and Sagar Mahna "Paradigm shift in engineering education during covid 19: from chalkboards to talk boards," 12th Int. Conf. on Computational Intelligence and Communication Networks (CICN), India, 25-26 Sept. 2020 pp. 287-293.

[11] Viranjay M. Srivastava, "Learning for future education, research, and development through vision and supervision," Int. African Conf. on Current Studies of Science, Technology & Social Sciences (African Summit), South Africa, 6 – 7 July 2020, pp. 392-394.

[12] K. Wolff, D. Blaine, and C. Lewis, "A cumulative learning approach to developing the scholarship of teaching and learning in an engineering community of practice," World Engineering Education Forum/Global Engineering Deans Council (WEEF&GEDC), Madrid, Spain, 15 – 18 Nov. 2021, pp. 311-318.

[13] Shadnaz Asgari, Jelena Trajkovic, Mehran Rahmani, Wenlu Zhang, Roger C. Lo, and Antonella Sciortino "An observational study of engineering online education during the covid-19 pandemic," Plos One, vol. 16, no. 4, pp. 1-17, 2021.

[14] Robert L. Boylestad, Electronic devices and circuit theory, 11th Ed., Pearson India Educational Services, 2012.

[15] Viranjay M. Srivastava and Ghanshyam Singh, MOSFET technologies for double-pole four throw radio frequency switch, Springer International Publishing, Switzerland, 2014.

[16] S. S. Ahmed, S. R. Mehrotra, S. G. Kim, M. Mannino, G. Klimeck, D. Vasileska, X. Wang, H. Pal, and G. W. Budiman, "MOSFET," https://nanohub.org/resources/mosfet, 2017.

[17] Fengyuan Li, Brandon Patterson, Jason Clark, and yi zeng, "SUGARCube - Cantilever," https://nanohub.org/resources/sugar, 2014.

[18] S. Unadkat, D. Parkos, and A. Alexeenko, "Simulation of beam dynamics for MEMS devices," The Summer Undergraduate Research Fellowship (SURF) Symposium, paper 57.

[19] Pradeep R. Nair, Jonghyun Go, Graeme J. Landells, Tejas R. Pandit, Muhammad Alam, Xin Jin, Piyush Dak, and Ankit Jain, "BioSensorLab," 2014.

[20] P. R. Nair and M. A. Alam, "Performance limits of nanobiosensors," Applied Physics Letters, vol. 88, no. 23, pp. 1-3, June 2006.

[21] P. R. Nair and M. A. Alam, "Dimensionally frustrated diffusion towards fractal adsorbers," Physical Review Letters, vol. 99, no. 25, pp. 1-4, Dec 2007.

[22] Fengyuan Li, and Jason Clark, "Comb Drive levitation," https://nanohub.org/resources/cdlev, 2014.

[23] Fengyuan Li, and Jason Clark, " Improved modeling of the comb drive levitation effect by using schwartz-christoffel mapping," Sensors & Transducers Journal, vol. 139, no. 4, pp. 24-34, April 2012.

[24] Naveenbalaji Gowthaman and Viranjay M. Srivastava, "Mathematical modeling of electron density arrangement in CSDG MOSFET: A nanomaterial approach," J. of Material Science, vol. 57, no. 18, pp. 8381-8392, May 2022.

[25] J. M. Monsalve, G. F. Giraldo, A. G. Avila, and G. Klimeck, "MEMS piezoelectric vibrational energy harvesting lab," https://nanohub.org/resources/piezoharvest, 2014.

[26] Viranjay M. Srivastava, "Relevance of VEE programming for measurement of MOS device parameters," IEEE Int. Advance Computing Conference (IACC), Patiala, India, 6-7 March 2009, pp. 205-209.

[27] Viranjay M. Srivastava, K. S. Yadav, and G. Singh, "Drain current and noise model of cylindrical surrounding double-gate MOSFET for RF switch," Procedia Engineering, vol. 38, pp. 517-521, April 2012.

[28] Viranjay M. Srivastava, K. S. Yadav, and G. Singh, "Double pole four throw switch design with CMOS inverter," 5th IEEE Conf. on Wireless Communication and Sensor Networks (WCSN), Allahabad, India, 15-19 Dec. 2009, pp. 1-4.

Technical papers

Quality of doctoral education in South Africa: The perspective of doctoral students at a university of technology

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Abstract — **The aim of this paper is to test if the challenges in ensuring quality in a doctoral education are true for students enrolled for a doctoral degree in a University of Technology in South Africa. Doctoral students dependent on strong academic support from their institutions and employers to successfully complete their course. Established traditional universities in South Africa have the advantage of high income, low student ratios and permanent staff with doctorates which aid doctoral production. However, newly established Universities of Technology in South Africa are still building capacity to address these concerns. An exploratory study aided with quantitative analysis in the form of descriptive statistics is deployed among the registered doctoral students on the kind of support they get from their employers as well as their institutions. This paper showcases a thorough literature review on the topic and identified that there is very little research on the contributions of Universities of Technology with regards to doctoral student production. Key results from the study show that 75% of the students are registered for a part time study with 66% employed on a fulltime basis. Of this only 40% can meet their study tasks on time. Other key findings show that majority of students have access to courses conducted by the institution with respect to proposal writing, literature review and research methodology courses albeit it is not directly related to their field of study.**

Keywords — Post graduate studies, Quality of Doctoral education , Universities of Technology

I. INTRODUCTION

The Organization for Economic Co-operation and Development (OECD), as per a study in December 2019, states that on average only 1.1 percent [1] of the global population that has been to university have a PhD. The majority of these PhD holders are from the developed economies of the world. A further breakdown of the numbers shows that no African or Asian country features in the top 20 share of doctorate holders [1].

There has been a push from the developing economies of the world to produce more PhD graduates [2]. China has been leading this drive with up to 50000 doctorates across all disciplines in 2009. Africa, which for the most part last century focused on basic education [3], has also sensed the need to expand its higher education sector to produce more doctorate holders. This has resulted in massive investment in the higher education sector in Africa, most notably in South Africa.

However, recent studies show that these investments have not brought about the surge in doctoral throughputs as expected. The lack of academic and financial support coupled with an inexperienced faculty are impeding Africa's push to produce more PhD graduates [3]. The challenge is exacerbated by low staff-to-student ratios, poor access to internet and a mismatch between tertiary education and the job market.

The mismatch between the job market and tertiary education is not a phenomenon that is unique to Africa. Most Western countries are experiencing challenges in placing doctoral graduates in the private sector [2]. In a post Covid-19 job market, even China is struggling to create jobs for its doctoral graduates [4].

This research article focuses on the challenges faced by doctoral students in terms of academic support, employment and employability from a University of Technology (UoT) perspective in South Africa. The UoT perspective is critical here as, in comparison with the traditional and comprehensive universities in South Africa, the UoT's are relatively young and only recently started focusing on research. The primary mandate of UoT's is to offer technical training. This makes them vulnerable to some of the pitfalls discussed in the introduction.

The research article is structured such that initially a literature review is done with respect to the challenges faced by UoT's in producing a high throughput of doctoral graduates. Then, the methodology used in the study is stated followed by a discussion of the results of the study and recommendations for improving the current status. Eight-two students registered to do their doctorate at the Central University of Technology, Free State were considered the target population.

II. BACKGROUND

Doctoral education has proven to be the spine of innovation and creativity [5]. According to Shulman [6], a doctoral graduate understands what is known and what is yet unknown. For this reason, doctoral education defines the apex of the research capacity of a university [7] and seen as the primary source of building the knowledge economy of a country [8].

The role of high-level skills [9] in growing the knowledge economy of a country has been touted as the driving force behind increase in doctoral outputs globally. While this trend has seemingly peaked in the more developed economies of the world, there has been a steady and at times alarming increase [10] in the developing economies like China and India.

Africa has not been left behind in this drive to produce more doctoral graduates. South Africa, which accounts for a third of the research in Africa is seen as the pioneer in doctoral[11] education in Africa. The National Development Plan (NDP) has targeted to produce 5000 doctoral graduates per annum by 2030 [12].

However, Universities South Africa (USAf), a body which overlooks Higher Education in South Africa has termed this target as being over ambitious[13] in a report tabled in 2014. This is considering data that showed that only about 2000 doctoral graduates were produced across all disciplines in 2014. Challenges such as, but not limited to, funding, aging faculty, low throughputs, employability and poor academic structure plague the system.

This article focuses on a few of these challenges, namely academic support, employment and doctoral supervision from the perspective of a student registered to do their doctorate at a University of Technology in South Africa. As alluded to in the introduction, the UoT perspective is the fulcrum of this research as factors like research capacity, academic support and general student engagement vastly differs in a UoT setting. Therefore, it is paramount that the readers are exposed to university clusters in South Africa before delving into the challenges they face.

III. METHODOLOGY

An exploratory study aided with quantitative analysis in the form of descriptive statistics is conducted in this paper [14]. Exploratory studies [15] pave way the for future research and usually involves only a single group of respondents, in this case students who are registered to do their doctoral studies at a UoT is South Africa.

Descriptive statistics are used to interpret challenges faced by the registered doctoral students at a UoT in terms of academic support and the effects of employment on their study. Quantitative analysis of the collected data brings a methodical approach to a decision-making process and avoids qualitative factors that may make the decisions biased and less rational [16].

The questionnaire was prepared based on extensive literature conducted on the challenges faced by South African universities to meet the growing demands of producing doctoral graduates. It was tailored to focus specifically on the challenges faced by UoT's as the target population emanates from such an institution.

A total of 126 email addresses were obtained from the database. Of these 44-email addresses were later found to be incorrect or not in use by the students. This meant that target population was 82. A web-based survey using google forms was sent out to the target population.

The questionnaire was split into three parts as follows;

- Part A - Contained five general questions on the gender, nationality, age group, type of registration and faculty of study of the target population
- Part B – Contained five questions on the registration, employment and work-study balance of the target population.
- Part C – Contained five questions on the staff capacity and support that students get from the institution in terms of access to attend courses relevant to their study.

IV. RESULTS AND ANALYSIS

The Central University of Technology, Free State has four faculties as stated in the previous section. The Engineering faculty is made up of the Built Environment, Civil, Electrical, Information Technology and Mechanical Engineering departments. The Health and Environmental faculty comprise of Agriculture, Clinical Technology, Dental, Radiography and Somatology departments. The Humanities faculty hosts the departments of Design Art, Media studies and Teacher Education. The Management faculty is made up of the departments of Accounting, Business Management, Public Management, Hospitality and Tourism departments.

As part of the general survey, responses showed that 46% were from the Faculty of Engineering, while 24% were from Management Sciences. The Faculties of Humanities and Health each had 15% of the respondents. This is depicted in Figure 1.

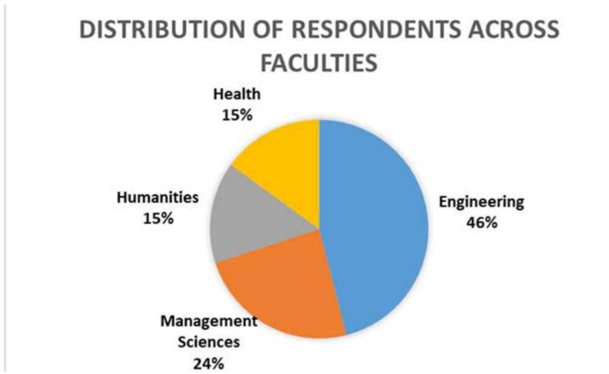

FIGURE 1: *Faculty distribution of respondents*

More than half of the respondents (52%) were South African nationals, while 30% were from the SADC region and 18% from the Rest of Africa. It is noteworthy to here that there were no students from outside Africa registered to do their study. With regards to the gender of the students, 61% of the respondents were male while 39% were female. Nationally, the number of female doctoral enrolments stood at 45% (Herman and Liezel, 2017).

The two factors which were portrayed as factors that may influence the efficiency of doctoral education were the nature of registration and age of candidates at the time of registration. It was seen that 75% of the students were registered to do their studies part time, 42% of the registered students were above the age of 40, while 12% were between 36-40. However, on a positive note, it was seen that 58% of the respondents were under the age 40. This is depicted in Figure 2.

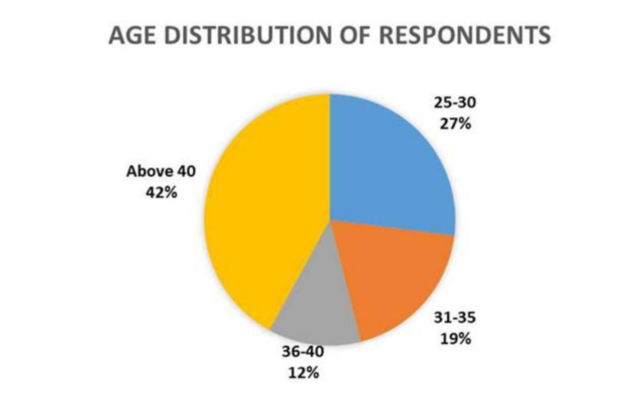

FIGURE 2: Age group of respondents

The ASSAf consensus report of 2010 (ASSAf, 2010) on how to meet the demands for high skills in an emerging economy show that the average age of doctoral graduates at the time of graduation in a UoT is 40. In this study it was unearthed that 58% of the doctoral students were under the age of 40 (see Figure 2). This finding bodes well as most students should graduate below that national average of 40. Furthermore only 3% of doctoral students were registered for more than 5 years and a majority of them registered for between 1 and 4 years.

The percentage of students registered to do their study part-time is generally quite high in South Africa. This element is corroborated in this study as well (see Figure 3) with three quarter of the students enrolled in this mode. The next part of the study analyses if this has had an impact on their work-study balance in terms of attending course related activities or deadlines.

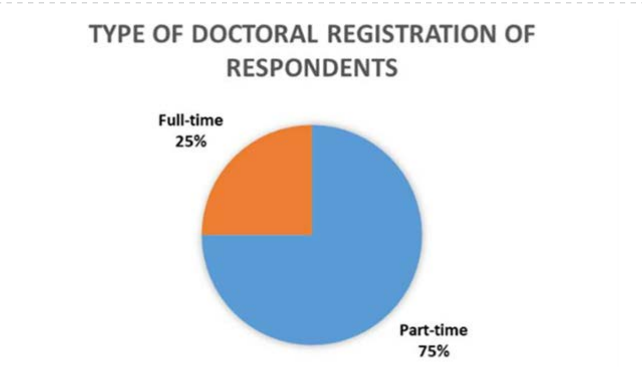

FIGURE 3: Type of registration of respondents

The second part of the survey focused on the challenges faced by doctoral students with respect to their registration and employment status. As depicted in Figure 3, 75% of the students are registered part time and the survey further showed that 66% of the doctoral students were employed on a full- time basis. This would mean that they were not on campus regularly. Out of these only 42% agreed that they were able to balance their academic and work responsibilities, while 46% were found to be struggling and 12% were neutral in their response. This is shown in Figure 4.

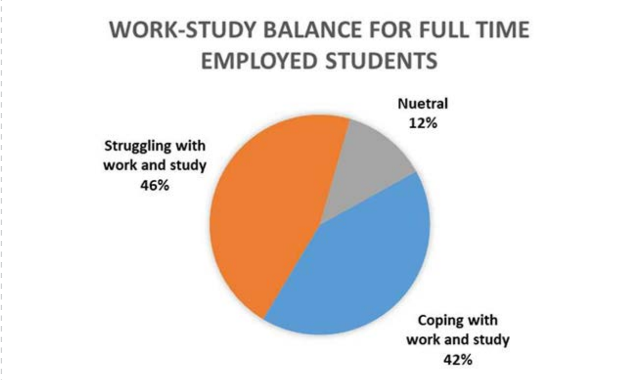

FIGURE 4: Work-study balance of full time employed students

In order to further test if being registered part-time or full-time employed had a negative impact on their study, the doctoral students were asked if they could attend seminars/ doctoral weeks/ conferences relevant to their study contrast, the majority (54%) of doctoral student concurred that they could attend these opportunities while 29% of these students found it difficult and 17% were neutral in their response. To corroborate this point two further questions were put to the students regarding how often the students met with their supervisors and how long it took to receive feedback on written work.

The survey showed the 31% of the students were able to meet their supervisors once in 2 weeks, while 25% were able to meet once a month and 28% were able to meet at least once a quarter. Similarly, 66% of students got feedback on written work within a week and 28% of the students got feed-back within a month. The results of these two questions further reinforced the fact that despite not being on campus, the doctoral students were able to get sufficient study support.

The third part of the survey focused on staff capacity and academic support in the form of access to courses to the doctoral students. Staff capacity is assessed by analysing factors such as the supervision record, supervisor expertise and experience. In terms of supervisor experience, it was established from the university statistics that almost 40% of the supervisors had between 0-5 years' experience supervising doctoral students. This is depicted in Figure 5.

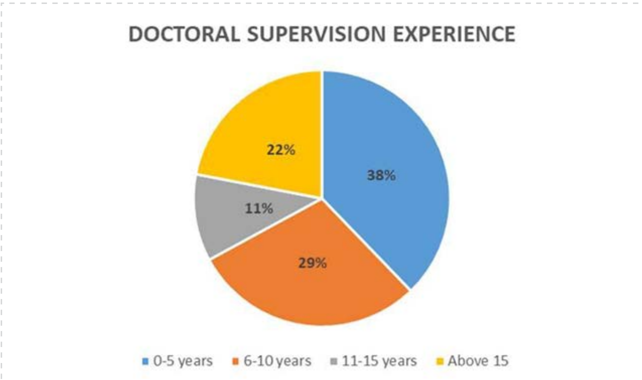

FIGURE 5. Doctoral supervisor experience in years

Among the doctoral students surveyed for this research, 60% considered their supervisor as being an expert in their field. However, it was seen that more than half (59%) of students were assigned study leaders by the faculty or head hunted by the supervisors themselves. It was also worth noting that less than only 20% of the students approached their supervisors for mentorship based on publications or projects done by their supervisors.

V. CONCLUSION

The aim of this research article was to test if the challenge of producing doctoral graduates was true for a University of Technology. This study was done because previous research shows that UoT's, which are clustered in the third tier, were always lagging the traditional and comprehensive universities in terms of research.

The article specifically focused on the challenges of ensuring quality in doctoral education. This was done by gathering the perspective of students enrolled to do their doctorate at a University of Technology. The perspectives of the doctoral students were then analysed quantitatively with descriptive statistics as part of an exploratory study.

The major findings of the study can be summarized as follows;

- There is an almost equal distribution between South African nationals (52%) and foreign nationals (48%) (SADC and Rest of Africa) when it comes to doctoral enrolments.
- 75% of the respondents are registered to do their studies part-time with 61% being male students.
- 46% of the respondents are under the age of 35.
- 66% of the respondents were employed on a full- time basis and 46% of these students were struggling to find a balance between work and study.
- 74% of all respondents were able to access preparatory level courses, where 53% chose to attend and 21% did not attend the courses.
- 13% of the respondents relied solely on their supervisors for these courses while 4% had no information about such courses being offered by the institution.
- 38% of staff members were relatively new to doctoral supervision
- 44% of students were assigned supervisors by the faculty

A comparison of the factors affecting the quality of a doctoral study, the current situation and the possible impact on doctoral production is done in Table 1

TABLE 1:

Factors affecting the quality of a doctoral study, the current situation and the possible impact on doctoral production		
Influencing Factor	**Current situation at CUT**	**Possible impact on doctoral production**
Age of doctoral students	58% registered student below 40	Lower than national average hence this has a positive impact on doctoral production.
Registration	75% students are registered to study part-time	Higher than the national average, but majority of students have access to courses hence aides positively on doctoral production
Employment	66% of registered students were employed on a full-time basis	On par with national average, but students still meet at regular intervals with supervisors, hence it aides positively on doctoral production.
Years of study	Only 3% of students are registered for more than 3 years	Much lower than national average, hence aides positively on producing doctoral students in under 5 years on average
Supervision experience	38% of staff member have less than 5 years supervision experience	Lower than national average, may have a negative impact on the quality of supervision

Based on the evidence gathered in this study and other similar studies [17] it can be assumed that UoT's have continued their growth sprout in terms of postgraduate research. In fact, the proportion of qualification offerings at blue cluster institutions (16%) is similar to green cluster institutions (17%). The rise in publication outputs from these clusters is also similar to blue cluster institutions rising by 132% while UoT's grew by 138% between 2009- 2017 (DHET, 2019).

However, challenges such as low supervision experience, poor supervisor selection criteria and relatively lower funding allocation still impede the number of doctoral graduations in the UoT's. The 2017 Research Outputs report by the Department of Higher Education and Training (DHET) shows that only 26% of UoT permanent staff members have doctoral degrees as opposed to the national average of 46%.

Based on the evidence gathered in this study and other similar studies, the following recommendations are proposed;

- Increase the number of full-time students by increasing the funding allocated for post graduate students especially in the form of monthly stipends.
- Doctoral supervision training programs must be made mandatory for all staff members that have completed their doctorate.
- Staff members should complete such programs while they are still in the early stages of post graduate supervision.
- Identify experts within departments or faculties who can provide tailor made preparatory level courses to students within that faculty. This will make these courses more relatable to the students and better understand the concepts.

REFERENCES

[1] "OECD work on careers of doctorate holders," 2019. [Online]. Available: https://www.oecd.org/innovation/inno/careers-of-doctorate-holders.htm.

[2] D. Cyranoski, N. Gilbert, H. Ledford, A. Nayar, and M. Yahia, "The phd factory," Nature, vol. 472, pp. 276–279, 2011, [Online]. Available: https://www.nature.com/news/2011/110420/full/472276a.html.

[3] I. Friesenhahn, "Making higher education work for Africa: Facts andfigures," SciDev, 2014. https://www.scidev.net/global/education/feature/higher- education-africa-facts-figures.html (accessed Oct. 25, 2020).

[4] Y. Xuemin, "China's college graduates find tough job market amid COVID-19," CGTN, Beijing, Aug. 17, 2020.

[5] B. Anderson, M. Cutright, and S. Anderson, "Academic Involvement in Doctoral Education: Predictive Value of Faculty Mentorship and Intellectual Community on Doctoral Education Outcomes," Int. J. Dr. Stud., vol. 8, pp. 195–215, 2013, doi: 10.28945/1923.

[6] L. Shulman, "Doctoral education shouldn't be a marathon.," Chronicle of Higher Education, 2010. https://www.chronicle.com/article/doctoral-education-shouldnt- be-a-marathon/ (accessed Oct. 25, 2020).

[7] A. Sverdlik, N. C. Hall, L. McAlpine, and K. Hubbard, "The PhD experience: A review of the factors influencing doctoral students' completion, achievement, and well-being," Int. J. Dr. Stud., vol. 13, pp. 361–388, 2018, doi: 10.28945/4113.

[8] S. Hancock, "A future in the knowledge economy? Analysing the career strategies of doctoral scientists through the principles of game theory," High. Educ., vol. 78, no. 1, pp. 33–49, 2019, [Online]. Available: https://link.springer.com/article/10.1007/s10734-018-0329- z#citeas.

[9] N. Cloete, J. Mouton, and C. Sheppard, Doctoral Education in South Africa – Policy, Discourse and Data, vol. 29. 2015.

[10] J. Louw and J. Muller, "A literature review on models of the PhD," Idea-Phd.Net, no. March, p. 34, 2014, [Online]. Available: https://www.idea-phd.net/images/doc- pdf/Louw_and_Muller_2014_Literature_Review_on_Models_of_the_PhD.pdf%0Ahttp://www.idea-phd.net/images/doc- pdf/Louw_and_Muller_2014_Literature_Review_on_Models_of_the_PhD.pdf%0Ahttp://chet.org.za/files/Louw and Muller 201.

[11] D. Teferra, "Manufacturing - and exporting - excellence and 'mediocrity': doctoral education in South Africa," South African J. High. Educ., vol. 29, no. 5, pp. 8–19, 2015, [Online]. Available: https://journals.co.za/content/high/29/5/EJC182521.

[12] C. N. Planning, "National Development Plan – 2030 Vision," 2011. http://www.gov.za/sites/www.gov.za/files/devplan_2.pdf (accessed Oct. 25, 2020).

[13] HESA, "South African Higher Education in the 20th Century," 2014. https://static.pmg.org.za/140305hesa.pdf.

[14] R. B. Kuriakose and A. J. Swart, "South African student perceptions of practical laboratory work - A case study from digital systems 1," in Proceedings - Frontiers in Education Conference, FIE, 2015, vol. 2014, doi: 10.1109/FIE.2015.7344371.

[15] M. Jara and H. Mellar, "Quality enhancement for e-learning courses: The role of student feedback," Comput. Educ., vol. 54, no. 3, pp. 709–714, 2010, doi: 10.1016/j.compedu.2009.10.016.

[16] R. Reddy, W, Higgins, D,Wakefield, "An investigation of property-related decision practice of Australian fund managers," J. Prop. Invest. Financ., vol. 32, pp. 282–305, 2014.

[17] R. Subbaye, "Differentiating' the size and shape of Universities of Technology in South Africa," in Southern African Association of Institutional Research, 2018, no. November, doi: 10.13140/RG.2.2.15616.89604.

Technical papers

Data driven strategies for enhancing student success

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***Abstract* — This paper demonstrates data-driven interventions and their impacts on student success. In particular, the relative contributions of instructor changes with associated course delivery changes, and tutoring/mentoring help in learning communities, are assessed. The results suggest that instructor change is a major parameter, and the contributions of tutoring programs are largely governed by the instructor's use of these programs in a strategic manner to help students where help is most needed. Additionally, course sequencing changes are also demonstrated using the Curricular Analytics software program. The addition of an engineering mathematics course to reduce the complexity associated with two Calculus courses is provided as an example. Even slight changes in the curricular complexity scores might result in significant improvements in students' ability to navigate through their curricular flow charts.**

Keywords— Data Driven Strategies, Drop/Fail Rates, Curricular Analytics, Learning Communities, Student Success

I. INTRODUCTION

In February 2014, the National Center for Education Statistics projected an increase of 14% in postsecondary degree-granting institutions enrollment from Fall 2011 to Fall 2022, which would have resulted in 23.888 million students enrolled in all post-secondary degree-granting U.S. institutions [1]. In June 2022, The National Student Clearinghouse Research Center reported (NSCRC) an enrollment of 16.17 million for the Spring 2022 semester [2]. The Education Data Initiative (EDI) provides a graph of college enrollment where until fall 2019, the total enrollment peaked in 2010 and deceased slightly from 20 million to 19.6 million in 4 years [3]. While there are some differences in the total counts between the NSCRC and the Education Data Initiative, they both note that the COVID years of 2020-2022 has seen a dramatic drop in total enrollment due to significant declines in undergraduate enrollment. Both NSCRC and EDI show increasing graduate enrollment over the past 5 years. The NSCRC report an increase in graduate enrollment of 3.5% between 2020 – 2022, but in stark contrast, undergraduate enrollments have decreased by over 9% during this period. Clearly, the impact on planning for U.S. Higher Education has been altered severely based on a gap of 16% fewer students than what was predicted a decade ago. This gap is largely due to a lack of enrollment at the undergraduate level due to the direct impact of the pandemic and the public perception of higher education as a result of the pandemic.

At present, there are several efforts to fully understand how best to transform U.S. higher education to meet the needs and challenges including those posed by the recent COVID-19 crisis. A recently published study by Sharaievska and colleagues provides an overall summary of experiences from students at 7 universities [4]. The authors highlight the "messy transitions" marking the first few months of online learning that created disruptions as well as the ongoing challenges due to changes in higher education institutions in response to budgetary and staffing decreases. Our study of student persistence in engineering is well aligned with their recommendation that students are in need of more personalized instruction and a greater connectivity to peers, instructors, and support services. Intuitively, during the emergence from the pandemic in the coming months, learning communities and greater attention to individual student mastery of concepts are good strategies to move forward.

The College of Engineering at New Mexico State University is historically known for its student-centric focus. There was a renewed focus to design strategic interventions in the recent years to improve student success. Three strategies are highlighted in this paper – instructor changes in transition and key courses, establishment of learning communities, and course sequencing changes. While student training through traditional classroom modes has always been the major emphasis, the college established in 2018, a learning communities concept designed to help students with academic and non-academic help outside the classroom hours. This help was based on students need, ex. tutoring in difficult/transition courses, identifying scholarship opportunities, and career path advice. The effectiveness of the learning communities and instructor changes is measured using student performance in terms of D/F/W (Drop/Fail/Withdrawal) grades. In addition, Curricular Analytics has proven to be a useful tool in data-based intervention related to course sequence changes. It allowed a close examination of the efficiencies in curricular design and identification of changes necessary to enhance student success. The effectiveness of this intervention is measured using metrics such as blocking factors to be described in a subsequent section. The Covid-19 crisis has accentuated the need to assess the relative contributions of these interventions.

II. INTERVENTION INITIATIVES

The learning communities and course-sequence changes are the two major interventions that need additional description before discussing metrics used for their effectiveness.

A. Eloy Torrez Family Learning Communities

The Eloy Torrez Family Engineering Learning Communities (ETFLC) was made possible through a generous donation from the Eloy Torrez family. The 7,921 square foot suite has 15 study rooms, 2 conference rooms, three classrooms, a computer lab, a small kitchen, and large open spaces for students' team discussions. Each study room is equipped with a large whiteboard, tables and chairs, and a desktop computer, making them the perfect place for students to work independently, or in small groups.

The Learning Center employees 22 peer learning facilitators, who provide tutoring, free of charge, and on a walk-in basis for math, science, and core engineering courses. The ETFLC manager works closely with engineering faculty to host timely exam review sessions. Students may attend these sessions either face-to-face, or online via zoom. The live sessions are recorded, and the zoom link is provided to all students enrolled in the course for viewing after the session is over. Students may also request tutoring sessions by appointment or online.

The Learning Communities has ample space for engineering student organizations to hold meetings, store supplies for events, and recruit new student members. Capstone teams also find the space to be useful to work on their group projects or meet with their industry clients. Career planning resources are also available and industry representative are invited frequently to facilitate training for resume-writing and job interviews.

The faculty and staff associated with the ETFLC are committed to providing engineering students with a supportive learning environment that will improve academic success, raise retention rates, and create a cohesive student community.

B. Curricular Analytics

The Curricular Analytics is an intervention tool to make decisions on course sequencing changes and the effectiveness of these changes. Curricular analytics allows quantification of the complexity of curricula, simulate student progress under various scenarios, and create degree plans that maximize the chances of students completing their degrees on time. It facilitates:

- Identification of bottlenecks and key courses in curricula
- Data-informed curriculum reform/revision efforts
- Program review and peer institution comparisons
- Personalization of degree plans, optimized for individual students
- Creation of 2-to-4-year articulation pathways [5].

III. METRICS AND MEASUREMENTS

A. D/F/W

The College collected a comprehensive set of data on D (Drop) and F (Fail), W (Withdrawal) rates for engineering courses. The efficiency of the intervention programs for various courses during different semesters is evaluated using D+F percentage data.

B. Metrics to measure Cirricular Analytics

The metrics described below are used to compute the overall complexity of curricula and degree plans, largely based on the flow chart and structure of a curriculum.

1) ***Blocking Factor:*** The blocking factor measures the extent to which one course blocks the ability to take other courses in the curriculum. That is, a course with a high blocking factor acts as a gateway to many other courses in the curriculum. Students who are unable to pass the gateway course will be blocked from taking many other courses in the curriculum.

2) ***Delay Factor:*** Many curricula, particularly those in science, technology engineering and math (STEM) fields, contain a set of courses that must be completed in sequential order. The ability to successfully navigate these long pathways without delay is critical for student success and on-time graduation. If any course on the pathway is not completed on time, the student will then be delayed in completing the entire pathway by one term. The delay factor metric allows us to quantity this effect.

3) ***Centrality:*** A course can be thought of as being central to a curriculum if it requires a number of foundational courses as prerequisites, and the course itself serves as a prerequisite to many additional discipline-specific courses in the curriculum. The centrality metric is meant to capture this notion.

4) ***Structural Complexity:*** The curricular complexity of a course is meant to capture the impact of curricular structure on student progression. Through experimentation, it has been found that a simple linear combination of the delay and blocking factors described above provides a good measure for quantifying the structural complexity of a curriculum. Specifically, there is a high correlation between increased structural complexity and decreased graduation rates.

Quantification of these factors to characterize curricular complexity is described at Curricular Analytics website [5].

IV. RESEARCH QUESTIONS

The purpose of this paper is to measure the effectiveness of the strategic interventions described above. Central questions of interest in this study are:

- To what extent are the intervention programs, instructor changes and learning communities in particular, impacting student performance as measured by the D (Drop) and F (Fail) rates?
- How can the curricular complexity score be used to make impactful changes in course sequencing?

V. RESULTS AND DISCUSSION

The data allowed a quick assessment of the effect of COVID-19. In general, Covid-19 is expected to negatively impact the D+F rate percentages primarily due to three main causes. First, there were students who had to make major adjustments in how they conducted their studies as they struggled to find a quiet location with good internet connectivity to attend lectures and complete assignments. Students reported that siblings and their family also relied on internet access, which greatly reduced their ability to have adequate internet connection. The college experienced restrictions that varied from no campus access to limited access using hybrid instruction, and students who did not plan to take classes online had many logistical challenges throughout these changes. Second, faculty members had to adapt a variety of course delivery formats, which are often changed with short notice to provide mitigation needed to protect health and slow the rate of infection. Faculty needed to split their attention during hybrid instruction causing less efficient transfer of information and less interaction with students. Third, the emotional and health toll on students, their families, as well as for faculty and their families created stresses that impeded learning and quality instruction.

Table 1 illustrates courses with D+F percentages and average enrollment for four different courses in Fall 2019 and Fall 2020. Due to Covid-19, the mode of course delivery changed from in- person in Fall 2019 to online or hybrid in Fall 2020. For all of these courses in Fall 2019 and Fall 2020, the instructor remained unchanged.

The data in Table 1 suggests that D+F (%) increased for two of the courses and decreased for two other courses in Fall 2020. There is no significant impact of Covid-19 and the associated changes in mode of course delivery on the D+F percentages. None of the students in these courses sought help from the ETFLC implying that the instructors' have made successful adjustments in course delivery modes and/or the students responded to Covid challenges effectively.

TABLE 1: *Covid-19's impact on the percentage of drop and fail rate*

Course		IE 311	CE 382	IE 351	ME 340
D+F (%)	Fall 2019	34.48	4.76	14.81	13.04
	Fall 2020	9.52	22.22	36.36	4.08
Average Course Enrollment		20	25	20	50

A. Eloy Torrez Family Learning Communities

The Eloy Torrez Family Learning Communities (ETFLC) is a program designed to give an outside-the-classroom opportunity for students to seek help with specific course content. Along with the D(Drop) and F (Fail) rates, the College monitored the number of students seeking help from ETFLC, where students get tutored by peer learning facilitators (PLF). Table 2 shows the number of students who sought help from ETFLC, the average enrollments in four foundational courses, and the D+F rates in these courses. The instructor remained unchanged for each of these courses through the three Fall semesters in 2019, 2020 and 2021.

In general tutoring was expected to impact D+F rates positively. The data in Table II suggests that this is not necessarily true. Upon further analysis (as discussed in the section below), the lower D+F rates are best achieved when ETFLC works in conjunction with the instructor such that they strategically guide the peer-learning facilitators of the ELC in their specific courses.

B. Instructor Changes

Table 3 demonstrates the data for courses with instructor changes along with the ETFLC head count for four courses. The data clearly shows that instructor change played the largest and most consistent role in student success. In courses such as ME 240, the instructors and PLFs might be strategically orienting their tutoring help in the modules of importance to students. In other courses, any changes in D+F rates, either positive or negative, are the result of instructors' individual commitment to student success, and the ETFLC played only a secondary role.

Based on all these circumstances, lower D+F rate percentages in foundational courses can be best achieved by selection of senior instructors with proven record and strategic deployment of ETFLC resources with teams of PLFs and instructors working together.

TABLE 2: *ETFLC'S effect on the drop and fail rate percentage*

Course		IE 311	ME 210	ME 328	ME 340
ETFLC student head count	Fall 2019	1	12	23	1
	Fall 2020	0	0	3	0
	Fall 2021	1	3	25	3
D+F (%)	Fall 2019	34.48	1.69	25.00	13.04
	Fall 2020	9.25	9.09	37.14	4.08
	Fall 2021	13.33	3.52	12.15	4.17
Average Course Enrollment		20	60	75	50

TABLE 3: *Influence of instructor changes on drop and fail rate percentages*

Course		EE 340	ME 228	ME 240	ME 338
ETFLC Student head count	Fall 2019	0	9	17	0
	Fall 2020	0	12	0	1
	Fall 2021	1	9	3	2
Instructors change years		Fall 2020	Fall 2020, 2021	Fall 2020, 2021	Fall 2021
D+F (%)	Fall 2019	4.17	20.41	32.31	17.24
	Fall 2020	22.22	33.33	11.48	0.00
	Fall 2021	16.28	15.38	3.08	12.12
Average Course Enrollment		20	50	60	20

C. Curricular Complexity

Many engineering courses require Calculus 1 (MATH 1511G) or Calculus 2 (MATH 1521G) as prerequisite courses. As can be seen in the BSME curriculum “Figure 1”, all but one course in Term 3 (first year sophomore level student) requires Calculus 2 (MATH 1521G) as a prerequisite. Program curricula for other engineering majors have similar calculus requirements for their courses. If a student fails Calculus 1 or Calculus 2 during their first year, it is not possible for them to progress in the curriculum resulting in a delay in the time to graduate from one to two semesters depending on the frequency courses being offered. At New Mexico State University, Calculus 1 has the second highest number of course attempts and Calculus 2 is sixth. The overall DF plus withdrawal (DFW) rate for engineering students in the Calculus 1 and 2 sequence is around 24 percent. On the other hand, the overall DFW rate for the statics and dynamics sequence, which is a common course sequence for engineering students, is around 12 percent.

From Fall 2017 to Spring 2021 the college of engineering lost 1,642 students. Students either dropped out of the university or switched to a non-engineering major. College algebra, pre- calculus, Calculus 1, and Calculus 2 are four of the top 7 courses students were enrolled in at the time they left engineering. The DFW rate for students in Calculus 1 was 78% and for Calculus 2 was 73 percent. These are very high, and they result in students not being able to progress in the curriculum and leaving the college and/or university.

To address these issues, the college of engineering developed an Introduction to Engineering Mathematics (ENGR 190) course. In the development of this course, the relevant concepts are pulled from Calculus 1 and 2, which are needed in the engineering courses that have calculus as a prerequisite. These topics became the foundation of the engineering mathematics course and the prerequisites for the engineering courses were changed to calculus or engineering mathematics. The prerequisite for the engineering mathematics course was the same as calculus 1 (i.e., precalculus) and was taught with an applications perspective and an accompanying laboratory component to reinforce the material covered in lecture. This new course would allow students to progress in the curriculum, give more time to complete Calculus 1 and 2 requirements, improve success in Calculus 1 and 2, and reduce degree complexity. “Figure 2”, shows the resulting degree complexity when the engineering mathematics course is added to the curriculum.

A comparison of the curricular complexities shows there is a small reduction in the curricular complexity from 240 – 237 “Figure 1, Figure 2”. The Calculus 1 and 2 sequence is on a separate path which allows students to progress in the curriculum. “Figure 3, Figure 4”, take a more detailed look at the metrics associated with Calculus 1 and 2 before and after the addition of the engineering mathematics course as well as the metrics associated with the engineering math course.

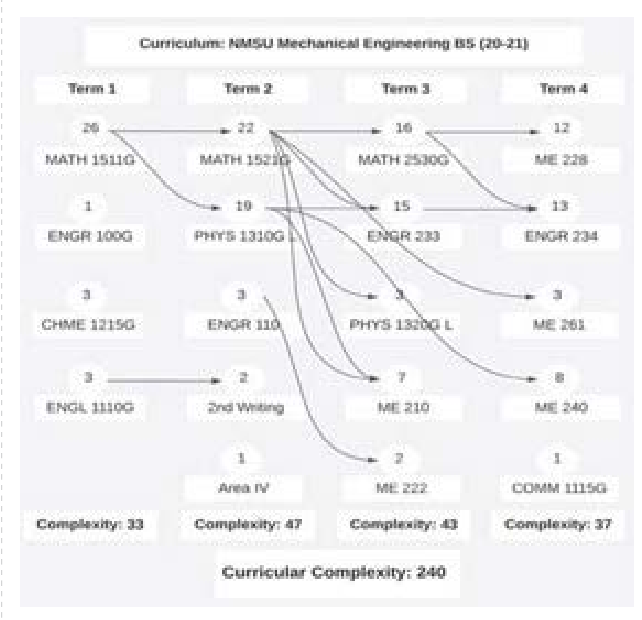

FIGURE 1: *Curricular Complexity of BSME Curriculum before ENGR 190*

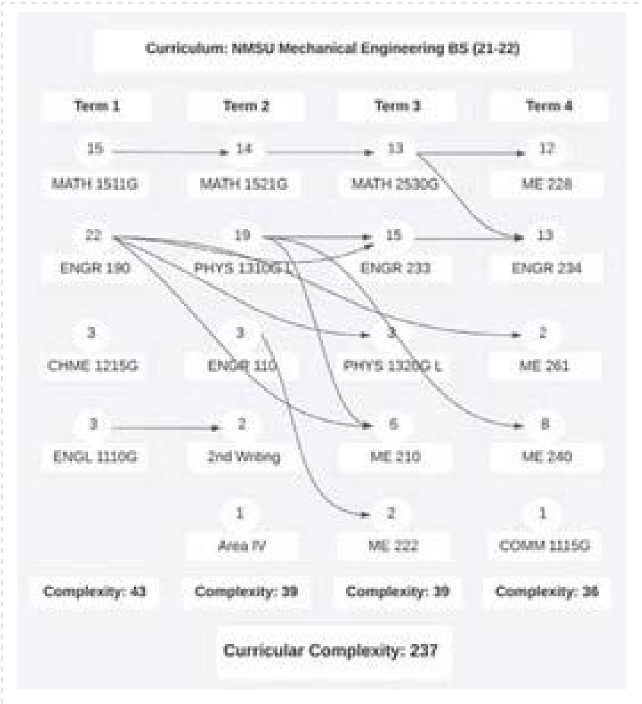

FIGURE 2: *Curricular Complexity of BSME Curriculum after ENGR 190*

FIGURE 3: *Change in Complexities after adding ENGR 190 course*

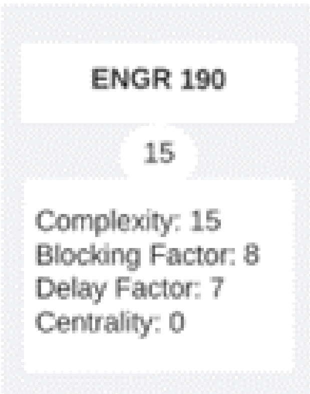

FIGURE 4: *Engineering Mathematics 190 Complexity Scores*

VI. CONCLUSIONS

Interventions outside classroom designed to impact student success can be measured using either D/F/W. The learning communities initiative and instructor changes in key courses have measurable impact on student performance. Based on the data, improved student performance in foundational courses can be best achieved not only by selection of senior instructors with proven record but also by strategic deployment of learning communities outside the classroom with instructors and tutors working together. The data also show curricular complexity analyses are useful to improve student success by reducing the number of bottlenecks in curricular flow charts. An example of an engineering-specific mathematics course added early in the flow chart demonstrated how the curricular complexity, blocking factor, and delay factor could all be improved.

REFERENCES

[1] Hussar, W.J., and Bailey, T.M. (2013). Projections of Education Statistics to 2022 (NCES 2014-051). U.S. Department of Education, National Center for Education Statistics. Washington, DC: U.S. Government Printing Office.

[2] National Student Clearinghouse Research Center, Overview: Spring 2022 Enrollment Estimates, found on the internet at https://pubproof.nscresearchcenter.org/current-term-enrollment- estimates/ctee_report_spring_2022/

[3] Hanson, Melanie. "College Enrollment & Student Demographic Statistics" EducationData.org, July 26, 2022, https://educationdata.org/college-enrollment-statistics

[4] Sharaievska, I., McAnirlin, O., Browning, M.H.E.M. et al. "Messy transitions": Students' perspectives on the impacts of the COVID-19 pandemic on higher education. High Educ (2022). https://doi.org/10.1007/s10734-022-00843-7

[5] Curricularanalytics.org. 2022. Curricular Analytics. [online] Available at: <https://www.curricularanalytics.org/> [Accessed 28 July 2022].

Technical papers

Latent factors for consistently predicting student success

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Abstract — **Developing Machine Learning models to predict the likelihood of a student's graduation has received significant interest in recent times. One clear application is to identify students most in need of support before actual failure occurs. There is a growing concern, however, about the range of applicability of such models. Machine Learning models are often limited by the consistency of their performance across years or even by programme in other words, although a model may be developed for a given course/module in a given year, the model accuracy tends to degrade when small differences occur in the time or field of study. In this study, the focus is on the identification of so-called Latent Factors, which are more fundamental characteristics derived from the student and field of study meta-data. Basing Machine Learning models on these more fundamental characteristics tends to produce models which, although reduces in accuracy, tend to preserve the prediction capacity over a broader period of time and scale of study area. The study investigates latent factors that include a student's "credit load capacity", level of activity in accessing course material (LMS access frequency), overall performance (measured as mean marks), the rate of change of performance (measured as the rate of change of mean) and consistency (measured as standard deviation). In addition, the modelling also considers the matric mean score of the students undertaking the coursework, historical consistency with peer modules (given by the Pearson R-Coefficient), course position in curriculum (given by the academic year of study when undertaken by students) and the mean number of attempts required to pass the course. It is shown that when these characteristics are integrated into a Machine Learning framework, the accuracy improves on the order of 24%**

Keywords — Machine Learning, Latent Factors, Student success

I. INTRODUCTION

Students' success has recently become a primary strategic objective for most institutions of higher education. With budget cuts and ever-increasing operational costs, academic institutions are paying more attention to sustaining students' enrolment in their programs without compromising rigor and quality of education. With the scientific advancements in Big Data Analytics and Machine Learning (the 4IR environment), universities are increasingly relying on data to predict students' performance.

Unlike past practices that concentrated more on historical trends and pattern recognition, many recent initiatives and research projects addresses the use of students' behavioural and academic data to classify students in order to predict their future performance using advanced statistics and Machine Learning [1]. This is further substantiated in the work presented by [12], wherein they sought to improve the predictive performance of their regression algorithms and concluded that hyper-parameter tunings improve predictive performance.

Educational data mining is becoming mainstream research for identifying approaches to improve the current standards of our educational systems. There are two main categories of educational data mining currently being pursued: one focusing on school education and the other on university education. Against a backdrop of a shrinking subsidy pool, Higher education administrators and policymakers continue to push for increased graduation rates to secure subsidy, while students and academics contend with ever-increasing class sizes and student dropout rates.

Further to this is the ever-increasing pressure to meet 1st time student enrolment targets, the push for qualifications that relevant to improve student absorption into the labour market, and to attract and retain top-tier faculty staff. All of these, converging and complicating the institutional ability to make intelligent investments decisions so that a justifiable return on investment (ROI) can be achieved.

The ability to innovate and lead in this environment requires finding approaches that improves assessments, feedback and student success while addressing the challenges of an increasingly virtual and dynamic student population.

Education Data Mining also known as EDM is an emerging field of research aimed at devising and using algorithms to explain educational strategies for further decision making. According to [2], the authors describe the process as mutating the traditional learning environment into a community-based learning environment.

Basing Machine Learning models on these more fundamental characteristics tends to produce models which, although reduces in accuracy, tend to preserve the prediction capacity over a broader period of time and scale of study area.

In this study, the focus is on the identification and use of Latent Factors, which are more fundamental characteristics derived from the student and field of study meta-data. According to [13] latent factor models are widely used and successful techniques for rating predictions. Latent factors are inferred from the patterns in the student data.

In this paper, the authors firstly investigate the "Credit Load Capacity" latent factor, which is a Poisson distribution of a student's performance with respect to credit load. Although it is commonly understood that credit overload reduces performance, there is little appreciation that credit "underload" may reduce a student's study momentum and the capacity to comprehend the broader concepts underpinning an academic programme.

Other latent factors are related to the student's level of activity in accessing course materials (measured as LMS access frequency), the overall performance (measured as mean marks), the rate of change of performance (measured as rate of change of mean) and consistency (standard deviation).

Course/module latent factors include matric mean score of students undertaking the coursework, historical consistency with peer modules (given by the Pearson R-coefficient), course position in curriculum (given by academic year of study when undertaken by students) and the mean number of attempts required to pass the course.

II. BACKGROUND

Data-driven predictions and adaptive feedback are becoming a cornerstone research in educational data analytics and involve developing methods for exploring the unique types of data that come from the educational context. [10] For example, predicting college student performance is crucial for both the students and educational institutions. It can support timely intervention to prevent students from failing a course, increasing efficacy of advising functions, and improving overall graduation rates. As discussed in [3], the authors firstly identified the data features useful for assessments and predicting student outcomes such as students' scores in homework assignments, quizzes, exams, in addition to their activities in discussion forums and their total Grade Point Average (GPA). Secondly, time series models in both frequency and time domains were applied to characterize the progression as well as the overall grade projections. In particular, the model analysed the stability as well as fluctuation of grades among students during the collegiate years (from freshman to senior) and disciplines.

Thirdly, Logistic Regression and Neural Network predictive models were used to identify students as early as possible who are in danger of failing the course that they were currently enrolled in. These models computed the likelihood of any student failing (or passing) the current course. The time series analysis indicate that assessments and continuous feedback are critical for freshman and sophomores (even with easy courses) than for seniors, and those assessments may be provided using the predictive models.

Numerical results are presented to evaluate and compare the performance of the developed models and their predictive accuracy. These methods allow us to discover new, interesting and useful knowledge based on student's usage data. Furthermore, universities started applying data mining and predictive analytics to data to identify various measures of performance. [4] analysed data from the University of Phoenix, the largest online campus in the U.S. to develop and validate the utility of a logistics model to provide timely, valuable information to academic advisers.

III. METHODOLOGY

In order undertake the study, quantitative data was obtained from the institutional Management Information System (MIS data) and the data processed through the Autoscholar software. In order to assess the machine learning method, we establish the basis of the model development.
In this case, a Population Balance framework was chosen due to its capacity to integrate distributions in student characteristics.

A. Population Balance Framework

In order to assess the machine learning method, we establish the basis of the model development. In this case, a Population Balance framework is chosen due to its capacity to integrate distributions in student characteristics. Data for the modeling was obtained from the institutional Management Information System and processed through the Autoscholar software.

Given a population bearing characteristics α (where α is generally a vector of characteristics e.g., height, weight, intelligence level) we seek to determine the unsteady property distribution given by 1.

$$1 = 1(t, a) \tag{1}$$

The distribution is influenced by birth and death of population members, and by the properties inherent rate of change at the individual population member level:

$$\frac{aa}{at} = f(t, a) \tag{2}$$

Individuals may enter or leave the population which is modelled as birth and death rate density function B and D. The population balance equation then applies [5][6].

$$\frac{d\psi}{dt} = \frac{\partial}{\partial\alpha}\left(\frac{\partial\alpha}{\partial t}.\psi\right) + B(\alpha,\psi) - D(\alpha,\psi) \tag{3}$$

In application to the problem of modelling student progress, α includes the student academic programme residence time (number of semesters registered for a programme) and the number of credits passed. The birth rate is the rate of registration in the programme and rate of death are the graduation, exclusion and dropout rates.

It is generally important to maintain the distinction between graduation and the other two death rates, but in this development, we focus on the progression rate, defined as the rate of credit accumulation.

We restrict attention in this paper to relatively simple academic programmes having 1 entry point (B), 1 intended exit point, multiple unintended (D) and multiple recycles. Other modifications may include the programme entries with credit transfers from other programmes or even other institutions.

In this study, we seek to develop a model which may predict such a depiction when given the student characteristic distributions estimated from the entrance/admissions data.

IV. MODEL APPLICATION

A. Monitoring and Evaluation Frameworks

When developing Improvement Science-type Monitoring and Evaluation frameworks, key components include determining the cause of outlier performance metrics, e.g., low graduation rates, and well as estimating the outcomes of applying particular interventions, e.g., change in the graduation rate in response to modifying the timetable structure. The population balance may facilitate such determinations.

Some case studies in this light are presented via results obtained from the AutoScholar Advisor system. Results obtained include the identification of under-performing academic programmes across the entire academic institution. The system ranks the programmes according to the number of fail events and presents a list of programmes according to the number of failure events in descending order. By clicking onto an academic programme, the system would also show under- performance in courses taken by students in these programmes.

The implication is that by applying the number of failure events as a critical metric of Monitoring and Evaluation, it becomes possible to identify the location of under-performance and hence re-direct Teaching and Learning resources to ameliorate the performance.

This is then cascaded to the level of the academic programme's performance via. the Cohort Tracker view of the AutoScholar. Figure 1 reveals that in the academic programme reviewed, only 10% of students graduated in the minimum time (4 years); 25% graduated in minimum time + 1 year (5 years), and 2% in min-time + 2 years (6 years). Overall, slightly more than 40% ever graduated and less than 10% transferred to other programmes in the institution. An estimated 50% of the initial cohort dropped out and never graduated.

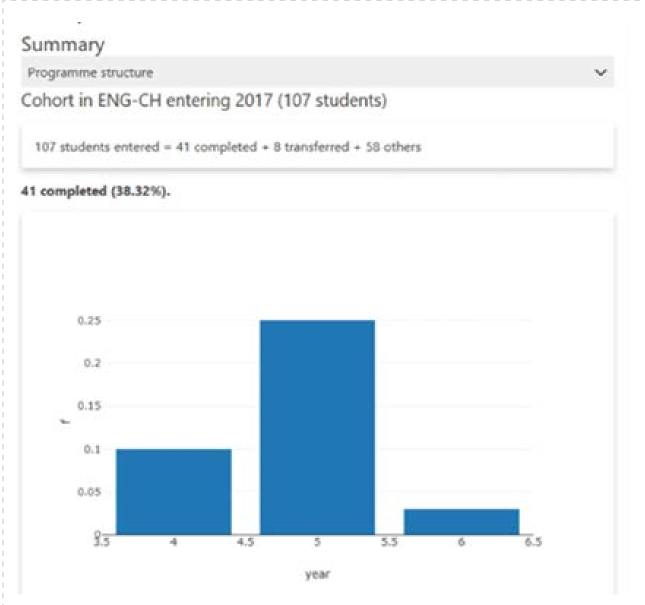

FIGURE 1: Cohort time to graduation

This analysis can be further cascaded to the coursework level given with Figure 2. In this view taken from the Autoscholar software, the system is examining the performance in each academic programme's coursework, and searching for the following issues:

a) Core courses occurring early in the programme with low pass rates – if these courses serve as pre-requisites, they pose significant progression barriers as gatekeepers.
b) Courses requiring multiple attempts before being passed.
c) Courses being attempted for the first time much later than intended in the curriculum design possibly due to pre-requisite problems from gatekeepers.

While this approach is originally intended merely to identify the regions in need of intervention and does also begin to support determining the actual reasons. Are there programme structural issues at play, is coursework management an issue, is the placement of coursework in the timetable a potential source of under-performance?

FIGURE 2: Programme coursework analysis

Now that these courses are identified, it becomes possible to map the associated variables against the performance ranking to reveal potential causes and hence derivate interventions and solutions.

Potential interventions include

1. Require student at-risk identification & messaging in high- risk modules
2. Review course placement in high-risk courses in view of semester credit loads
3. Students to engage with support and study activities until status returns to normal.

B. Student Advising

To promote the motivation of students to improve performance levels, it is possible to auto-generate advice in the light of the class of graduation that a student is on track to achieve with the view to improving this class of pass. If the "class of pass" is determined by overall Credit Weighted Average (CWA), then it is possible for a student to improve the class of pass by raising the CWA in future semesters.

The class of pass report generated by the AutoScholar is shown in Figure 3. In addition to reporting the class of pass the student is currently on track to graduate with, the system also specifies the CWA required to achieve a higher level of pass.

This report is made available to staff reviewing a whole academic programme as well as students through the student component of the Autoscholar Advisor module. In this report, the system also specifies the CWA required in the remaining credits.

However, it further reviews the courses the student has currently registered for together with the assessments already completed in those courses. It then calculates the results required in the upcoming assessments in order to maintain the CWA needed to achieve a higher class of pass.

Furthermore, integrated into the same interface is a link ("Improve my results") for the student to self-evaluate and self-identify the causes of non-performance and hence undertake activities aimed at improving results or engaging with academic or student support services (Figure 3).

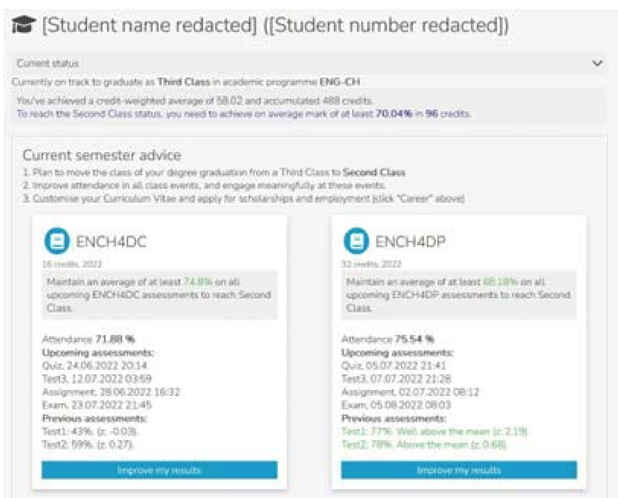

FIGURE 3: Class of degree and semester advice

V. APPLICATION OF LATENT FACTORS

Now that it is clear there are useful applications of a model which can be applied for predictive purposes, the interest shifts to the development of models whose predictive capacity is maintained over reasonably long period. Although it is possible to produce a Machine Learning model which determines the required rates to solve a Population Balance, the predictive capacity is often limited to the data over which it is trained. With the passing of each semester and particular in the face of new interventions aimed at improving student success, it is often the case that the models lose predictive capacity through low accuracy. The cause of accuracy loss is that such models are trained typically on simple correlations amongst the courses in an academic programme. More specifically, the course results may be cross correlated to yield models which appear to be predictive. It is proposed here that instead of this approach, the course results data be used to infer characteristics about the students and about the coursework instead. The models are therefore the results of correlating more fundamental characteristics. In principle, such an approach should result in more persistent model accuracy.

A parallel may be drawn with model development in the field of Artificial Neural Networks (ANNs) which are based on the creation of a layer of "neurons", or smaller functions mathematically translating an input into an output. In a single layer of neurons, we correlate a set of inputs directly to a set of outputs. In Deep Learning, the ANN is based on multiple layers of such neurons, where the inner layers of neurons may be regarded as relationships among the parameters of a model, or so-called Latent Factors. These can be regarded as the underlying factors or fundamental aspects which influence the outcomes of a process.

In the case of interest, such latent factors may include for example a student's level of diligence or effort, the inherent difficulty of specific coursework and so on. These factors are more subjective than for example student records, but they may arguably exert more influence on a model's predictive capacity. To investigate this possibility, we wish to examine this possibility without influencing the results through the advantages that specific Machine Learning algorithms afford. Instead, we apply simple multi-linear regression in two instances, viz. when correlating course records results vs when correlating factors related to student and coursework performance.

A. Direct course correlation

We establish the benchmark "direct" course results correlation by selecting one engineering course at the third-year level and correlating the results over a 5-year period with the results from its two pre-requisite course results. The raw results are shown in Figure 4. Although the trend is overall in the right direction, the variance is on the order of 15% which renders this model of limited predictive capacity.

However, this is not necessarily of concern for this study, since the persistence of the accuracy, and its comparison with the latent factor-based approach, is of greater importance.

To ease the process of comparison, we summarise the model's capacity by the Pearson R-co-efficient of the same model predicted on each year's results over a 5-year period. The results are shown in Figure 5.

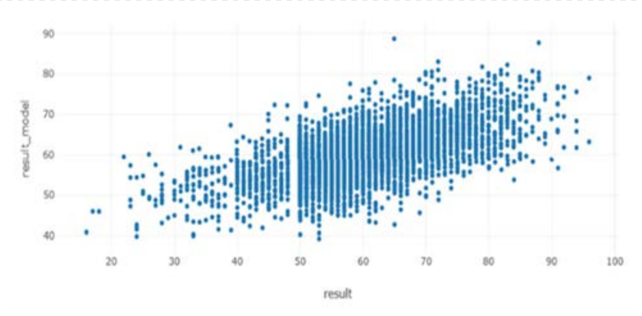

FIGURE 4: *Direct result model prediction*

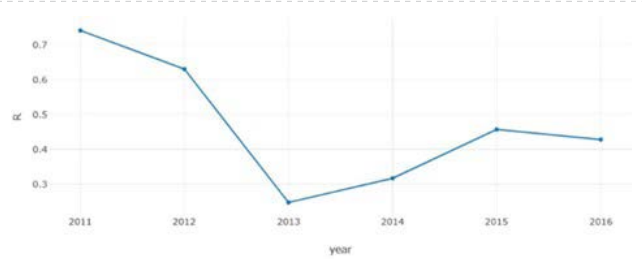

FIGURE 5: *Direct model annual performance*

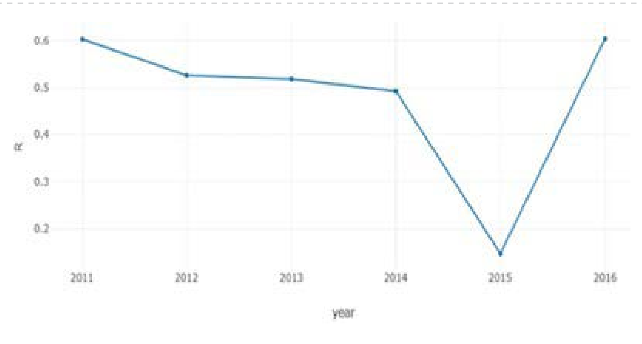

FIGURE 6: *Latent factor-based model annual performance*

Overall, this model's accuracy is declining over the 5-year period as denoted with the decreasing trend.

B. Latent factor model correlation

The same data set was used to develop a model based on statistical methods intended to serve as latent factors. Among these metrics are included each student mean course results in each semester, the rate of change of mean results over each semester, the semester-based credit accumulation rate and the rate of change of the semester credit-accumulation rate. From the coursework perspective, the mean or class average and the rate of change of these values of time together with the pass rate and the variance in mean and pass rate were included as latent factors.

The model was then developed from these latent factors. It should be noted that while a relatively large number of latent factors were developed (on the order of 10), the number of inputs were still lower than in the "direct" case, making for "smaller" models having fewer parameters. Figure 6 shows the result, where the model persistence is clearly superior to the Direct case.

The model is initially slightly lower in accuracy but retains this accuracy over a greater period of time. The reader is reminded that the model was deliberately restricted to simple multi-linear regression rather than a Machine Learning model which would achieve far higher accuracies, but which would also reduce the extent to which these two approaches could be compared.

CONCLUSION

We proposed that a Population Balance model (PBm) would provide a suitable framework to predict student success, with applications ranging from the whole institution, to the academic programme, to the coursework down to the individual student levels.

The AutoScholar Advisor system was used to investigate the possibilities and illustrate current automated advising. Two methods were proposed for developing the sub-models required by the PBm, with a special interest in the preservation of the model accuracy over time on the order of 5 years. In direct correlation, we simply correlated an engineering courses results against its pre-requisites and found that the model persistence declined significantly over time.

In contrast, we developed a Latent Factor model, which correlated instead statistical metrics about each student and the coursework of interest. While the accuracy is slightly lower, the persistence of the model was found to be preserved over the 5-year period of the investigation. For the sake of the fairness of the comparison, the correlations were restricted to simple multi-linear regression.

It is therefore proposed that an approach based on Latent Factors with Machine Learning algorithm support will yield models which are both accurate and more persistent than current methods.

REFERENCES

[1] H. Zeineddine, U. Braendle, A. Farah, (2021) Enhancing prediction of student success: Automated machine learning approach, Computers and Chemical Engineering, v89

[2] Silva, C. and Fonseca, J., 2017. Educational Data Mining: a literature review. Europe and MENA Cooperation advances in information and communication technologies, pp.87-94.

[3] Olama, M., Thakur, G. and Sukumar, S.R. (2014) Predicting student success using analytics in course learning management systems. Proceedings of SPIE - The International Society for Optical Engineering. DOI: 10.1117/12.205064

[4] R. Barber and M. Sharkey. Course correction. (2012) Proceedings of the 2nd International Conference on Learning Analytics and Knowledge - LAK '12, page 259, New York, New York, USA, Apr, ACM Press.

[5] Himmelblau DM, Bischoff KB (1968) Process analysis and simulation: deterministic systems. Wiley, New York.

[6] Hulburt HM, Katz S (1964) Some problems in particle technology: A statistical mechanical formulation. Chem Eng Sci, 19(8):555-574.

[7] E. Alyahyan, D. Dilek Düştegör. (2020) Predicting academic success in higher education: literature review and best practices, International Journal of Educational Technology in Higher Education, 17

[8] E. Buraimoh, R. Ajoodha, K. Padayachee, Application of Machine Learning Techniques to the Prediction of Student Success, (2021) IEEE International IOT, Electronics and Mechatronics Conference (IEMTRONICS), Toronto, ON, Canada, 21-24 AprilK. Elissa, "Title of paper if known," unpublished.

[9] V. Kuleto, M. Ili, M. Dumangiu, M. Rankovi, O. M. D. Martins, D. Păun, L. Mihoreanu (2021) Exploring Opportunities and Challenges of Artificial Intelligence and Machine Learning in Higher Education Institutions, Sustainability, 13.

[10] Romero, C., Ventura, S. and García, E. (2008) Data mining in course management systems: Moodle case study and tutorial. Computers & Education

[11] Yağc, M. (2022) Educational data mining: prediction of students' academic performance using machine learning algorithms. Smart Learning Environments. 9:11

[12] Mduma N, Kalegele K, Machuve D. (2019) Machine learning approach for reducing students dropout rates. International Journal of Advanced Computer Research.; 9(42):156-169.

[13] Cheng Z.,Zhu L.,Ding Y.,Kankanhalli M. (2018) Aspect-aware Latent Factor Model. World Wide Web Conference.; 639–648.

Technical papers

Students' performance prediction using multimodal machine learning

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***Abstract* — Technological intervention in the field of education has gained significant relevance, especially during the post-pandemic era. The three dimensions of interaction that influence learning are the student's interaction with the content, peers, and instructors. Learning ecosystems are expected to ensure these interactions in a seamless way. Technological interventions have provided us with provisions to establish the interactions. The data that we obtain while the student is interacting with content, peers, and instructors can serve as feedback to students and instructors. The motivation of the current study lies in the direction of investigating 'what' and 'how' current practices of estab- lishing the interaction with content, peers, and instructor are influencing students' performance. The other dimension includes how demographic factors like gender influence the performance of students when technological interventions are made.The sample considered in the study included 140 first-year engineering students in a private university. The outcome of the study helped to do early prediction of student failures and identification of factors that influences the student's success. The data for the study was collected from multiple modalities. Clickstream data was collected from a learning management system to understand the interaction of students with the course content. Student collaboration data was collected from GitHub to understand the interaction of students with peers. Demographic data was collected from student academic performance to understand how past performance and demographic factors influence future performance.The findings reveal that the student interaction with the content and the student performance have a positive relationship with a correlation coefficient of 0.68. The algorithms including random forest, naive Bayes, decision tree, support-vector Machine, and extreme gradient boosting were used to perform multiclass classification to predict the performance. The students were grouped into four classes including 'Excellent', 'Good', 'Average', and 'Poor' using decision tree with a classification accuracy of 96%.**

Keywords — Performance prediction, Learning Ecosystems, Student Interactions, Demographic Factors

I. INTRODUCTION

Covid-19 pandemic introduced us to the world of quarantining and working from home. It also brought a significant amount of changes in the field of education. Online and blended modes of education have received greater acceptance by the academic community [1], [2]. The decision to continue with these modes of delivery in this post-COVID-19 pandemic era needs to be evaluated. Performance prediction of students' can help in evaluating the effectiveness of online and blended mode of delivery. Hence, the performance prediction of students' has gained a greater significance in academic society. Students' performance is influenced by the interaction of students with course content, peers, and the course instructors. The learning ecosystems established around the student are expected to ensure that these three in- teractions effectively engage the student. The assessment of student's performance is an important attribute of the learning ecosystem, as it provides feedback to the students as well as the instructors [3]. The predicted performance of the student can help instructors monitor the learning progress of the students and provide feedback. It also allows them to customise the interventions to meet the student's needs. This can further help students to improve their performance [3].

There is a plethora of research studies available on student performance prediction. Several previous research studies have found that the data collected from online learning platforms is useful in predicting student perfor- mance [4], [5]. On the other hand, student participation in social media platforms and discussion forums has also been used to predict student performance [5]–[8]. Studies also show that demographic characteristics influence stu- dents' performance [9]–[11]. Some works also propose the usage of multimodal data to understand students' behavior [12].

In the horizon of the aforementioned situation, the study is situated in the context of a private engineering university where a blended mode of delivery was adopted at university level [1]. The blended mode of delivery combined online and physical modes of learning. The courses were delivered through the institution's moodle- based learning platform, the Learning Management Sys- tem (LMS). The content was delivered in asynchronous mode and synchronous mode. Studio-based videos, screen- casting videos, demonstration videos, and reading mate- rials were made available to the students as a part of the asynchronous mode of delivery [2]. The synchronous mode of delivery included hands-on activities such as group projects and formative assessments conducted to evaluate students. The university was in need of evaluating the effectiveness of this blended learning in terms of students' performance to decide whether to continue with it even after the pandemic. The described situation served as motivation for initiating the current research study.

Artificial intelligence (AI) has been growing extensively and has paved it's way into many fields including the field of education [13]. It has been researched and used to predict student performance by various researchers [10]. A systematic literature survey(SLR) [14] was conducted and the outcome of the SLR helped the authors to arrive at list of constructs and machine learning (ML) models used by researchers towards predicting the student performance. Some of the ML models used by the researchers include logistic regression [10], random forest [6], [9], naive Bayes [7], [15], decision tree [4], [11], support vector machine(SVM) [7], [9], [16], and XGBoost [16].

The advancement of ML and DL algorithms towards application in the field of education helped the authors to define the scope of this study. The data included in the study lies in the first-year engineering course titled engineering exploration [17] The reason behind the choice of the course for the study is the nature of the course itself. It is an Project Based Learning (PBL) course [18] and the course demands the interaction of students with all three dimensions including content, peer and instructor. The study was initiated with the following research questions:

1) How the current practices of establishing interaction of student with the content, peers, and instructors are influencing the student's performance?
2) How does the demography (gender) of the student influence the performance in the online and blended mode of delivery of a first-year engineering course?

Students with diverse backgrounds [19], learning styles [20], and varied motivation levels enroll for engineering degrees. Some students enroll in engineering degrees due to peer and/or parental pressure and as a result lack motivation. Early failure prediction of such students help the instructors make timely interventions and scaffold students.

The study involves investigation of student interactions in three dimensions including interaction with the content, interaction with the peers, and interaction with the teachers. The collection of data to understand the three dimensions resulted in heterogeneous data that needs to be fed to the ML model. The modalities of data considered in the study included click stream data collected through LMS that reflected the student's interaction with the content, GitHub contributions, and collaborations that reflected the interactions with the peer acted as another modality while demographic details was the other one.

The rest of the paper is organised as follows. Related work is reviewed in Section II. The methodology adopted is described in Section III. The results are discussed in Section IV, followed by inferences and future directions in the conclusion section.

II. RELATED WORKS

Student performance prediction has been studied extensively in the past for various purposes like identifying the students at risk of failing and identifying and customising the student learning environments. The predicted values are the grade point averages, knowledge, and scores [21]. Generally, the body of work used classification approaches to classify students into discrete categories such as "Pass" or "Fail" [9], [11]. Most works have used quantitative approaches. Some works refer to the context where qualitative analysis [22] is performed. In the study [22], 27 students from an African classroom were considered and their interaction with content was qualitatively analyzed. The authors of [22] concluded that there is a strong correlation between performance and engagement implying the students who were more engaged would perform better than those less engaged.

In [5], the authors used both qualitative and quantitative methods. They used statistical information like the number of messages, posts read, times visited, etc. for the quantitative analysis and performed qualitative analysis to understand the content of messages. They concluded that the combination of qualitative and quantitative measures improves the prediction accuracy with a value of 90.3%. In [10] the authors used a combination of demographic factors, student's past academic records, and clickstream data of that students which was collected from their activities in the virtual learning environment. They defined the students with a predicted performance below 40% as students at risk of failing. They have concluded that demographic characteristics and students' clickstream activities have a significant impact on student performance. Artificial neural networks (ANNs) give better results with an accuracy of 94% when compared to baseline classification models like support vector machines (SVM) and logistic regression(LR).

Peer interaction is also an important factor influencing students' performance. In the work [6], the authors have used the activities of students on social media platforms like wiki, blog posts, and Twitter, to predict the students' performance. The authors considered factors like the number of posts a student posted on the platform, how many times the student was active on a particular day, and the length of their posts. They concluded that students' actions on social media tools are good predictors of academic performance. They also concluded that the large margin nearest neighbor regression (LMNNR) algorithm proved very suitable for the task of prediction achieving an accuracy of 85%.

Previous academic records of the student also can be used in predicting the student's performance [23]. In this study, the authors propose the usage of the previous inter- nal assessment marks of the students to predict whether the student will fail or pass the final exam. They experimented with Adaptive Boosting, Deep Neural Networks(DNN), and artificial immune recognition system v2.0 for the task of classification. Their results indicate that DNN performed the best with an accuracy of 95.34%.

The factors discovered in the literature can be di- vided into four categories: demographic characteristics, academic records, content interaction, and peer interaction [5]. A complete discussion of these factors may be found in Table I. The algorithms utilized were divided into two categories: machine learning (ML) and deep learning(DL). Table II lists the various ML and DL algorithms that were used in this study. In general, classification approaches are seen to be employed more frequently.

The student's performance was described using a variety of criteria. Using multi-class classification techniques, they were typically categorized as pass/fail/distinction or other similar categories. These classifications were determined based on the final results of the tests (grade point averages or the total final marks) [9], [11].

TABLE 1: *Attributes commonly used*

Identified Category	Attributes Considered	References
Demographic Factors	Gender, age, parent's educational level, parents' involvement, students study environment, school and classroom environment, possession of computers, region, family income and expenditure, nationality, birthplace.	[7], [9]–[11]
Academic records	Internal assessment marks, assignment submission marks, past performances.	[23]
Content interaction	Click stream data, number of clicks per day, number of ac- tive days, number of resources accessed, number of videos watched, announcement views.	[4], [7], [9], [10], [22]
Peer interaction	Activities of students on wiki, blog posts and twitter or any other discussion forums.	[6]–[8]

TABLE 2: *Methods used in this study*

Methods	Approaches	References
Machine Learning	Logistic Regression, SVM, Naive Bayes, Decision Tree, Random Forest , XGBboost.	[4], [6], [7], [11]
Deep Learning	Deep Neural Networks (DNN), Long short term memory (LSTM),etc.	[10], [22]

TABLE 3: *Factors Used and Their Descriptions*

Factors	Description
Interaction with Content (Click Stream Data)	Total number of times the student visited LMS
	Number of times the student visited the website per day on an average
Interaction with Peers	Total number of Commits made by each student on GitHub.
Academic Performances	Formative assessment marks (I 1-3 marks of 8 consecutive assessments conducted in the physical mode of delivery)
Demographic Factors	Gender

III. METHODOLOGY

For the purpose of this study, 140 students pursuing the course of engineering exploration [1], [17] were consid- ered. The course uses project-based learning [18] peda- gogy. Students work in teams to develop a functional pro- totype as a solution towards the identified problem [24]– [26]. The course focuses on first-year engineering students and teaches them about the engineering design process, the multidisciplinary nature of engineering, problem-solving, data analysis, team building, professional ethics, sustain- ability, and project management [17]. Students use agile practice [27] to complete the project. This course was delivered using the blended approach for the semester Jan- Jun 2020 [1]. This transition from physical mode to online mode opened up new research studies in the direction of measuring the effectiveness of blended learning and personalized learning. The factors and methods identified in the previous section were considered while building the implementation pipeline.

A. Data Collection

The data used consisted of 140 students pursuing the course engineering exploration. The online mode and physical mode of learning constitute the blended mode (synchronous and asynchronous) of delivery. Clickstream data was the reflection of students' interaction with the content, and GitHub collaboration was the reflection of students' interaction with their peers. These two factors were considered under the asynchronous mode of deliv- ery. The previous performance (marks of the previous formative assessment) of the student is considered under the synchronous mode. The marks of the formative as- sessments conducted from January to March 2020 were used to predict the performance of students in formative assessments scheduled in the next part of the semester (after March) as well the semester-end exams.

Students' performance is influenced by their interaction with peers, content, and instructors [28]. LMS set up by the university is a moodle based online platform through which the content of the course was accessed along with the required resources for the course. The clickstream data, that was obtained from the LMS platform, was considered as a part of the interaction with the content dimension. The GitHub collaborations made by each student were con- sidered under the interaction with peers dimension. Other than this the previous academic records of the students were considered along with gender of the student. The multimodal data, i.e., clickstream data, Github collabora- tions, academic records, and demographic data, collected from different sources were used to further this study. Figure 1, shows the implementation pipeline adopted to classify the students based on their performance. Table III, lists all the factors used for the purpose of this study in detail.

B. Data integration and Cleaning

Integration of the multimodal data was a crucial part of this study. Early data fusion techniques were used to arrive at the fused data. The missing values in the data were replaced with the mode.

C. Classifier

The processing of the data and integration of the data was done using Python libraries such as NumPy and Pandas. The cleaned and fused data was split into train and test data with a ratio of 80-20. The training data was used to develop five different machine learning models namely: random forest, naive Bayes, decision tree, support vector machine (SVM), and XGBoost. The parameters for these classifiers were set using grid search cross-validation.

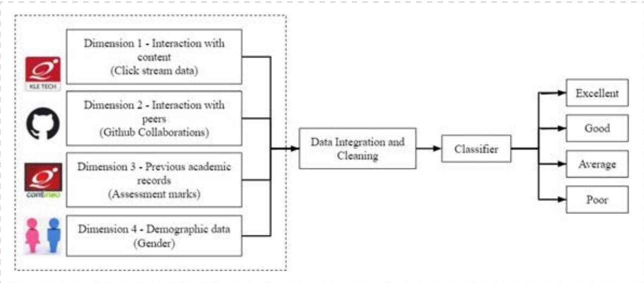

FIGURE 1: Proposed pipeline for implementation

D. Predicted Output

The output of the classification task is the prediction of students' performance. The students were graded out of 20. The classifiers decided the category to which the student belonged to based on the input data. The students were categorised into 4 categories. The categories were as follows:

- Excellent: Final score is greater than 15
- Good: Final score is greater than 10 and less than 15
- Average: Final score is greater than 5 and less than 10
- Poor: Final score is less than 5

The number of students present in each category "poor", "average", "good", and "excellent" was 29, 31, 43, 37 respectively. The evaluation metric considered in this work is the accuracy of the machine learning classifiers. The accuracy of a machine learning model is a metric for determining which model is the best at recognising relationships and patterns between variables in a dataset based on the input or the training data. The formula to calculate the accuracy is provided in equation 1.

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} \qquad (1)$$

$$TP = True_{Positive},\ TN = TrueN_{egative},$$
$$FP = False_{Positive},\ FN = False_{Negative}$$

IV. RESULTS AND DISCUSSION

To address the mentioned research questions, data was collected and analysed. A correlation heatmap of all the parameters or factors considered in this work results is shown in Figure 2.

The correlation heatmap provides information regarding the amount of correlation between the factors considered. From the above matrix, it was observed that the total number of times a student visits the LMS platform has a positive correlation of 0.68 with the final grade of the student. That implies the more the number of visits, the higher will be the grade of the student. This in turn tells Figure 2 Correlation heatmap us that the interaction with content has a positive influence on the student's performance. The number of commits has a low positive correlation of 0.12. This suggests that the interaction of students with peers does not have a linear relationship with student's performance. The demographic data(gender) also does not have a linear relationship with students' performance. It has a correlation of 0.15 with the student's performance. The results obtained from all the classifiers can be observed in Table 5:

***TABLE 5:** Comparison of the results obtained by the ML algorithms on the test data*

Model	Accuracy
Decision tree	96%
Random forest	93%
SVM	93%
Naive Bayes	89%
XGBoost	79%

From Table 5, we can observe that the decision tree, random forest, SVM, naive Bayes, and XGBoost gave an accuracy of 96%, 93%, 93%, 89%, and 79% respectively. Clearly, the decision tree classifier outperformed all the other classifiers with an accuracy of 96 %. Figure 3, rep- resents the validation curve of the decision tree classifier.

It shows that the model has low bias and low variance.

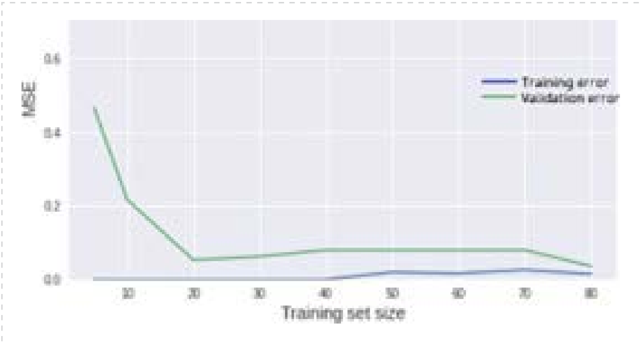

FIGURE 3: Validation curve of decision tree classifier

V. CONCLUSION

The study shows that the current practices of establish- ing interaction of students with the content have a positive influence on the student's performance. The interaction with peers reflected through GitHub contributions, and demographic data (gender) do not have a linear rela- tionship with the student's performance. The study also shows that the use of multiple modalities not only helped the triangulation but also in training the classifiers. The decision tree classifier performed best with an accuracy of 96%.

Studying the third dimension of interaction, i.e., in- teraction with instructors, and its influence on student performance is the future scope of this study. Along with this the interdependencies among the three dimensions of interaction also needs to be studied. The following study was limited to a set of 140 students from a particular in- stitution. A study including a larger and more generalized dataset will ensure that the models also get trained in a generalized manner.

REFERENCES

[1] M. Vijaylakshmi, P. Baligar, K. Mallibhat, S. M. Kavale, G. Joshi, and A. Shettar, "Transition from in-person learning to technology enhanced learning in engineering education: Faculty challenges," pp. 1–5, 2021.

[2] K. Mallibhat and N. Iyer, "Program level adaptations during pandemic: Opportunities and faculty perceptions," pp. 3138–3145, 4-6 July, 2022 2022. [Online]. Available: https://dx.doi.org/10. 21125/edulearn.2022.0778

[3] W. Xing, R. Guo, E. Petakovic, and S. Goggins, "Participation-based student final performance prediction model through inter- pretable genetic programming: Integrating learning analytics, edu- cational data mining and theory," Computers in Human Behavior, vol. 47, pp. 168–181, 2015.

[4] M. Hussain, W. Zhu, W. Zhang, and S. M. R. Abidi, "Student engagement predictions in an e-learning system and their impact on student course assessment scores," Computational intelligence and neuroscience, vol. 2018, 2018.

[5] L. P. Macfadyen and S. Dawson, "Mining lms data to develop an "early warning system" for educators: A proof of concept," Computers & education, vol. 54, no. 2, pp. 588–599, 2010.

[6] E. Popescu and F. Leon, "Predicting academic performance based on learner traces in a social learning environment," IEEE Access, vol. 6, pp. 72 774–72 785, 2018.

[7] V. Vamshidharreddy, A. Saketh, and R. Gnanajeyaraman, "Stu- dent's academic performance prediction using machine learning approach," Int. J. Adv. Sci. Technol, vol. 29, no. 9, pp. 6731–6737, 2020.

[8] C. Romero, M.-I. López, J.-M. Luna, and S. Ventura, "Predicting students' final performance from participation in on-line discussion forums," Computers & Education, vol. 68, pp. 458–472, 2013.

[9] P. Sokkhey and T. Okazaki, "Hybrid machine learning algorithms for predicting academic performance," Int. J. Adv. Comput. Sci. Appl, vol. 11, no. 1, pp. 32–41, 2020.

[10] H. Waheed, S.-U. Hassan, N. R. Aljohani, J. Hardman, S. Alelyani, and R. Nawaz, "Predicting academic performance of students from vle big data using deep learning models," Computers in Human behavior, vol. 104, p. 106189, 2020.

[11] S. Rizvi, B. Rienties, and S. A. Khoja, "The role of demographics in online learning; a decision tree based approach," Computers & Education, vol. 137, pp. 32–47, 2019.

[12] M. N. Giannakos, K. Sharma, I. O. Pappas, V. Kostakos, and E. Velloso, "Multimodal data as a means to understand the learning experience," International Journal of Information Management, vol. 48, pp. 108–119, 2019.

[13] A. Hellas, P. Ihantola, A. Petersen, V. V. Ajanovski, M. Gutica, T. Hynninen, A. Knutas, J. Leinonen, C. Messom, and S. N. Liao, "Predicting academic performance: a systematic literature review," in Proceedings companion of the 23rd annual ACM conference on innovation and technology in computer science education, 2018, pp. 175–199.

[14] Y. Joshi, M. Kaushik, and M. Vijaylakshmi, "Systematic literature review: An investigation towards finding constructs for performance prediction of students in an online engineering course," 2022 World Engineering Education Forum and The Global Engineering Deans Council (WEEFGEDC), pp. 1–5, 2022.

[15] A. Daud, N. R. Aljohani, R. A. Abbasi, M. D. Lytras, F. Abbas, and J. S. Alowibdi, "Predicting student performance using advanced learning analytics," in Proceedings of the 26th international con- ference on world wide web companion, 2017, pp. 415–421.

[16] B. Sekeroglu, K. Dimililer, and K. Tuncal, "Student performance prediction and classification using machine learning algorithms," in Proceedings of the 2019 8th International Conference on Educa- tional and Information Technology, 2019, pp. 7–11.

[17] P. Baligar, S. Kavale, M. Kaushik, G. Joshi, and A. Shettar, "Engineering exploration: A collaborative experience of designing and evolving a freshman course," pp. 1–5, 2018.

[18] M. Kaushik, "Evaluating a first-year engineering course for project based learning (pbl) essentials," Procedia Computer Science, vol. 172, pp. 364–369, 2020.

[19] N. N. Kulkarni, M. Kaushik, and G. Joshi, "Engineering pro- fession: understanding freshman perspective," in 2016 IEEE 4th International Conference on MOOCs, Innovation and Technology in Education (MITE). IEEE, 2016, pp. 332–337.

[20] M. Kaushik and G. Joshi, "Transitional learning style preferences and its factors in newer generation engineering students," in 2016 IEEE 4th International Conference on MOOCs, Innovation and Technology in Education (MITE). IEEE, 2016, pp. 263–267.

[21] A. Hellas, P. Ihantola, A. Petersen, V. V. Ajanovski, M. Gutica, T. Hynninen, A. Knutas, J. Leinonen, C. Messom, and S. N. Liao, "Predicting academic performance: a systematic literature review," pp. 175–199, 2018.

[22] J. Mutahi, A. Kinai, N. Bore, A. Diriye, and K. Weldemariam, "Studying engagement and performance with learning technology in an african classroom," in Proceedings of the Seventh Interna- tional Learning Analytics & Knowledge Conference, 2017, pp. 148– 152.

[23] S. Hussain, Z. Muhsin, Y. Salal, P. Theodorou, F. Kurtog˘lu, and G. Hazarika, "Prediction model on student performance based on internal assessment using deep learning," International Journal of Emerging Technologies in Learning, vol. 14, no. 8, 2019.

[24] M. Kaushik, P. Baligar, and G. Joshi, "Formulating an engineering design problem: A structured approach," Journal of Engineering Education Transformations, 2018.

[25] P. Baligar, K. Mallibhat, S. Kavale, and G. Joshi, "Evaluating an engineering design problem for its complexity," IEEE Transactions on Education, vol. 65, no. 1, pp. 73–80, 2021.

[26] M. Kaushik, P. Pillai, and N. C. Iyer, "Prototype implementation: An effective learning method in process automation," Journal of Engineering Education Transformations, vol. 28, no. 2 & 3, pp. 45–50, 2015.

[27] J. Gadad, V. Talageri, M. Kaushik, and M. Asundi, "An experience of implementing agile project management practice in pbl course at first-year engineering course," in EDULEARN22 Proceedings, ser. 14th International Conference on Education and New Learning Technologies. IATED, 4-6 July, 2022 2022, pp. 5391–5398. [Online]. Available: https://dx.doi.org/10.21125/edulearn.2022.1274

[28] T. Anderson, "Modes of interaction in distance education: Recent developments and research questions," Handbook of distance edu- cation, pp. 129–144, 2003.

Technical papers

Online programming learning platform: The influence of gamification elements

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Abstract — **Numerous studies have been conducted to discover educational technologies that could be utilised to enhance students' understanding of fundamental programming concepts. The advantage that various online programming learning platforms provide, is immediate feedback and automated guidance with the completion of assignments, enhancing student comprehension. Despite the various advantages of online learning environments, the lack of online persistence is viewed as one of the most pervasive disadvantages. Gamification of online learning environments have been proposed as a solution to enhance student engagement, and persistence, but little research has focused on how specific gamification elements influence the persistent use of online programming learning environments. The aim of this study was therefore to fill this gap and to determine what influence various gamification elements have on the persistent use of an online programming learning platform. The population of the study consisted of first year students enrolled at the IT department of the Central University of Technology (CUT) in the Free State Province of South Africa. Data was collected by making use of a survey that was posted on the learner management system of CUT. The results of the study showed that the points and badges that students received as rewards, as well as the badges and avatars that assisted them to express themselves in a unique way, had a very important influence on their engagement and immersion in a gamified programming learning environment. Moreover, the use of a leaderboard to create a competitive environment had no influence on the engagement and immersion of students. The study also showed that higher levels of meaningful engagement and flow experience have a significant influence on keeping students motivated to persistently use a gamified programming learning platform. The practical implication of the findings of the study are that designers and developers of gamified programming learning environments should prioritise designing a comprehensive reward system over the creation of a competitive environment.**

Keywords — gamification, higher education, programming, online learning, persistent use

I. INTRODUCTION

"Whether you want to uncover the secrets of the universe, or you just want to pursue a career in the 21st century, basic computer programming is an essential skill to learn." — Stephen Hawking [1]. The importance of computer science (CS) education is emphasised by various educators and governing bodies worldwide. These institutions foresee that the biggest proportion of science, technology, engineering, and mathematics (STEM) employment growth in the coming years will be in computer science related professions [2]. Furthermore, individuals entering a STEM career in the next ten years will need to possess a reasonable amount of progressive computational skills [3]. Additionally, various experts, including Apple CEO Tim Cook, emphasise that computer programming skills will become an essential skill that everyone should possess [4]. Computer programming courses are, consequently, an indispensable component of STEM education. However, students find it difficult to become proficient in computer programming content offered in higher education (HE) programming courses, causing poor pass rates, low levels of student engagement and dwindling motivation [5]. Several scholars postulate that conventional teaching practises do not offer a solution to the challenges that a large number of students, enrolled in computer programming courses, are confronted with [6]. Much research has been conducted to discover technological education tools that can be utilised to enhance students' understanding of fundamental programming principles [7].

Advantages that various online programming learning platforms provide, are immediate feedback and automated guidance with the completion of assignments, enhancing student comprehension [8]. Despite the various advantages of online learning environments, the lack of online persistence is viewed as one of the most pervasive disadvantages [9]. Gamification of online learning environments has been proposed as a solution to enhance student engagement and persistence [10]. Gamification of engineering education is the practice of adding gaming elements into educational activities in order to make it more enjoyable. Consequently, various aspects of academic performance are enhanced including higher levels of motivation and commitment to the learning process [10]. However, investigation of how specific gamification elements influence the persistent use of online programming learning environments in HE programming courses is lacking. The aim of this study was therefore to fill this gap in the literature and to investigate what influence various gamification elements have on the persistent use of an online programming learning platform. The two research questions of the study were as follows: 1) Which response variables have been investigated in gamified programming HE courses? 2) What influence does various gamification elements have on the persistent use of an online programming learning platform?

II. PREVIOUS RESEARCH ON GAMIFIED PROGRAMMING COURSES IN HE

Studies that were conducted over the past ten years that focused on the gamification of HE programming courses were reviewed and the impact of the gamification interventions are summarised in Table 1. It can be seen from Table 1 that gamification had a very predominant positive impact on five of the response variables that were investigated namely engagement, programming knowledge, motivation, attitude and perception of gamification comprising a total of 16 studies (72.73%). Only five studies reported that gamification had no impact (22.73%) and only 1 study (4.54%) reported a negative impact of gamification. It should be noted that none of the reviewed studies investigated online persistence of gamified programming learning environments.

TABLE 1: *Previous research on gamified programming courses in HE*

Response Variable	Impact	*N*	Study Reference
Student engagement	Positive	6	[11], [12], [13], [14], [15],[16]
Student Programming Knowledge	Positive	5	[11], [13], [17], [18], [19]
Student Programming Knowledge	No Impact	4	[5], [14], [15], [20]
Student Motivation	Positive	2	[21], [19]
Student Attitude	Positive	2	[5], [22]
Student Perception About Gamification	Positive	1	[17]
Student Programming Knowledge	Negative	1	[21]
Student engagement	No Impact	1	[20]

III. GAMIFIED LEARNING ENVIRONMENT

At the Central University of Technology (CUT) in the Free State province of South Africa, students were predominantly taught online during 2020 and 2021 due to the COVID 19 pandemic. During this time frame, Information Technology (IT) lecturers at CUT witnessed a large cohort of students not participating in the online learning process with low levels of online participation and online persistence, also witnessed at other HE institutions [23]. In an effort to combat low online participation, a gamification environment was created for the 405 students enrolled in the module Internet Programming I at CUT in 2021. The Khan Academy platform [24] was selected to form part of the gamification environment for the following reasons. The first reason is the high quality programming learning content, comprised of videos, assignments and a simulated programming environment. Secondly, the platform provides real-time feedback for programming assignments with virtual assistants in the form of various characters telling users where syntax errors are and how to fix them. Thirdly, the Khan Academy platform has implemented several gaming elements including badges, points, avatars, and specific goals [25]. Fourthly, all learning content are free of charge. Lastly, Khan Academy has an instructor platform where lecturers can assign learning tasks which can be monitored per student [25]. Two subjects on the Khan Academy platform were selected to be included in the learning content of students, namely "Introduction to HTML/CSS: Making web pages" and "HTML/JS: Making webpages interactive". The gamified environment also contained WhatsApp groups consisting of 30 students each. At the end of each week, the points students received on the Khan Academy platform were published on a leaderboard. Each leaderboard published on the WhatsApp group, only contained the names of the 30 students in the group.

IV. THEORETICAL FRAMEWORK

The research model for the study was constructed using the Mechanics-dynamics-aesthetics theory (MDAT) [26] and the Stimulus-Organism-Response (S-O-R) Framework [27]. According to MDAT, gamification adds game mechanics (for example points and badges) to current work procedures or electronic platforms instead of creating full-fledged games [28]. The term game dynamics indicate the way in which a user will behave when interacting with game mechanics [29]. A list of the game mechanics that trigger specific dynamics in the gamified learning environment created for the current study is summarised in Table 2 and adapted from [30].

TABLE 2: *Game mechanics and game dynamics used in the gamified environment of study*

Game mechanics	Game Dynamics	Interaction
Points, badges	Rewards	Points and badges that students earn will inspire them to strive for more rewards.
Leaderboard	Competition	A leaderboard will arouse students' desire to compete with other students to perform better.
Avatars, badges	Self- Expression	Avatars and badges will enable students to create unique identities to express themselves.

The second theoretical framework used to develop the research model for the study namely the S-O-R framework, proposes that several components of the environment referred to as the "stimulus", induce conscious mental activities or emotional states in individuals referred to as the "organism", which influence their behavioural reactions to the stimuli referred to as the "response" [27]. In the gamified environment that was created for students, the various game dynamics is viewed as the stimulus that evokes a state of flow and meaningful engagement (organism), which leads to the response of persistent use of the gamified learning platform. Flow experience is one of the main concepts that has been utilised to expound the persistent use of numerous game-based and gamified learning environments [31][32]. Flow is a state of mind that was discovered and termed by [33] to elucidate the mental state of operation in which an individual carrying out an activity is utterly absorbed in an emotional state of complete enjoyment, energised focus and immersion. Moreover, meaningful engagement represents a cognitive state in which an individual perceives an experienced event as meaningful and fully grasps the significance of the experience [34]. Meaningful engagement stems from the Self-

Determination Theory which illuminates the motivation of individuals to carry out activities without external inspiration [35]. In a meaningful engagement state, individuals are continually conscious of the context in which specified tasks are accomplished, and individuals actively figure out novel routes to accomplish their objectives. Moreover people feel that they possess the ability to overcome challenges that requires thought and skill for resolution [36]. Subsequently, a users' meaningful engagement that results from interacting with a gamified information system (IS) has been suggested to be a major predictor of persistent use [37]. From the above discussion, it can be seen that it is expected that both meaningful engagement and flow experience of students that were evoked by various gamification elements will have a positive influence on their behavioural response namely the persistent use of the gamified learning platform. The research model of the study is shown in Figure 1.

V. METHODS

A quantitative, cross-sectional research design was used in the study and a survey was used to collect data. The population of the study comprised of students that were enrolled in the subject Internet Programming I at the Bloemfontein and Welkom campuses of CUT in 2021. Students were exposed to the gamified learning environment discussed in section III for 10 weeks. The link to the survey was posted in the learner management system used by students at CUT and students were requested to voluntarily complete the survey. Ethical clearance to conduct the study was obtained from CUT in 2021. The scale for each construct consisted of a 7-point Likert scale with two anchor points namely (1) 'Strongly Disagree' and (7) 'Strongly Agree'.

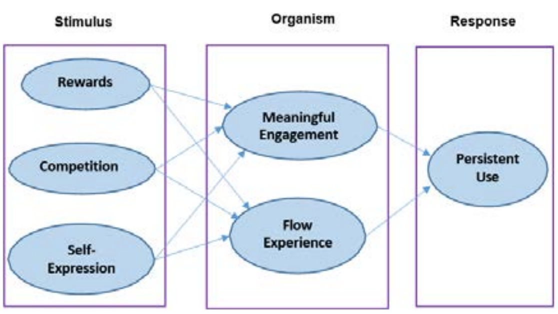

FIGURE 1: *Research Model*

All items in the scales were adapted from extant literature to assure content validity of the measuring instrument. The rewards construct was measured with 3 items adapted from [38]. Furthermore, the self-expression construct was measured with 3 items adapted from [39]. Additionally, the competition construct was measured with 3 items adapted from [40]. Moreover, the flow experience construct was measured formatively by the control (3 items), immersion (4 items) and enjoyment (3 items) constructs, adapted from [41]. Likewise, the meaningful engagement construct was also measured formatively by the self-expansion, meaning and active discovery constructs each containing 3 items, adapted from [34]. Lastly, the persistent use construct was measured with 5 items that were adapted from [42]. A Structural Equation Model was constructed and SMART PLS version 3.37 was used to analyse the collected data.

VI. RESULTS

The demographic characteristics of respondents are summarized in Table 3.

TABLE 3: *Descriptive information of the sample*

	Frequency	Percentage
Gender		
Male	39	40.62
Female	57	59.38
Total	**96**	**100.00**
Usage of Khan Academy		
Never	0	0
Very Rarely	0	0
Rarely	0	0
Occasionally	2	2.08
Frequently	42	43.75
Very Frequently	52	54.17
Total	**96**	**100.00**

As shown in Table 3, the sample consisted out of 40.62% male students and 59.38% female students. Furthermore, it can be seen that the largest majority of students (54.17%) responded they use the Khan Academy environment very frequently, with 43.75% responding to using it frequently. Only 2.08% of students responded to using it occasionally.

A. Measuring model assessment

The initial phase of the PLS-SEM analysis was to scrutinise the constructs in the measurement model according to the phases indicated in Figure 2.

FIGURE 2: *Phases in the measurement model analysis*

The results of the reflective and formative measurement models are shown in Table 3 and IV. Firstly, the factor loadings of all items (except Rew03) was higher than the threshold level of 0.7 demonstrating satisfactory indicator reliability according to [43]. Secondly, according to Table 3 and IV the average variance extracted (AVE) from each construct exceeded the threshold value of 0.5 demonstrating satisfactory convergent validity of the measurement model [43]. Thirdly, the Cronbach's alpha (α) and the composite reliability (CR) of each construct was higher than the threshold level of 0.7, [43] demonstrating satisfactory internal consistency reliability of all constructs. Fourthly, discriminant validity was scrutinised making use of the heterotrait-monotrait ratio (HTMT) which should not be higher than 0.9 [43]. According to Table 4, the HTMT ratio of all constructs are below 0.9, demonstrating that the measurement model demonstrate discriminant validity.

TABLE 4: *Reflective constructs measurement results*

Reflective Constructs	Items	Factor Loadings	α	CR	AVE
Competition	Comp01	0.859	0.713	0.840	0.638
	Comp02	0.825			
	Comp03	0.701			
Persistant Use	PUse01	0.834	0.870	0.906	0.658
	PUse02	0.838			
	PUse03	0.731			
	PUse04	0.882			
	PUse05	0.764			
Rewards	Rew01	0.906	0.745	0.854	0.673
	Rew02	0.929			
	Rew03	0.585			
Self- Expression	SExpr01	0.914	0.850	0.910	0.771
	SExpr02	0.880			
	SExpr03	0.838			

TABLE 5: *Formative constructs measurement results*

Formative Constructs	Items	Factor Loadings	α	CR	AVE
Flow Experience					
Control	Con01	0.872	0.795	0.880	0.711
	Con02	0.876			
	Con03	0.778			
Enjoyment	Enjoy01	0.899	0.885	0.929	0.814
	Enjoy02	0.946			
	Enjoy03	0.860			
ImmDersion	Imm01	0.711	0.832	0.888	0.666
	Imm02	0.845			
	Imm03	0.863			
	Imm04	0.837			
Meaningful Engagement					
Active Discovery	ADisc01	0.834	0.788	0.875	0.700
	ADisc02	0.813			
	ADisc03	0.863			

TABLE 6: *HTMT ratio's*

	CUI	Competition	Rewards
Competition	0.371		
Rewards	0.646	0.620	
Self-Expression	0.391	0.521	0.559

B. Structural model assessment

The statistical significance of the relationships in the research model were assessed by making use of the bootstrapping procedure of SmartPLS v3.3.7. Table 7 displays these results. When the p-value of a relationship between two constructs is lower than 0.05, it means that there is a statistical significant relationship between the constructs.

TABLE 7: *Structural model results*

Relationship	β	T value	P Value
Competition -> Flow Experience	0.049	0.430	0.334
Competition -> Meaningful engagement	0.122	1 152	0.125
Flow Experience -> Persistent use	0.362	2 760	0.003
Meaningful engagement -> Persistent use	0.335	2 030	0.021
Rewards -> Flow Experience	0.411	5 525	<0.001
Rewards -> Meaningful engagement	0.462	4 807	<0.001
Self-Expression -> Flow Experience	0.432	5 827	<0.001
Self-Expression -> Meaningful engagement	0.214	2 040	0.021

When investigating Table 7, it can be seen that only two relationships had p values higher than 0.05 namely the relationship between competition and flow experience (β=0.049, p=0.334) and between competition and meaningful engagement (β=0.122, p=0.125). This therefore means there is not a statistical significant relationship between competition and flow experience and competition and meaningful engagement. However, there exists positive statistical significant relationships between all of the following constructs: Flow experience and persistent use (β=0.362, p=0.003); meaningful engagement and persistent use (β=0.335, p=0.021); rewards and flow experience (β=0.411, p<0.001); rewards and meaningful engagement (β=0.462, p<0.001); self-expression and flow experience (β=0.432, p<0.001) and self-expression and meaningful engagement (β=0.214, p=0.021).

The R^2 values of the structural model is shown in Figure 2. It can be seen that the R2 value of meaningful engagement is 0.432. This means that a combination of the rewards and self- expression constructs can explain 43.2% of the variance in the meaningful engagement construct. According to [44], R^2 values of 0.12 or lower represent a low effect size, values between 0.13 to 0.25 represent medium effect size, and values of 0.26 or higher represent high effect size. From these guidelines, it can be seen that together, the rewards and self- expression constructs had a high predictive power towards the meaningful engagement construct. Similarly, a combination of the rewards and self-expression constructs can explain 55% (R2=0.55) of the variance in the flow experience construct, representing high predictive power [44]. Moreover, as can be seen from Figure 2, the combination of the meaningful engagement and flow experience constructs can explain 42% (R^2 =0.42) of the variability in the persistent use construct representing high predictive power.

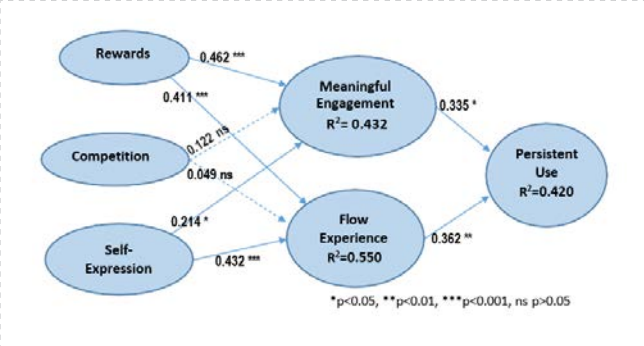

FIGURE 3: *Structural model analysis*

VII. DISCUSSIONS

The aim of the study was to investigate what influence various gamification elements have on the persistent use of an online programming learning platform. Based on the SOR framework, the gamification elements were the external factors (stimulus) that lead to a change in students' intrinsic state (organism) [45]. Students' intrinsic state refers to their internal experiences including their cognitive state (conceptualised as meaningful engagement) and their affective state (conceptualised as flow experience) [45]. Subsequently, the intrinsic states of students, influenced their final behavioural responses, conceptualised as their persistent use of the Khan Academy platform.

In order to investigate the strength of the relationships between constructs in the study, the standardised beta (β) was used, as shown in Table 7. The higher the β value of a relationship, the stronger the predictive power of one construct towards another. According to the recommendations by [46] a β value of 0.10 indicates a small effect size, 0.20 indicates a medium effect size, 0.3 indicates a large effect size, and 0.40 or higher indicates a very large effect size.

From Table 7, it can be seen that the rewards construct (β =0.462, p<0.001) had a very high influence on the meaningful engagement construct when compared to the self- expression construct (β =0.214, p=0.021) which had a medium influence on the meaningful engagement construct. This result is in contrast to the findings of a study conducted on a gamified information system (IS) by [34], that found that the rewards construct (β =-0.044, p>0.05) did not have a statistical significant influence on the meaningful engagement construct. However, a study conducted by [34] found that the self- expression construct (β =0.349, p<0.01) had a large influence on the meaningful engagement construct. Furthermore, from Table 7 it can be seen that the competition construct (β =0.0.122, p<0.125) did not influence the meaningful engagement construct. This is also in contrast to the study performed by [34] who indicated that the competition construct (β =0.252, p<0.01) had a medium influence on meaningful engagement in a gamified IS.

The findings above indicate that the points and badges that students received as rewards on the Khan Academy platform played a very important role to ensure that they were meaningfully engaged with the activities they performed. Rewards that students received motivated them to actively discover new paths to seek answers and to complete activities to learn new content. Moreover, the rewards students received enhanced their perception that their interaction with the Khan Academy platform was meaningful. Furthermore, rewards students earned increased their ability to deal with challenges they faced and improved their feelings that the activities they performed were important to them.

When the gamification elements that had an influence on flow experience are investigated, it can be seen from Table 7 that the self-expression (β =0.432, p<0.001) construct had the highest influence on flow experience. This finding is in agreement with past research that indicated that giving students room to express their self-identity by selecting the names and types of their avatars, improve their intrinsic motivation and learning of academic content [46]. On the Khan Academy platform students can modify their profiles by choosing their own avatar which matures and grows as they advance through the learning phases. Students' ability to express themselves in the Khan Academy platform by the badges they earned as well as the avatars that they selected made a very important contribution to the enjoyment, sense of immersion and sense of control they experienced while using the Khan Academy platform.

Furthermore, according to Table 7, the rewards construct (β =0.411, p<0.001) also had a very high influence on the flow experience of students. This result is in line with a study that reported that leaners rated the rewards they received in educational games as the most important reason they enjoyed and wanted to continue playing these games [47]. It is clear that the points and badges that students received as rewards in Khan Academy played a very important role to ensure they were absorbed in a state of enjoyment and focused attention while using the platform. However, Table 6 indicates that the competition construct (β =0.049, p=0.334) was the only gamification element that did not have a statistically significant influence on flow experience. These results are similar to various findings on online gamified learning environments that indicate that learners strongly favoured collaboration over competition [47]. This finding implies that the leaderboard that was communicated to students made no impact on the level of enjoyment and immersion they experienced while using the platform.

The study lastly confirmed the internal experiences of students including their meaningful engagement (β =0.335, p=0.021) and their flow experience (β =0.336, p=0.003) that was triggered by the rewards and self-expression gamification constructs, had a large influence on their persistent use of the Khan Academy gamified programming learning environment. The flow experience had the highest influence on persistent use which is consistent with prior research that indicated that flow experience is one of the main constructs explaining the persistent use of numerous game-based and gamified learning environments [31][32]. Meaningful engagement had the second highest influence on persistent use which is in agreement with the study of [34] that found that meaningful engagement (β =0.516, p<0.001) had a very high influence on the persistent use of a gamified IS.

Moreover, as can be seen from Figure2, flow experience and meaningful engagement of students together predicted 42% of the variability of the persistent use of the gamified programming learning platform of the study, representing high predictive power [44]. This finding is similar to previous research that indicated that the meaningful engagement and flow experience constructs predicted 48.2% of the variability of the persistent use of a gamified IS [34].

VIII. CONCLUSION

This study made a unique contribution to existing literature by explaining what influence gamification elements have on changing the internal experiences of students in order to sustain their persistent use of a gamified programming learning platform. The results of the study showed that the points and badges that students received as rewards, as well as the badges and avatars that assisted them to express themselves in a unique way, had a very important influence on keeping students engaged in a meaningful way and placing them in state of enjoyment and focussed attention. The study showed that higher levels of meaningful engagement and flow experience have a high influence on keeping students motivated to persistently use a gamified programming learning platform. Moreover, the results indicated that the competition construct had no influence on the engagement or immersion of students. The practical implication of the findings of the study are that designers and developers of gamified programming learning environments for HE programming students, should prioritise the designing of a comprehensive reward system over the creation of a competitive environment.

Due to the fact that the population of the study only included one first year group in the Free State province of South Africa and only one gamified programming learning platform namely Khan Academy, the results of the study cannot be generalised to the wider population of South Africa. Recommendations for forthcoming studies would consequently be an appeal to academic scholars at institutions from other geographical areas to use the model developed for the study for testing and validation purposes in other related gamified learning environments.

REFERENCES

[1] Internet Pillar, "150 Inspirational Stephen Hawking Quotes on Life, Love, Time and AI," 2022. https://www.internetpillar.com/stephen-hawking-quotes/ (accessed Jun. 26, 2022).

[2] C. Muñoz and M. Smith, "As Computer Science Education Week Approaches : Calling all CS Learning Champions !," 2015. https://obamawhitehouse.archives.gov/blog/2015/11/25/computer-science- education-week-cs-ed- week-approaches-calling-all-cs-learning-0 (accessed Mar. 30, 2022).

[3] G. Leibowitz, "Steve Jobs Believed Everyone Should Learn This 1 Skill," 2017. https://www.inc.com/glenn-leibowitz/steve-jobs-believed-everyone-should- learn-this-1-s.html (accessed Mar. 27, 2022).

[4] M. Davis, "Will coding become a basic life skill ?," 2019. https://bigthink.com/technology-innovation/coding-life-skill?rebelltitem=4#rebelltitem4 (accessed Mar. 27, 2022).

[5] J. Du, H. Wimmer, and R. Rada, "'Hour of Code': Can It Change Students' Attitudes toward Programming ?," J. Inf. Technol. Educ. Innov. Pract., vol. 15, pp. 53–73, 2016.

[6] J. Agapito and M. M. Rodrigo, "Designing an Intervention for Novice Programmers Based on Meaningful Gamification: an Expert Evaluation," in Proceedings of the 25th International Conference on Computers in Education, 2017, pp. 736–745.

[7] G. Nel and L. Nel, "Motivational Value of Code.org's Code Studio Tutorials in an Undergraduate Programming Course," Commun. Comput. Inf. Sci., vol. 963, pp. 173–188, 2019.

[8] J. Swacha, R. Queirós, J. C. Paiva, J. P. Leal, S. Kosta, and R. Montella, "A Roadmap to Gamify Programming Education," in 1st International Computer Programming Education Conference, 2020, vol. 81, pp. 26:1-26:7.

[9] S. Lakhal, H. Khechine, and J. Mukamurera, Explaining persistence in online courses in higher education: a difference-in-differences analysis, vol. 18, no. 1. Springer International Publishing, 2021.

[10] J. K. Acosta-Medina, M. L. Torres-Barreto, and A. F. Cárdenas-Parga, "Students' preference for the use of gamification in virtual learning environments," Australas. J. Educ. Technol. 2021, 37(4)., vol. 37, no. 4, pp. 145–158, 2021.

[11] M. B. Ibanez, A. Di-Serio, and C. Delgado-Kloos, "Gamification for Engaging Computer Science Students in Learning Activities : A Case Study n," IEEE Trans. Learn. Technol., vol. 7, no. 3, pp. 291–301, 2014,

[12] P. Neve, L. D, G. Hunter, N. Edwards, and G. Alsop, "More than just a game : Improving students' experience of learning programming through gamification," 2014, Accessed: Oct. 16, 2019. [Online]. Available: ww. heacademy. ac. uk/system/files/comp-224-p. pdf.

[13] P. Fotaris, T. Mastoras, R. Leinfellner, and Y. Rosunally, "Climbing Up the Leaderboard: An Empirical Study of Applying Gamification Techniques to a Computer Programming Class," Electron. J. e-Learning, vol. 14, no. 2, pp. 94– 110, 2016.

[14] M. Ortiz, K. Chiluiza, and M. Valcke, "Gamification in Computer Programming: Effects on learning , engagement , self-efficacy and intrinsic motivation," in Proceedings of 11th European Conference on Game-Based Learning, 2017, no. October, pp. 507–514.

[15] R. Z. Cabada, M. Lucía, B. Estrada, J. Mario, and R. Félix, "A virtual environment for learning computer coding using gamification and emotion recognition," Interact. Learn. Environ., pp. 1–16, 2018,

[16] A. Rojas-López, E. G. Rincón-Flores, J. Mena, F. J. García-Peñalvo, and M. S. Ramírez-Montoya, "Engagement in the course of programming in higher education through the use of gamification," Univers. Access Inf. Soc., vol. 18, no. 3, pp. 583–597, 2019.

[17] J. Moreno and A. Pineda, "Competitive programming and gamification as strategy to engage students in computer science courses," Rev. Espac., vol. 39, no. 35, pp. 11–25, 2018.

[18] S. P. Shorn, "Teaching computer programming using gamification,", Proceedings of the 14th International CDIO Conference, 2018.

[19] M. Ortiz-Rojas, K. Chiluiza, and M. Valcke, "Gamification through leaderboards: An empirical study in engineering education," Comput. Appl. Eng. Educ., vol. 27, no. 4, pp. 777–788, 2019.

[20] C. Pilkington, "A Playful Approach to Fostering Motivation in a Distance Education Computer Programming Course: Behaviour Change and Student Perceptions," Int. Rev. Res. Open Distrib. Learn., vol. 19, no. 3, 2018.

[21] F. L. Khaleel, N. S. Ashaari, and T. S. M. T. Wook, "An empirical study on gamification for learning programming language website," J. Teknol., vol. 2, no. 81, pp. 151–162, 2019.

[22] M. Piteira, C. J. Costa, and M. Aparicio, "A conceptual framework to implement gamification on online courses of computer programming learning: implementation.," in Proceedings of 10th International Conference of Education, Research and Innovation (ICERI2017), 2017, pp. 7022–7031.

[23] E. G. Rincon-Flores and B. N. Santos-Guevara, "Gamification during Covid-19: Promoting active learning and motivation in higher education," Australas. J. Educ. Technol., vol. 37, no. 5, pp. 43–60, 2021.

[24] Khan Academy, "Khan Academy Environment," 2022. https://www.khanacademy.org.

[25] B. B. Morrison and B. DiSalvo, "Khan academy gamifies computer science," in Proceedings of the 45th ACM technical symposium on Computer science education - SIGCSE '14, 2014, no. August, pp. 39–44.

[26] R. Hunicke, M. LeBlanc, and R. Zubek, "MDA: A Formal Approach to Game Design and Game Research," in Proceedings of the AAAI Workshop on Challenges in Game AI, California, USA, 2004, pp. 4–9.

[27] A. Mehrabian and J. A. Russell, An approach to environmental psychology. The MIT Press., 1974.

[28] A. Suh, C. Wagner, and L. Liu, "Enhancing User Engagement through Gamification Enhancing User Engagement through Gamification," J. Comput. Inf. Syst., vol. 58, no. 3, pp. 204–213, 2018.

[29] Bunchball, "Gamification 101: An Introduction to Game Dynamics," 2018. http://www.bunchball.com/gamification101 (accessed Dec. 03, 2019).

[30] Bunchball, "Gamification 101 : An Introduction to the Use of Game Dynamics to Influence Behavior," White Paper, 2010. http://jndglobal.com/wp- content/uploads/2011/05/gamification1011.pdf (accessed Feb. 16, 2022).

[31] Y. Zhao, A. Wang, and Y. Sun, "Technological environment, virtual experience, and MOOC continuance: A stimulus–organism–response perspective," Comput. Educ., vol. 144, no. October 2019, p. 103721, 2020.

[32] J. Hamari, D. J. Shernoff, E. Rowe, B. Coller, J. Asbell-Clarke, and T. Edwards, "Challenging games help students learn: An empirical study on engagement, flow and immersion in game-based learning," Comput. Human Behav., vol. 54, pp. 170–179, 2016.

[33] M. Csíkszentmihályi, Finding flow: The psychology of engagement with everyday life. New York: Harper Perennial, 1990.

[34] A. Suh, C. M. K. Cheung, M. Ahuja, and C. Wagner, "Gamification in the Workplace : The Central Role of the Aesthetic Experience," J. Manag. Inf. Syst., vol. 34, no. 1, pp. 268–305, 2017.

[35] S. Nicholson, "A User-Centered Theoretical Framework for Meaningful Gamification,", Paper Presented at Games+Learning+Society 8.0, Madison, WI. 2012.

[36] S. Nicholson, "Two paths to motivation through game design elements: Reward- based gamification and meaningful gamification.," in Proceedings of iConference, 2013, pp. 671–672.

[37] Y. Chen, T. Burton, V. Mihaela, and D. M. Whittinghill, "Cogent: A Case Study of Meaningful Gamification in Education with Virtual Currency," Int. J. Educ. Technol., vol. 10, no. 1, pp. 39–45, 2015.

[38] A. Kankanhalli, M. Taher, H. Cavusoglu, and S. H. Kim, "Gamifciation: A New Paradigm for Online User Engagement," in Proceedings of 33rd International Conference on Information Systems, 2012.

[39] M. Ma and R. Agarwal, "Through a glass darkly: Information technology design, identity verification, and knowledge contribution in online communities," Inf. Syst. Res., vol. 18, no. 1, pp. 42–67, 2007.

[40] C. L. Lee and H. J. Yang, "Organization structure, competition and performance measurement systems and their joint effects on performance," Manag. Account. Res., vol. 22, no. 2, pp. 84–104, 2011.

[41] R. Agarwal and E. Karahanna, "Time Flies when You're having Fun: Cognitive Absorption and Beliefs about Information Technology Usage," MIS Q., vol. 24, no. 4, pp. 665–694, 2000.

[42] M. C. Lee, "Explaining and predicting users' continuance intention toward e- learning: An extension of the expectation-confirmation model," Comput. Educ., vol. 54, no. 2, pp. 506–516, 2010.

[43] J. F. Hair, G. T. M. Hult, C. Ringle, and M. Sarstedt, A primer on partial least squares structural equation modeling (PLS-SEM), 2nd Edition. Los Angeles: SAGE Publications, 2017.

[44] J. Cohen, "A power primer," Psychol. Bull., vol. 112, pp. 155–159, 1992.

[45] X. Zheng, J. Men, F. Yang, and X. Gong, "Understanding impulse buying in mobile commerce: An investigation into hedonic and utilitarian browsing," Int. J. Inf. Manage., vol. 48, no. March, pp. 151–160, 2019.

[46] D. C. Funder and D. J. Ozer, "Evaluating Effect Size in Psychological Research: Sense and Nonsense," Adv. Methods Pract. Psychol. Sci., vol. 2, no. 2, pp. 156– 168, 2019.

[47] M. I. Venter and L. De Wet, "Model for the Continuance Use Intention of Mobile Learning," J. New Gener. Sci., vol. 17, no. 1, pp. 73–89, 2019.

Technical papers

Peer-to-peer interaction for learning and assessment in the post-COVID era

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***Abstract* — The onset of the COVID-19 pandemic necessitated a change in the mode of delivery of most of our teaching programs. Within a few months, academics responded to the lack of contact with students by generating and using online content to deliver their modules. Even before this forced change, curricula had already undergone significant development. But whereas teaching methods had morphed over time, learning approaches and assessment strategy remained stagnant. The change to online teaching and assessment during the pandemic revealed that in many modules, assessments are still testing at low cognitive levels, rewarding recall instead of understanding. It also revealed that plagiarism and collusion in online assessments were rife, and the type of assessments offered created an enabling environment for this. Students seldom engage with the course material during the semester, except for assignments. Almost all learning occurs in the short period before the main exam session (or in recent years, with the possibility of deferring exams, the students can extend this period into the supplementary session). The change to continuous assessment placed an unusual strain on students accustomed to this particular learning style. They were now forced to engage with material throughout the semester. In this study the student network was considered. Counter intuitively, this has actually strengthened as a result of the pandemic, with students using a variety of communication platforms to engage with one another. As part of this work, the informal study groups and other partnerships that have arisen were investigated as a means to support the formal teaching program. A system based on peer-to-peer interaction was piloted in an undergraduate chemical engineering program, over two modules at the third- and fourth-year levels. The system awards points for various peer activities that usually occur in an informal way, which can be translated into bonus marks on assessments. In doing so, the system addressed a potentially contentious but powerful supposition, i.e. is there a way to exploit the knowledge sharing potential of plagiarism and collusion for a better purpose? Such systems have traditionally been used in businesses and large corporations to motivate and reward employees. The recent pilot has demonstrated that the system, as implemented within an undergraduate program and linked to assessments that test at higher cognitive levels, can improve student engagement and performance.**

Keywords— peer-to-peer, student networks, online teaching, learning interventions, engineering education

I. INTRODUCTION

The onset of the COVID-19 pandemic resulted in a rapid migration of traditional contact learning programmes to an online format. This necessitated different strategies for student engagement in teaching and learning [1]. The traditional "lecture-tutorial-test-examination" (LTTE) format was replaced in many instances by the use of multiple assessments and different assessment types within a continuous assessment framework. The conventional semester is usually composed of a series of lectures (to introduce material), tutorials (to reinforce the theory and allow for practical application), assignments and tests (to gauge the students understanding and allow for feedback and learning). The latter has a low weighting to the overall course mark and typically demands a low investment from the student. A study period of one or two weeks is provided at the end of the semester, when students engage heavily with learning material in preparation for the exam. The semester timeline during COVID-19 was very different, requiring students to engage with course material at a high-investment level for most of the semester in preparation for multiple assessments. Students hence found it challenging to transition to this form of learning. A possible result of this was the widespread plagiarism and collusion experienced in online assessments, including the use of various knowledge sharing websites, participating in tests physically together as groups, or even obtaining assistance from higher level students during assessments (the latter two prevalent without proctoring) [2]. A beneficial consequence of this increased communication between students was that it opened up opportunities for using this as a basis for peer-to-peer learning. Apart from interactions between individual students, the lecturer and course content [3], the interaction between groups of students is encouraged and even prioritized. This could be formally driven through discussion seminars, collaborative project work or community activities [4]. However, during the online mode, the students could also informally engage in various direct and indirect ways (problem solving or developing and disseminating learning material). In this study, a simple peer-to-peer system was developed and implemented at the third- and fourth-year levels of an undergraduate chemical engineering programme. The effectiveness of the system was evaluated based on the student performance relative to other professional modules within the programme (not offering a peer-to-peer learning opportunity), as well as across modules with similar learning outcomes. This study sought to answer the following research question: Is there a way to exploit the knowledge sharing potential of student networks and peer-to-peer interaction for a beneficial teaching and learning purpose?

II. THEORETICAL FRAMEWORK AND LITERATURE REVIEW

Peer-to-peer systems have traditionally been used in businesses and large corporations to motivate and reward employees. It relies on a trust process, where employees rate and highlight peer interventions of others within the organization that have made some tangible impact to their own development, output or progress [5]. If used correctly, it has the ability to strongly motivate the cohort, and instil a helping behaviour both directly and indirectly [6]. The strength of this approach is linked to social identity theory, which recognizes that individuals are more willing to assist others when there is a shared identity and purpose [7, 8]. This system is different to peer evaluation, insofar as only positive recognition is provided [9]. In the context of higher education, the peer-to- peer system has found good practical implementation when using problem and project-based assessments. Formally, the lecturer can establish relationships between students through project groups and have them allocate and distribute tasks amongst themselves to carry out the necessary work related to the project. This has limitations when more conventional individual assessments are used [10]. In the latter case the peer-to-peer interaction may be facilitated through the development and sharing of learning material (indirect interaction) or informal study sessions and tutorial support (direct interaction) [4]. An important part of the process is the reporting structure, which serves as the basis for the recognition and/or reward that is given for participation in the system. Therein lies the most significant challenge to a robust and fair system that allows for meeting the goals of the teaching and learning intervention, whilst minimizing the propensity for exploitation by the student cohort [11, 12]. Another challenge with assessing the impact of a voluntary peer-to-peer system is accounting for external factors, since these can seldom be controlled. Examples of these external factors are the ability of students to use scientific databases, student access to the internet, personal motivation towards the course and the overall difficulty of the course content relative to the students' previous knowledge.

III. METHODS

A simple peer-to-peer system was developed for implementation within the four-year undergraduate chemical engineering programme. The system rewards students with points for indirect assistance, including uploading solutions to supplementary problems, uploading a relevant literature source for assignments, or a summary of a case study or section of the module. These points are weighted according to their impact on the assessments, and the students are able to accumulate points over the course of the semester. A sample of the feedback form is provided in Figure 1. Equally important is the direct assistance that students provide to their peers, including assistance with tutorials, study sessions and questions in class). These are also allocated points on the feedback form, tiered according to the number of peer interaction events that the students have participated in (or students that they have assisted). A cross-check is provided on each form for instances were other students may have aided the student providing the feedback.

The peer-to-peer system was piloted within a 4th level module covering applied chemical reactor technology. This module has a direct link in terms of content and learning outcomes to a 3rd level module in chemical reactor fundamentals. The learning outcomes of the two modules are listed below:

3rd level module: To demonstrate the ability to understand and calculate reaction rates, yields and compositions in well-defined chemical reaction systems.

4th level module: To demonstrate the ability to design and optimize complex chemical reactors.

The 4th level module is usually referred to as a professional module, as it is an exit level module within the programme. The 3rd level module is referred to as a feeder module, since it covers fundamental material necessary for the applied modules at the 4th level. The performance of two cohorts of students that participated sequentially in the 3rd and 4th level modules over the period 2020/2021 and 2021/2022 was collated and analysed. To evaluate the efficacy of the peer-to-peer system, the performance of the two student cohorts were evaluated relative to other professional modules at the 4th level. The students actual course mark, which was a weighted average for all assessments undertaken through a continuous assessment framework, was used as the basis for the comparison. In order to visualize the results of the comparison, the differences in the course marks for the target module relative to other 4th level professional modules were calculated. In order to demonstrate the improved performance of the students participating in the programme over the two consecutive years, the differences in their course marks for the 4th level and 3rd level modules relative to the class averages were calculated. Finally, the course mark distribution for those students that did and did not participate in the programme were compared.

For the 2020/2021 cohort, 104 (of a possible 120) students participated in both modules, whereas for the 2021/2022 cohort 69 (of a possible 72) students participated. The participation in the peer-to-peer system was on a voluntary basis, with the incentive that sufficient credit points obtained could be translated into a gain in the overall module mark. This was not formalized, but was kept at a minimal level. For example a student could obtain a bonus mark to allow an increase from 59 to 60, 74 to 75, etc., such that the bonus marks would not induce an unproportionate inflation of marks.

Evidence of active participation

Item	Credit points per item	Number of uploads	Score
Uploading solutions to supplementary problems	20	1	20
Uploading a relevant literature resource	10		
Uploading section summary	20	7	140
TOTAL			160

Evidence of peer interaction (indicate here the students you assisted)
(Score range: >5 = 100 credits; 3-5 = 70 credits; 2-3 = 50 credits; 1 = 20 credits)

Assisting others	
Name of student	**Task (e.g. assistance with tutorials, questions in class, study sessions) – provide short narrative**
S1	Assisted with methods for calculating effectiveness factor of various catalysts, shared literature sources for kinetics and solved tutorial 1 together
S2	Shared literature sources for design of fixed bed reactors
S3	Assisted with methods for calculating effectiveness factor of various catalysts
S4	Shared section summaries and summaries of exercises, together with guidelines for tutorials 1 and 2
TOTAL	70

The following to be completed as a cross check (indicate here the students that assisted you)

Assisted by others	
Name of student	**Task (e.g. assistance with tutorials, questions in class, study sessions) – provide short narrative**
S1	Shared section summaries for fixed bed reactors and multi-tubular reactors

FIGURE 1: *Sample of the peer-to-peer bonus system student feedback form.*

IV. RESULTS AND DISCUSSION

When the system was introduced in 2021, the direct participation was relatively low, i.e. the total number of students that submitted feedback forms was 10% of the total number of 3rd/4th level cross-module students. The students' performance in the 4th level reactor technology module (hereafter referred to as the target module) was directly compared to their performance in two contemporary professional modules at the same level. These contemporary modules are at the same level of complexity and cover the same graduate attributes as the target module. The results of this comparison are shown in Figs. 2 and 3.

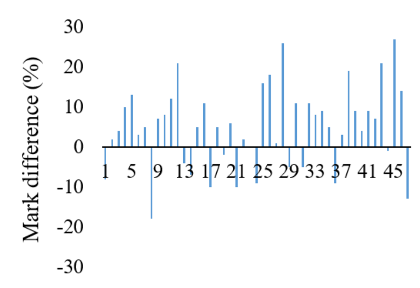

FIGURE 2: *Comparison of student performance in target module relative to the first contemporary professional module, 2021.*

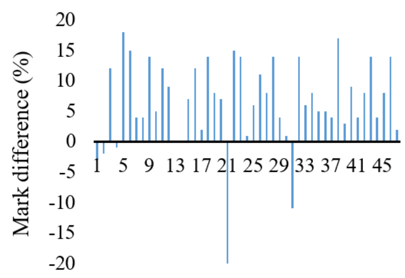

FIGURE 3: *Comparison of student performance in target module relative to the second contemporary professional module, 2021.*

There was a strong positive response in both modules, with a median mark difference of +5 and +7 in each of them, relative to the target module. The performance is of course dependent on more external factors such as the motivation for this course, the difficulty of concepts, etc. It was therefore prudent to study the student performance in the target module relative to the feeder module from the 3rd level (within which no peer-to-peer system had been introduced). Figure 4 shows the difference between the student's overall module mark and the class average, for both 4th level and 3rd level reactor technology modules respectively. Within this cohort, practically all the students that participated in the peer-to-peer system improved their performance in the module relative to that completed earlier in their curriculum. A paired samples t- test was conducted at the 90% level of significance. The calculated t-statistic of 2.22 was above the critical value of 1.86, indicating that the performance (in terms of the average mark difference) in the 4th level module was statistically better than the 3rd level module.

The participant's performance relative to those students that did not participate in the peer-to-peer system was also probed. The distribution of marks for both sets of students are collected and presented in Figs. 5 and 6, respectively. A clear shift in the performance is noted, with students that participated in the peer-to-peer system obtaining far better course averages than those that did not. For instance, just over 40% of students that did not participate scored between 50- 60% for the course, whereas 45% of students that did participate scored between 60-70%. It should be noted that those that participated are a much smaller number compared to those that did not participate in the system.

Although the direct participation in the peer-to-peer system had an impact on the performance of the students in the target module (as demonstrated by Figs. 4, 5 and 6), the performance of the entire student cohort relative to other professional modules in the same semester also improved (as shown in Figs. 2 and 3), which is evidence that the various indirect interventions by the students (supplementary reading material, solutions and summaries) also led to a favourable outcome.

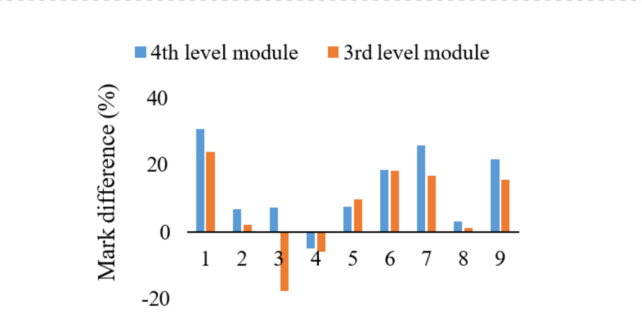

FIGURE 4: Comparison of student performance in target module relative to the feeder module from the previous semester, 2021.

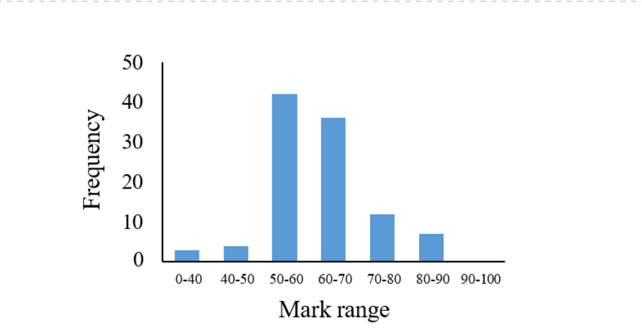

FIGURE 5: Mark distribution for students that did not participate in the peer-to- peer bonus system, 2021.

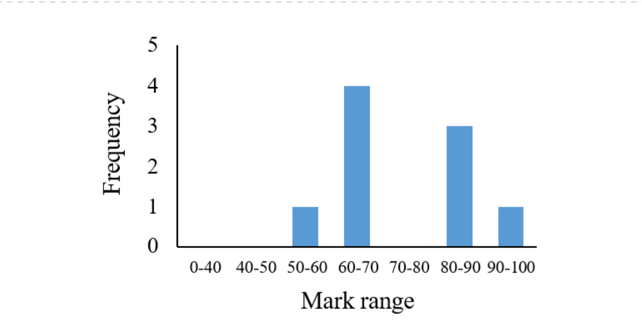

FIGURE 6: Mark distribution for students that participated in the peer-to-peer bonus system, 2021.

When the system was run for the second time in 2022, the direct participation increased to 38% of the total number of 3rd/4th level cross-module students. The comparison of the student performance relative to the two contemporary professional modules was still favourable with a median mark difference of +8 and +2 in each of them, relative to the target module (see Figs. 7 and 8). The performance of the participating students, relative to their performance in the 3rd level module, was more varied, as shown in Figure 9. The paired samples t-test showed that the calculated t-statistic was -0.2, lower than the critical value of 1.71, and hence the improvement in performance was not explicitly clear from this measure. A clearer comparison is seen in Figs. 10 and 11, which again show a positive shift in the mark distribution for the students that participated in the system. About 55% of students that did not participate scored between 50-60% for the course, whereas 40% of students that did participate scored between 60-70%, and almost 20% scored between 70-80%.

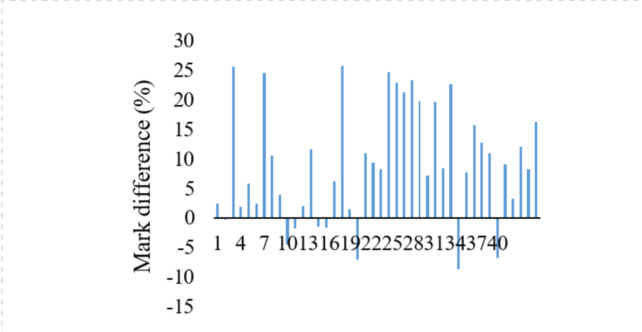

FIGURE 7: Comparison of student performance in target module relative to the first contemporary professional module, 2022.

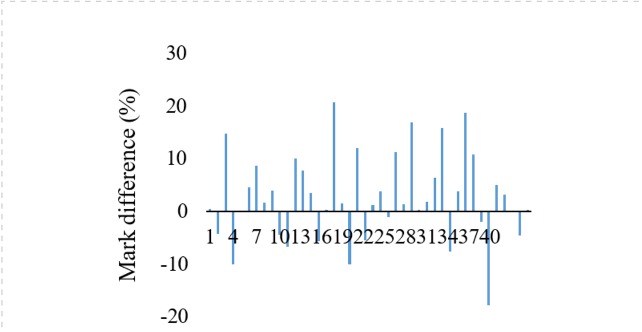

FIGURE 8: Comparison of student performance in target module relative to the second contemporary professional module, 2022.

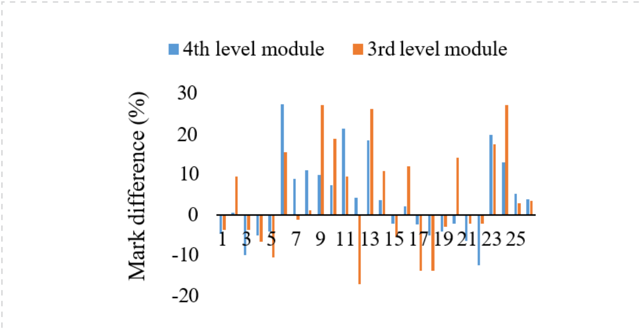

FIGURE 9: Comparison of student performance in target module relative to the feeder module from the previous semester, 2022.

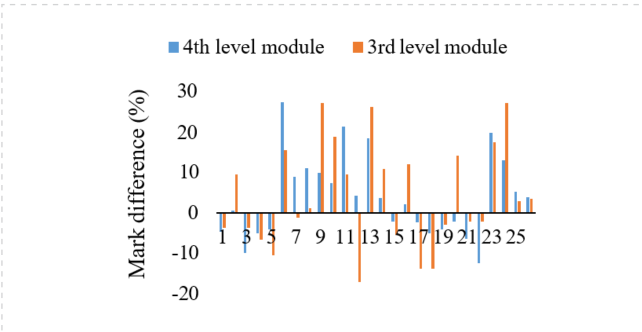

FIGURE 10: Mark distribution for students that did not participate in the peer-to- peer bonus system, 2022.

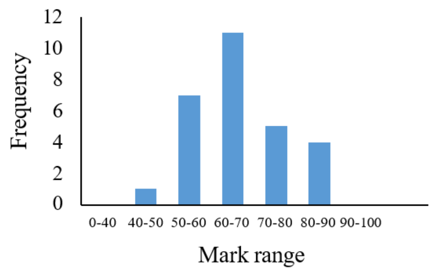

FIGURE 11: *Mark distribution for students that participated in the peer-to-peer bonus system, 2022.*

It is methodologically difficult to definitively state that the students' improved performance was due to the peer-to-peer system. It is equally likely that high-performing students volunteered to participate in the bonus system and their scores may be reflective of their pre-requisite knowledge. It can be cautiously inferred from the results of these analyses, that the peer-to-peer system was successful in leveraging the learning potential of the student communication networks during remote online teaching, bridging the gap between theory and practice and allowing for a more wholistic development of the students' understanding of complex engineering problems. It would serve as a useful tool within other levels of the programme, even as the contact teaching mode is re- established. The results should be considered with some caution,

V. CONCLUSION

Final-year undergraduate students in chemical engineering were slow to adopt a newly introduced peer-to-peer reward system, but participation grew almost four-fold in two years. Those students directly participating in the system were able to out-perform their peers, obtaining better course averages. Moreover, the students also performed better relative to the lower level feeder module. An interesting outcome of the pilot study was that the entire student cohort (over both years) was able to gain some improvement relative to contemporary professional modules through indirect interaction with the resources developed and curated by the participating students. The peer-to-peer platform has the potential to grow into a valid method of enhancing student collaboration for a beneficial purpose. There are of course several challenges in developing a robust and fair peer-to-peer system. It is acknowledged that the evidences provided by the students need to be rigorous, to prevent exploitation of the system by groups of non-participants. As a point for improvement, the completion of the peer-to-peer form could be made more rigorous, to include more evidences in the narrative. The reward system also needs to be formalized, and to accommodate students that participate both as "sources" and "sinks" within the collaborative framework. Lastly, qualitative feedback from students on the use of the system would be valuable for interrogating its efficacy and guiding its improvement.

REFERENCES

[1] M.A. Khan, "COVID-19's impact on higher education: A rapid review of early reactive literature," Edu. Sci., vol. 11, pp. 421, 2021.

[2] A. Verhoef, and Y. Coetser, "Academic integrity of university students during emergency remote online assessment: An exploration of student voices," Transform. Higher Edu., vol. 6, pp. 1-12, 2021.

[3] P. Kumar, A. Kumar, S. Palvia, and S. Verma, "Online business education research: Systematic analysis and a conceptual model," Int. J. Manag. Edu., vol. 17, pp. 26-35, 2019.

[4] S. Chandra, and S. Palvia, "Online education next wave: peer to peer learning," J. Inform. Technol. Case Appl. Res., vol. 23, pp. 152-172, 2021

[5] C. Bradler, R. Dur, S. Neckermann, and A. Non, "Employee recognition and performance: A field experiment," Manag. Sci., vol. 62, pp. 3085-3099, 2016.

[6] P.W. Black, A.H. Newman, B.R. Stikeleather, and N.J. Waddoups, "Performance feedback type and employees' subsequent willingness to help other employees," J. Manag. Acc. Res., vol. 31, pp. 25-39, 2019.

[7] D. De Cremer, and M. Van Vugt, "Collective identity and cooperation in a public goods dilemma: A matter of trust or self-efficacy," Curr. Res. Soc. Psych., vol. 3, pp. 1-11, 1998.

[8] D.E. Abrams, and M.A. Hogg, Social identity theory: Constructive and critical advances. Berlin: Springer-Verlag Publishing, 1990.

[9] L.W. Wang, "Recognizing the best: The productive and counterproductive effects of relative performance recognition," Cont. Acc. Res., vol. 34, pp. 966-990, 2017.

[10] M. Stigmar, "Peer-to-peer teaching in higher education: A critical literature review," Mentor. Tutoring: Partnersh. Learn., vol. 24, pp. 124-136, 2016.

[11] N.S. Ho, and L.T.M. Nguyen, "Challenges in the implementation of peer-to-peer recognition," SHS Web of Conferences ICMeSH 2020, vol. 124, pp. 08007, 2021.

[12] D. Engels, C. Haupt, D. Kugelmann, and K. Dethleffsen, "The peer teachers' perception of intrinsic motivation and rewards," Advan. Phys. Edu., vol. 45, pp. 758-768, 2021.

Technical papers

A case study: Using STACK questions in an engineering module

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***Abstract* — Computer-assisted assessment (CAA) can give im- mediate feedback to students, which leads to better learning. This paper presents a case study of using STACK in a third- year mathematical engineering module. STACK is an advanced computer-assisted assessment tool that can automatically mark mathematical equations.**

STACK is a Moodle plugin that allows students to enter mathematical formulae as answers. It checks if the student's answer is mathematically equivalent to the model answer and can provide hints to the student. Students attempt the same question several times, getting hints with each incorrect attempt.

STACK questions were used in three different settings: short practice problems that students did at home; long tutorial sessions that students did in class; a two-hour semester test.

This paper reflects on the use of STACK during a semester. It summarises feedback from students that were collected during interviews, it discusses systemic challenges when implementing STACK questions, and it looks at the mark distribution of STACK-based questions. Overall, STACK proved to be a useful formative assessment tool. The immediate feedback allowed all the students to solve all the tutorial problems before the end of the tutorial session. The downside to using STACK during the semester test was that students were became anxious because they immediately knew when their answers were wrong.

Keywords — Computer-assisted assessment, STACK ques- tions, STEM assessment

I. INTRODUCTION

Engineering students have to develop the skills to solve mathematical problems and clearly present their calculations. Consider for example the graduate attributes that are required by the Engineering Council of South Africa [1]: graduate attribute 2 - application of scientific and engineering knowl- edge and graduate attribute 6 - professional and technical communication. Graduate attribute 2 expects students to "Ap- ply knowledge of mathematics ... to defined and applied engineering procedures, processes, systems and methodologies to solve broadly-defined engineering problems." Graduate at- tribute 6 expects students to "Communicate effectively, both orally and in writing, with engineering audiences and the affected parties." Effective feedback and formative assessment strategies can develop these skills.

Feedback should be carefully designed. Hattie and Timper- ley reviewed the research on feedback [2]. They show that feedback can be a very effective tool that promotes learning. However, not all feedback is beneficial. They explain that immediate feedback about a task (FT) is beneficial, while immediate feedback about a process (FP) detracts from the learning experience. Anthony and Walshaw [3] argue that effective feedback should not give a full solution but should challenge students to rethink the problem.

Trenholm, Alcock and Robinson [4] contend that hints and comments in an undergraduate mathematics module are the best types of feedback, as opposed to giving the full solution or only marks.

In small classes, the lecturer can easily provide guidance and feedback as and when it is needed. This is not possible anymore in the large classes that are typical of engineering modules. The feedback that students get in large classes is often delayed and limited to marks for correct steps. Some lecturers choose to give students a partial or full memo with the hope that this feedback will help students. Although this approach has benefits, it does not effectively develop the skills to solve mathematical problems and communicate the solution. Lecturers, therefore, try other approaches to give better feedback. Here follows a few of the approaches that have been used, but there are many more discussed in the literature. A lecturer can use information and communication technologies during a lecture to quickly gather answers from all the students [5]. The lecturer immediately looks at the responses and can choose to discuss misconceptions about the work. Teaching assistants can facilitate in-class activities to make lectures more engaging and give immediate feedback [6]. Peer assessments can provide quality feedback in a timely manner [7]. Computer-assisted assessment (CAA) is a tool that can check if a student's answer is correct and give immediate feedback and hints if it is not [8].

STACK is a advanced CAA plugin for Moodle [9]. It allows students to enter mathematical formulae as answers which the system will then evaluate. The system can give hints to the students every time they enter an incorrect answer. The STACK question type is well suited to science, technology, engineering and technology (STEM) modules.

II. CONTEXT AND AIMS OF THE STUDY

This study reflects on the use of STACK question in an engineering module during 2022. The semester module is a precursor to classical control systems for mechanical engineers. It is presented in the first semester of the third year. There are usually 200 students enrolled in the module.

STACK was chosen as a CAA tool because it is open-source, very advanced and flexible.

A typical problem in the module is solved in one page of handwritten mathematical formulae. The problems are closed and therefore have only one answer. However, the exact expression of the answer is not unique. There are many math- ematically equivalent ways to express an answer. Equations 1 and 2 are examples of final answers.

$$kx_2 = m\ddot{x}_1 + b\dot{x}_1 + kx_1 \tag{1}$$

$$e_s = \Omega/\alpha_r + J\dot{\Omega}\ \alpha_r R \tag{2}$$

Traditionally, students submitted written answers to home- work and tutorial problems. The work would be marked by marking assistants and returned to the students a week or two later. The assistants could not give formative feedback on what in particular was wrong with an answer or what concepts the students needed to develop. For the most part, they marked steps in the answer as correct or incorrect. Very few students collected the marked work, which shows that they found little value in the feedback.

The approach to use STACK questions is done for two reasons. 1) Develop the problem solving skills of students. This is done by giving them immediate feedback. 2) Develop the ability of students to present a worked out solution. This is done by giving them a separate mark for the way in which they present the solution. This mark is independent of the mark they get for the technical correctness of the solution.
This paper reflects on the implementation of STACK in the module and on how the lecturer and students experienced the STACK questions.

III. METHODS

A. Reflective practice

Reflection is an important practice for teachers [10]. It helps them to evaluate their teaching in terms of existing theories in education and it helps them to explain to others what they have done. Gibbs' reflective cycle [11] is a framework for reflection that is often used by teachers.

Gibbs' reflective cycle has six stages: (1) description - what happened?; (2) feelings - how did you feel?; (3) evaluation - what was good and bad about the experience?; (4) analysis - make sense of the situation; (5) conclusion - what has been learned?; and (6) action plan - what will be done differently?

We reflected on the use of STACK during the semester by going through one reflective cycle.

B. Functions of an online assessment system

Tait [12] discusses three functions that open and distance learning (ODL) systems should perform. The functions are:
(1) cognitive - learning resources and course materials should develop the learning of students, (2) affective - the ODL system should create a positive environment in which students can develop and learn, and (3) systemic - the processes and systems should be user-friendly and effective. These three functions are relevant to CAA. We, therefore, used it to reflect on the use and implementation of STACK questions.

C. Implementation of STACK questions

As mentioned earlier, students need to develop the skills to solve mathematical problems and communicate the solution. We aimed to achieve this by implementing stack questions into the module. A STACK question only assesses the final answer of a student. It does not evaluate the process that a student followed to get the final answer, nor does it consider how a student presents the solution.

We felt that if the system only assesses the final answer, the students will not consolidate their knowledge before they do the next question. The final written solutions of students were therefore marked to motivate them to neatly write out the final solution.

The mark that a student gets for a question is a combination of two parts: technical correctness and presentation. The technical correctness is immediately assessed by STACK while the presentation is assessed by marking assistants. With this approach, students get immediate feedback on the technical correctness of their answers but delayed feedback on the quality of the presentation.

A marking assistant can quickly mark the presentation of a solution. The reason is that the assistant does not have to evaluate the technical correctness of the solution. The mark is only based on how well the solution is presented. The solution should be clear, concise and presented logically, like a worked- out example in a good textbook.

The STACK questions were used as practice problems, in tutorial sessions and a semester test. Students lose between 15% and 20% of the mark for every incorrect answer. The questions were set up in such a way that students would get five or more hints before the correct final answer is shown to them. By then, they should have all the information to present a clear and logical answer.

The practice problems were done at home by the students at their own pace. The marks students got for the problems counted very little towards the final module mark. Only the STACK answers were marked, the students did not submit their written solutions.

The tutorials were done in a classroom. Around 100 students were in the classroom with two teaching assistants to guide them when required. The teaching assistants were not allowed to give any answers or to help the students find the solution. They helped with technical issues with the interface, and they would explain the material at a conceptual level. A tutorial typically consisted of two questions that should be completed in two hours. Late submissions were allowed. Students were assigned to work together in groups of two. They had to first do the STACK questions and then write their complete solutions on paper. The mark they got for the tutorial was the average of the mark they get from the STACK question and the mark they get for their written solution.

The semester test consisted of three questions. The first question was compulsory, while students could choose to do either the second or third question. The marks for each question were calculated in the same way as for tutorial questions. Half of the marks were allocated to the STACK questions and the other half to the written solution.

D. Data gathering

We got feedback from students during two focus group sessions. There were five students in each session and a session lasted about half an hour.

Students were encouraged to speak freely during the session about anything related to the STACK questions. Students were prompted to discuss their experience with the system by considering the functions that a CAA should perform, namely, to develop their understanding of the work (cognitive), be pleasant to use (affective) and be easy to use (systemic).

We analysed the marks that students got for a tutorial and for the semester test.

IV. RESULTS

A. Interviews

Here are points that students raised regarding their learning experience. The points are sorted according to the three functions of an online assessment system.

1) ***Cognitive:*** The fact that students got immediate feedback forced them to work on the problem until it is correct or until the system gives them the correct answer.

They appreciated the fact that they could go back to their solution and try to find the mistakes they made.

Students experienced the practice problems and tutorials as formative learning opportunities, but not the semester test.

At times, especially in practice problems, the student would not understand the relevance of the hint. In these cases, they would go back to the theory to figure out how to use the hint. They learned a lot by first making sure they understood the solution using STACK before they wrote the final solution clearly on paper. This approach forced them to organize their ideas and present them clearly and logically. By the time they submit the written solution, they have a good understanding of the work.

Some students had access to memos of the tutorial problems from previous years. They would use the memos as another source of hints. They saw the tutorial as an opportunity to learn, not as an opportunity to accumulate marks.

Students noted that just knowing that the answer is incorrect is valuable, even if the hint is not relevant.

Immediate feedback helped students to form a good theoretical foundation.

2) ***Affective:*** Students understood how the system works in the background and what its limitations are. This meant they were not likely to get upset or frustrated by the system. Except during the semester test, when they could not accept losing marks because the system was inadequate.

They felt stressed during the semester test.

They enjoyed the experience of solving a problem and knowing immediately that they are correct.

It builds confidence to get an answer correct. They “get a dopamine kick” when they see that their answer is correct.

Some students felt the 50/50 split between the marks for the STACK answer and the written answer should be different. However, this was only the case for the semester test. They do not mind what the split is for the tutorial questions.

Students enjoyed that the system is interactive.

3) ***Systemic:*** The interface that students use to enter equations is not user-friendly. They would often get a question wrong because they have made an error in entering the answer, not because the answer is wrong.

Students would often make only a sign error, but the system would mark the entire answer as incorrect and give them a useless hint.

The answer can be an exceedingly long equation. It takes a fair amount of time to enter the answer to some of the problems. This put the students under time pressure during the semester test and the tutorials. They did not experience it as a problem during the practice problems, but the practice problems typically had shorter answers.

The system is sensitive to minute details. For example, it would sometimes interpret terms like “mg” as a single variable while the students meant the expression to be “m · g”. Or the students would enter “F ” and forget to add the footnote “Fi”. They felt it is unfair that this is penalised in the same way as any other type of mistake.

The hints were not always useful. At times, the hint would give them the information they already knew.

When a student gets stuck during a tutorial, they are less likely to ask a teaching assistant for help. The hints would often give enough information for the students to find the mistake in their solution.

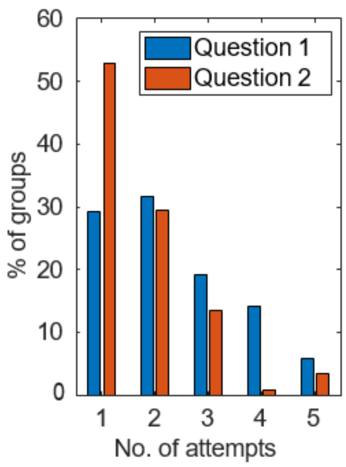
Students that got the semester test questions right on the first or second try had a big advantage since they could take their time to organize their thoughts and neatly write the solution. It takes longer to answer a STACK question than a tradi- tional question. Students do not mind this, except when the tutorial takes much longer than the two hours allocated to it, or when they are under time pressure during the semester test. The students could notice that the system becomes slow during the semester test because there were many users active at the same time. This was not a problem during the tutorials or practice problems.

One should be computer literate to use STACK. It is necessary to refresh a web page and know how to enter the underscore “ ” or caret “ˆ”.

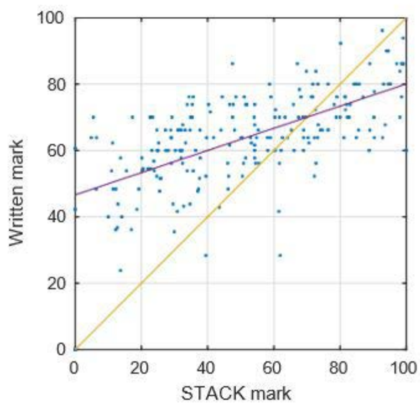
It is necessary to type at a reasonable speed.

B. Tutorial and semester test results

The format of the tutorial is explained in section III-C. The number of attempts at the two questions of a tutorial is shown in Figure 1a. Students were allowed a maximum of five tries. Figure 1b shows the marks that students got for the STACK and written parts of the semester test paper.



(a) Tutorial



(b) Semester test

FIGURE 1: (a) The distribution of the number of attempts the students made at each of the two questions in a tutorial. (b) The distribution of marks for the semester test. The final mark for the test is the sum of the STACK mark and the mark for the written presentation of the solution.

V. DISCUSSION

The discussion follows the stages of Gibbs' reflective cycle. Where applicable, each stage reflects on the three functions that a CAA system should perform.

A. Stage 1 - Description

The implementation of the STACK questions is discussed in section III-C. Students completed 21 STACK practice problems at home, six STACK problems in tutorials and two of three STACK questions during the semester test.

B. Stage 2 - Feelings

1) ***Cognitive:*** Students felt they learned the work better because of STACK. Their confidence was boosted when they finally got to the correct answer to a question.
2) ***Affective:*** Students generally enjoyed doing STACK questions. They felt good every time the system showed them their answer is 100% correct. The STACK questions caused significant additional stress during the semester test.
3) ***Systemic:*** At times, students were irritated by the STACK interface.

C. Stage 3 - Evaluation

1) ***Cognitive:*** Overall, students learned better by doing STACK questions. They worked on a problem until they got to the correct answer.
2) ***Affective:*** Students appreciated the interactive nature of learning with STACK.
3) ***Systemic:*** The interface was troublesome at times. They may have found the correct answer, but if they made a typing error, the mistake was penalised in the same way as a conceptual error.

The hints were not always useful. They may convey information that the students already knew and used in the problem.

The CAA system was always available online. It was noticeably slower during the semester test, but it never mal- functioned.

D. Stage 4 - Analysis

1) ***Cognitive:*** The STACK questions allowed students to get to a point where they know how to solve the given problems. The process is different to the traditional approach. With the traditional approach, students would be given a question to do and get feedback on their solution a few days later. Or they may be given a question as well as the final answer. However, with the STACK approach, students are more engaged with the problem. They would critically review their solution after every attempt, each time getting a hint that, hopefully, guides them towards the solution. When the students have entered an answer into the system, they know immediately if their answer is correct.

All the groups were able to solve both problems of the tutorial. Figure 1a shows the distribution of the number of attempts each group required to solve the problems. If students did not get feedback, as in a traditional tutoring session, they would only have had one attempt. Figure 1a shows that only 30% of the groups were able to solve problem 1 with the first attempt and only 53% were able to solve problem 2 with the first attempt. However, because of the feedback system, all the groups were able to solve both problems during the tutorial session.

To find the solutions to tutorial problems, students needed to work through one or two pages of maths. The questions were as difficult as it gets, and it took up to an hour to complete one question. It is remarkable that a system such as this works well for mathematical problems that have solutions spanning one or more pages.

Most students did not collect their marked tutorials, which means they did not review the feedback they got for the way they presented their answers. However, if they were not marked for their presentation, they would most probably not have done it. When students are required to submit a neatly written solution, they at least make an effort to organize their ideas and present their work clearly. This in itself may be valuable enough without them looking at the feedback.

2) ***Affective:*** The STACK questions did not work well as semester test questions. The main reason is that students were under pressure during a semester test. Getting immediate feed- back that their answer was not correct added more pressure. Furthermore, it took much longer to do a STACK question than it does to do that same question in a traditional handwritten manner. The reason is that students had to review their work if the STACK system showed them it is incorrect, whereas with a traditional approach they would not know their answer is incorrect.

3) ***Systemic:*** The hints that the system provided were mostly useful, but not always. Nevertheless, the system in- dicated to students if an answer was incorrect and they were given another try. They kept reviewing their work even though the hint was not useful.

STACK questions did not work well for the semester test. With a traditional semester test, the lecturer could announce corrections in the paper during the test, without affecting the class too much. It is much more difficult to make corrections to an online test while the test is being written. If a question in a traditional semester test is unclear or if many students interpret the question differently, it is relatively easy to adjust the memo afterwards and accommodate answers that are not exactly like the memo. This was impossible for the way the online test was implemented.

Students needed little help from teaching assistants during the tutorials. The hints with each incorrect answer allowed all the groups to get the correct answer within the maximum allowed number of tries. It might have happened that groups shared answers to avoid getting zero marks for the STACK part of the tutorial. Even if this happened, the STACK questions still encouraged students to keep working on the solution until they understood it well.

It appeared that students tried to get the entire solution correct, not just the final answer. The fact that students had to submit a complete written solution probably contributed to this.

E. Stage 5 - Conclusion

1) ***Cognitive:*** Students benefited from immediate feedback. They were able to solve difficult problems with minimal help from teaching assistants or the lecturer. At the end of every tutorial session, all the groups managed to solve all the problems.

2) ***Affective:*** Students enjoyed immediate feedback and noticed how their confidence increased every time they solved a problem.

The interface sometimes caused frustration.

3) ***Systemic:*** The STACK questions should be carefully programmed so that it does not mark an answer incorrect that is technically correct. In other words, it should assess the answer in a way the lecturer would assess the answer.

F. Stage 6 - Action plan

1) ***Cognitive:*** Keep using STACK questions in practice problems and tutorials, but do not use them in semester tests. Create more questions for practice problems. Students do the practice problems when they are at home, while they are working through the material. The practice problems will help them evaluate their level of understanding and supply them with hints that they can use to reread the textbook.

2) ***Affective:*** Make students aware of how they learn and how the system helps them to learn. The STACK questions are a useful tool that complements other tools like practicals, lectures, online videos and so on.

Address the problems with the interface that irritate stu- dents.

3) ***Systemic:*** The existing STACK questions should be refined and debugged so that they behave in the way one would expect. Investigate other interfaces that students can use to enter their answers. A what-you-see-is-what-you- get equation editor will be best.

New questions should be thoroughly tested before they are used by students.

VI. CONCLUSION

This paper reflects on an approach to assess the answers of students to typical mathematical problems. The approach was two-fold: it used STACK questions to provide immedi- ate feedback; and assigned a separate mark for the written solution.

Overall, the use of STACK questions was successful. It helped students to develop their problem-solving skills by providing immediate feedback. The system allowed all the students to solve all the tutorial problems during the face-to- face sessions. This is in contrast to traditional tutorial sessions, where few student are able to solve all the tutorial problems.

The written solutions of students were marked to encourage students to develop their skill of presenting a solution in an logical and professional manner. Most students did not collect their marked solutions to see the feedback. It is therefore not clear how well the students' skills to present their calculations have been developed. Despite this, it is still useful that students were required to neatly write out their final solutions. A neatly written out solution helped them to consolidate what they have learned.

The study did not manage to measure the usefulness of giving students a separate mark for the written solution. This is an important limitation which future work should address.

REFERENCES

[1] MB Mtshali. Qualification Standard for Bachelor of Science in Engi- neering (BSc(Eng))/ Bachelors of Engineering (BEng): NQF Level 8. Engineering Council of South Africa, 2019.

[2] J Hattie and H Timperley. The power of feedback. Review of educational research, 77(1):81–112, 2007.

[3] G Anthony and M Walshaw. Effective pedagogy in mathematics, volume 19. International Academy of Education Belley, France, 2009.

[4] S Trenholm, L Alcock, and C Robinson. An investigation of assessment and feedback practices in fully asynchronous online undergraduate mathematics courses. International Journal of Mathematical Education in Science and Technology, 46(8):1197–1221, 2015.

[5] KM Shea. Beyond clickers, next generation classroom response systems for organic chemistry. Journal of Chemical Education, 93(5):971–974, 2016.

[6] SI Rooney, JL McGurk, ER Elliott, UJ Williams, and LD Segan. Facil- itating the transition of a traditional engineering course to a structured, active, in-class learning environment as a teaching assistant. In 2015 ASEE Annual Conference & Exposition, pages 26–755, 2015.

[7] N Quirke-Bolt. The effects of peer feedback, within an 'assessment as learning' approach, on the learning and development of student-teachers. Practitioner Research in Higher Education, 13(1):27–36, 2020.

[8] T Pelkola, A Rasila, and C Sangwin. Investigating bloom's learning for mastery in mathematics with online assessment. Informatics in Education, 17(2):363–380, 2018.

[9] CJ Sangwin. Assessing elementary algebra with stack. International Journal of Mathematical Education in Science and Technology, 38(8):987–1002, 2007.

[10] J Biggs and C Tang. Teaching for quality learning at university. McGraw-hill education (UK), 2011.

[11] G Gibbs. Learning by doing. Further Education Unit, 1988.

[12] A Tait. Planning student support for open and distance learning. Open Learning: The Journal of Open, Distance and e-Learning, 15(3):287– 299, 2000.

Technical papers

Appropriate online laboratories for engineering students in Africa

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***Abstract* — The intensity of engineering practical in a typical African Engineering laboratory is usually low because of several problems such as funding to procure adequate quantity of laboratory equipment, overcrowding due to insufficient workspaces, infrastructural problems such as power and human resource problems, shortage of qualified laboratory technologists or unmotivated faculty members. Creating an environment to use same physical engineering laboratory equipment 24/7 from anywhere will increase the capacity of laboratory facilities. The aim of this project is to design and create features to enable physical engineering laboratory equipment to be used remotely on a 24/7 basis in African higher education institutions. To get started, researchers from the five regions of Africa were assigned to work on basic science and engineering equipment such as calorimeter, pendulum, coefficient of friction apparatus, drilling fluid laboratory. As a proof of concept, the normal manual interface of a simple calorimeter, located in an institution was interfaced with digital communication features and the response on the physical facility was observed through cameras appropriately positioned. Preliminary result for one basic science equipment in the training of engineers confirmed the feasibility of this approach of remote laboratory engagement. Interfacing using existing virtual learning management systems are being further investigated. The use of this approach has potential to increase laboratory capacity as more students can perform their practical at times convenient to them, the remote location, notwithstanding.**

Keywords — Online Laboratory, Africa, Basic Science, Basic Engineering, Engineering Education, Virtual Learning.

I. BACKGROUND

The idea of working remotely on laboratory-based exercises is not new and has been explored for over two decades. The iLabs and Digital Twins (DT) are examples of successfully deployed online laboratory initiatives in Africa and different industries across the world.

A. Digital Twins

A Digital Twin (DT) is a virtual instance of a physical system that is continually updated with the latter's performance, maintenance, and health status data during the physical system's life cycle [1]. The concept of DT was first introduced in 2003 at University of Michigan Executive Course on Product Lifecycle Management [2]. Since then, many researchers have demonstrated its importance and applications in many domains. Fuller et al. [3] presented the challenges, applications, and enabling technologies of DT. Madni et al. [1] focused on the benefits of integrating digital twins with system simulation and Internet of Things (IoT) to support model-based system engineering. Madubuike and Anumba [4] investigated the enhancement of healthcare facilities management using DT with focus on its associated potential benefits. Patros et al. [5] developed a multi- dimensional framework for classifying energy and other DTs and proposed how energy DT can be applied to different phases of the production lifecycle. Laaki et al. [6] focused on DT prototype development for analysing communication requirements in a mission-critical applications such as 4G mobile networks-based support for remote surgery using a robotic arm and virtual reality. The development of a solar power plant DT using ontological engineering approach was carried in [7]. Qi et al. [8] proposed the combination of DT with intelligent manufacturing services to produce more suitable manufacturing planning and precise production control to achieve smart manufacturing.

These researchers have demonstrated the importance of DT in many areas but the huge financial resources required for its creation has so far have restricted DT research and its application domains to large-scale industrial products or projects that can benefits from the use of digital model such as engineering systems, automobile manufacturing, aircraft production, building construction, manufacturing, and power utilities. The application of DT to laboratory equipment to enable students in higher institutions have access to engineering practical remotely has not been sufficiently explored in many African universities.

B. iLabs

iLab operations software is a modular, web-based, asset management software tool designed to support operations for centralised labs and shared resource facilities.

In East Africa, iLABS@MAK was started in 2008 as a research and innovation project under the Department of Electrical and Computer Engineering, Makerere University. Initially, the project's work mainly revolved around the development of online laboratories (iLabs) to support Science and Technology Curricula in Uganda, but over time research into other areas was undertaken. iLabs enable users who are remotely removed from the physical laboratory equipment to interact and experiment with the equipment over a communication network (intranet or internet), thus providing a low-cost, flexible, convenient, and reliable experimentation platform. For more than 12 years iLABS@MAK has been developing iLabs which are used to supplement some of the undergraduate hands-on laboratories at the Department of Electrical and Computer Engineering. We describe three successes at Makerere University, namely:

i. In interactive remote iLab for a wind energy system. This iLab enables remote experimentation via the internet about the variables on which wind power output depends, including wind speed, temperature, humidity, number of turbine blades, and pitch angle. The lab setup consisted of; a wind fan, wind speed sensor, miniature wind turbine, NI ELVIS II prototyping board, and Arduino microcontroller. Figure 1 shows the set of the physical hardware. The user interface of the laboratory which also contains a window for observing a video of the physical equipment relayed in real-time. The lab supports courses about wind energy systems which are offered under the B. Sc. in Electrical Engineering and M. Sc. in Renewable Energy at Makerere University.

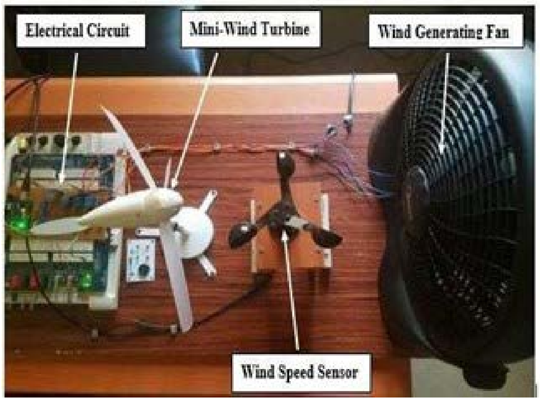

FIGURE 1: *Laboratory set-up of the interactive wind energy iLab*

ii. A remote direct sequence spread spectrum communication lab utilising Emona DATEx. This iLab addresses the key practical aspects of Direct Sequence Spread Spectrum (DSSS) communication. It facilitates real-time control of the equipment with the users able to set, manipulate and observe signal parameters in both the frequency and time domains. Both simulation and data acquisition modes of the experiment are supported which gives a richer learning experience. The lab supports curricula of the B.Sc. in Telecommunication Engineering degree of Makerere University in the courses of Wireless Technologies and Mobile Communication Systems. Figure 2 shows the data acquisition user interface of the iLab.

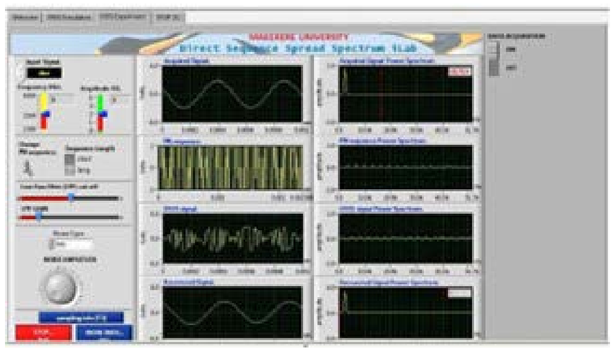

FIGURE 2: *Data acquisition user interface*

iii. An online digital filters and sound effects laboratory utilizing National Instruments Signal Processing Educational Engineering Device for Youth 33 (NI SPEEDY 33) and LabVIEW Digital Signal Processing (DSP) Module. This laboratory supports experimentation about digital filters and sound effects on digital processing techniques. In the lab, the NI SPEEDY is programmed to carry out the different processing on an applied signal at the input. This laboratory supports courses about DSP which are under the programs: B.Sc. in Computer Engineering, B.Sc. in Electrical Engineering, and B. Sc. in Telecommunications in Engineering at Makerere University. Figure 3 shows the demonstration of the Wah- Wah effect using the iLab

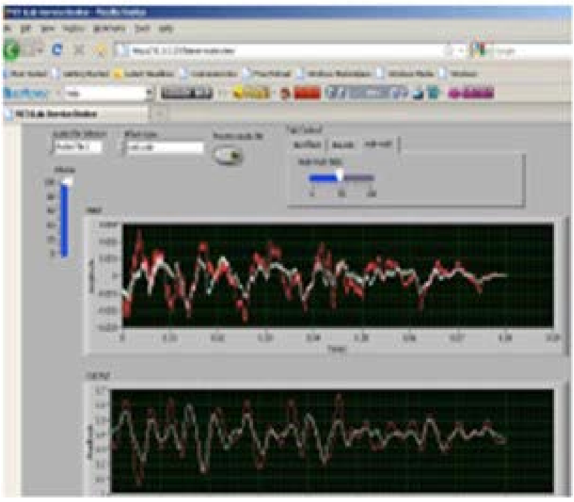

FIGURE 3: *Demonstrating the Wah-Wah effect*

II. MOTIVATION FOR THE PROJECT

These researchers have demonstrated the importance of various initiatives to promote online laboratories, but the huge financial resources required for its creation have so far restricted the research and its application domains to educational systems. The application of online laboratory equipment to enable students in higher institutions have access to engineering practical remotely has not been properly explored in many African universities.

In a study carried out by the African Engineering Deans Council, AEDC, [9], there are over 470 Universities or Higher Educational Institutions (HEI) offering close to 2,500 engineering programmes. The study also shows that there are between 120,000 to 200,000 engineering students in these universities. When the students in the Polytechnics are considered, there will be close to 500,000 students in the engineering and technology programmes in Africa. Thus, the potential for Africa is quite huge.

Generally, education is not well funded in Africa. Table 1 shows public spending on Education as a percent of Gross Domestic Product (GDP) in 14 African countries in 2020.

TABLE 1: ***P****ublic spending on Education, percent of Gross Domestic Product (GDP) in 14 African countries in 2020*

Country	%	Population (2020)
Namibia	9.41	2,540,905
Sierra Leone	9.26	7,976,983
Lesotho	7.38	2,142,249
South Africa	6.84	59,308,690
Swaziland	5.34	1,160,164
Kenya	5.08	53,771,296
Mauritius	4.61	1,271,768
Rwanda	3.41	12,952,218
Tanzania	3.10	59,734,218
Uganda	3.01	45,741,007
Malawi	2.91	19,129,952
Liberia	2.31	5,057,681
Guinea	2.20	13,132,795
Mauritania	1.89	4,649,658
Nigeria	6.7 of Budget	206,139,589

Source: www.Worldometers.info

In 2015, UNESCO member states agreed on a level of educational funding of 4 to 6% of GDP or 15 to 20% of public expenditure. However, the education spending efficiency is low while some are below the UNESCO recommended benchmark of 4 to 6% of GDP and the 6.7% budget allocation to education in Nigeria is below the UNESCO benchmark of is to 20%. The paucity of funds has resulted in inadequate provision of facilities for teaching and research in faculties of engineering in Africa universities. The inadequacy in teaching, laboratory and workshop facilities has contributed to the diminution of the quality of the engineering graduates.

Consequently, the intensity of engineering practical in a typical African Engineering laboratory is usually very low because of funding to procure adequate quantity. Also, overcrowding due to insufficient workspaces and infrastructural problems such as power and human resource problems such as qualified laboratory technologists or unmotivated faculty effects education in Africa. Therefore, creating an environment to use same physical engineering laboratory equipment 24/7 will increase the capacity of laboratory facilities.

III. AIM AND OBJECTIVES

The aim of this project is to design and create features to enable physical engineering laboratory equipment to be used remotely on a 24/7 basis in higher education institutions in African countries. This work aims to address this research gap by developing online laboratories that would facilitate remote access to physical engineering laboratory equipment thereby enabling the sharing of laboratory facilities across African universities. The specific objectives are:

1. Identify engineering laboratory equipment in all engineering disciplines that can be retrofitted to be used remotely for student practical.
2. Design and construct affordable communication interface to the engineering laboratory equipment and provide a platform to validate the online experimental results from the physical equipment.
3. Determine regional or country challenges and processes to ameliorate their impact on engineering experiential learning process.

The research questions are:

a. Are there identifiable laboratory equipment in the engineering discipline that can be retrofitted to be intelligent or quasi-intelligent to enable remote communicability and manoeuvrability?

b. How affordable can the retrofitting of physical laboratory equipment to become an internet of things (IoT) enabled be feasible and achievable through collaboration by African Engineers?
c. Are there solutions to the African regional or country challenges impacting on the engineering experiential learning process?

IV. METHODOLOGY

To get started, researchers from the five regions of Africa were assigned to identify some basic science and basic engineering equipment normally used for teaching engineering students in their first year or preliminary engineering year. Five simple instruments were selected from the large numbers identified equipment, Then, while the regional research activities are on-going, one basic science equipment was chosen to jointly develop a proof-of-concept (POC) design through collaboration by African Engineers. A calorimeter was chosen for the POC. Smart projects were assigned as shown in Table 2. The purpose for the division was to begin to create a regional collaborations format for future research activities.

TABLE 2: *Simple Smart Project Allocation by Africa Regions*

Region	Smart Projects (IoT-enabled)
Western Africa	Constant-Volume Calorimeter
Eastern African	Torsion Pendulum
Central Africa	High Pressure High Temperature (HPHT) Filter Press
Northern Africa	Coefficient of Friction Apparatus
Southern Africa	Specific Gravity Apparatus (Hydrometer)

A calorimeter is a device that is used for measuring the warmth of chemical reactions or physical changes, also as heat capacity. The process of measuring this heat is known as calorimetry. The most common types of calorimeters are Adiabatic calorimeter, reaction calorimeters, Bomb Calorimeters (constant-volume), Calvet-type calorimeters, differential scanning calorimeters, isothermal titration calorimeters. A simple coffee cup constant-volume calorimeter was chosen for the POC study.

The overall project schematic is shown in Figure 4. It shows the calorimeter, the camera, and an android phone. The first stage was to decide on affordable design to make the apparatus smart and Internet of Things (IoT) enabled. Figures 5 and 6 shows the configuration. This consist of the following components that are readily available and affordable.

- GSM Module
- ARDUINO Microcontroller
- Temperature Sensor/Thermocouple
- DC Motor
- DC Heater
- Vero Board/Bread Board
- Portable Solar System (Africa Project)
- Wide angled phone connected on the institution's Learning Management System such as Moodle.

The specific heat at constant volume, cv, shall be determined. The equation used was:

$$q = {}_{cv}(T_f - T_i)$$

where, $c = (^{au})$
ar v

is change in internal energy with temperature at constant volume. The specific heat at constant volume, $_{cv}$, is the energy required to raise the temperature of the unit mass of a substance by one degree as the volume is maintained constant

$_q$ is the amount of heat in joules
T_f and T_i are the final and initial temperatures

The heater and the DC stirrer motor can be started through communication with the GSM module controlled by the microcontroller. The experiment results are entered into the student's mobile phone and heat is calculated. Other calculations can be done if three of the parameters of the equation are available. The display on student phone interface is shown in Figure 7.

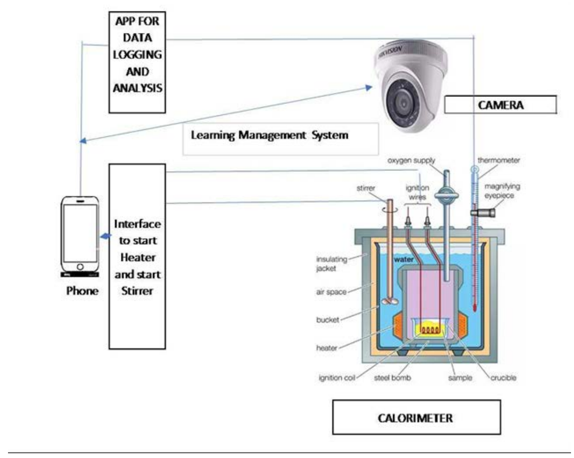

FIGURE 4: *The Project Schematics*

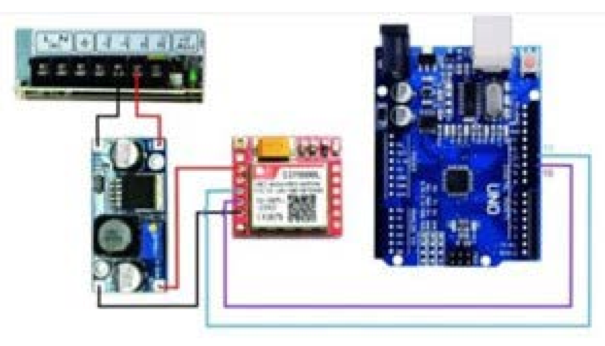

FIGURE 5: *Simple IoT enabled Configuration for Calorimeter*

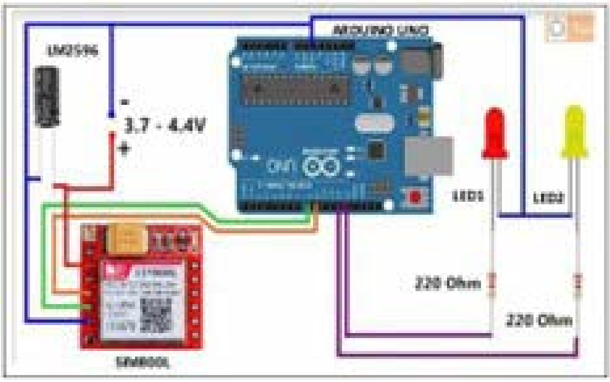

FIGURE 6: *Simple IoT enabled Configuration (stand alone)*

FIGURE 7: *Student's Mobile Phone User Interface*

V. RESULTS AND DISCUSSIONS

Communication between the android phone and the microcontroller were fully established and the application calculated the amount of heat with the experiment data obtained, such as initial and final temperatures, mass of the fluid. The cv is provided. At the point of writing, various experiment configurations were planned across geographic locations within a country and across two African regions but for limitation of time. The workability was however established within the time constraint.

VI. CONCLUTIONS, IMPACT ON ENGINEERING EDUCATION AND FURTHER WORK

Within the time, logistics and inter-regional communications constraints, the objective of designing and constructing an affordable communication interface to a simple basic science laboratory equipment and provide a platform to validate the online experimental results from the physical equipment was achieved.

Communications, especially synchronous communication, such as through zoom, was sometimes a problem and the delays in sending communication codes through GSM was also a problem but could be surmounted with time. Language barriers limited the full involvement of all language blocks in Africa was also encountered. Africa has four language groups, namely, English, French, Portuguese, and Arabic. This however can be surmounted with time. Power and internet communications can be addressed using the AEDC/AEEA project on *Affordable and Reliable Power and Communication Device for Continuous Online Learning for African Students,* Bolu et al, [10].

With regards to the impact on Engineering Education Bolu et al, [11] enumerates some benefits such as:

a. Laboratory exercises can be performed anytime thus increasing laboratory availability especially where laboratory facilities are scarce,
b. Regional industry collaboration will be enhanced,
c. Inter-university collaboration among students across universities in Africa will also be enhanced.
d. Opportunities for the development of software for online connection to laboratory equipment, machines, etc. will increase.
e. The availability of affordable locally made devices for remote laboratory where experiments can be carried out remotely will be extremely beneficial particularly to students. This will enable the students to experiment with alternative means of achieving the desired outcomes and to determine whether these outcomes can be achieved outside the physical setting of a laboratory in an online engineering programme.
f. The availability of these devices will enhance the understanding of the basic engineering concepts by students and will improve their knowledge of the fundamentals of the engineering programmes thus improving the quality of engineering graduates

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REFERENCES

[1] A. Madni, C. Madni, and S. Lucero, "Leveraging Digital Twin Technology in Model-Based Systems Engineering," Systems, vol. 7, no. 1, p. 7, Jan. 2019.

[2] M. Rinaldi, M. Caterino, M. Fera, and R. Macchiaroli, "Reducing the physical ergonomic risk by job rotation: A simulation-based approach," in IFAC-PapersOnLine, 2021, vol. 54, no. 1, pp. 61–66.

[3] A. Fuller, Z. Fan, C. Day, and C. Barlow, "Digital Twin: Enabling Technologies, Challenges and Open Research," IEEE Access, vol. 8, pp. 108952–108971, 2020.

Technical papers

Improvement of student-centred experiential learning in thermofluids laboratory practices

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***Abstract* — Thermodynamics and fluid mechanics are two of the most essential courses in the teaching of engineering, as they appear in every engineering degree programme. They also are complicated subjects for the students to understand without any practical or visual aids. This project aims to improve the experiential learning of engineering students by a safe student- centred design of thermo-fluids laboratory practices. Three different approaches were used in the practices to ascertain which one is the best to implement. A total of 48 students were divided in three groups depending on the background they are provided with before the experiment, namely, no background, explanatory videos, and hand-on computer simulations or programming. In addition to the simulations, C programming of a specific fluid mechanics theory was given, in another course, to the students prior to tests on the same theory in fluid mechanics. Results showed that letting the students start the practices without any visual aid was also really confusing for them. It is unclear if the ones that watched the videos before- hand had a better understanding of the experiments. However, the result showed that hands-on computer programming prior to the tests significantly improved the understanding of the theory as evidenced by the test scores.**

Keywords — visual teaching, education, thermodynamics, laboratory practice, improvement, experiential learning, student- centred, fluid mechanics.

I. INTRODUCTION

Thermodynamics and fluid mechanics are two of the most essential courses of engineering, as they are taught in all the different types of engineering degrees programmes. As a result, it is imperative that the students get a full understanding of the matter. Laboratory practices are essential in the teaching of engineering, as they are the practical implementation of the theory seen in class. It seems that in the teaching of thermodynamics and fluid mechanics, this need for a practical approach is especially important because of the complicated theoretical nature of these subjects. The complement between theoretical and laboratory work are crucial for the development of lifelong learning [1], and to increase the motivation among students, as their experience is dynamic and not monotonous [2]. It also helps develop problem- solving skills for work in companies [3], Skills like foresight in uncertainty, collaborating with others and decision-making taking responsibility [6] are the ones that are essential for all engineers [4][5].

The main focus of professors worldwide has been getting the students to be more engaged during the experiments because the current traditional way of approaching laboratory practices does not motivate the students to critically engage in the experiments, it rather directs them to opt for a more superficial and targeted learning approach [7]. The desired change is achieved by many ways. One of them is an open-ended project, even though there is research that suggest that this is not a good idea for engineering students [8]. This means that the students are given an assignment and with it, freedom to reach a possible solution. The idea is for them to solve problems by using critical and creative thinking, as "learning is best conceived as a process, not in terms of outcomes" [9]. Usually, these projects are given to teams, which also provides the students with the ability to cooperate and to collaborate with their classmates with an objective in mind. The main problem is that the students need to learn how to manage the laboratory material, and this can only be done in a structured orderly way, without leaving too much room for improvising. Therefore, in the research, the process discussed to reach the desired open-end laboratory is a slow one, that begins in the first year with a more fixed laboratory practices and ends in the final project for the degree, which should be quite open [10]. Students are not given any direct responsibility from the beginning of their academic career. This technique shows that an open-ended project provides them with a deeper understanding of the matter [11] [12] [13], it also provides them with communication skills [14].

The second way that is explored is the student-centred approach. This idea basically means that the students are the ones that should drive the laboratory, with the staff only serving as assistance for any problems or doubts that they may have [15] [16]. This will necessarily increase their involvement in the practices, as they will not have the option of sitting back and checking out of the practice, the students will need to dive in to the experiment and make decisions if they want to finish it on time [17] [18]. However, as mentioned before, they will not be alone, as they will have questions, and the staff has to make sure that the safety requirements are met throughout the whole of the laboratory practices [19] [20] [21]. This approach motivates creative problem solving in students, as they are not being spoon-fed with everything [22], it also increases student satisfaction, as their responsibilities increase [23]. The data in some research show a better performance of the students that follow this approach [24]. It is also crucial to help visualise the theory if the students are to be engaged, it is obvious that the less you understand something, the more likely you are going to find it dull [25]. This is an idea that has proven to be useful is the use of computer simulations before conducting the experiments [26] [27]. For individual work and data collection, the simulated experiments are better than the hands-on ones. Nonetheless, for groups, the work, data collection and motivation are higher if indeed the team worked as a group [28]. Therefore, a combination of both ways of teaching could improve the learning experience of the students overall, especially if they were to do the simulation before the experiment, and in this way, they could draw connections between the two [29] [30]. There is an innovative approach that consists of using video and simulation before the experiment, and afterwards, a laboratory report is expected from the students. The results of the study showed that both the video and the simulations really helped the students to understand better the real laboratory experiment, resulting in a better understanding of the theory [31]. Another technique that is widely being implemented is group activities [32] [33], which helps the student develop teamwork skills as communication, leadership, time management and collaboration among others.

The students are also being asked to embrace an active role in the designing of the courses [34]. Research shows that the student's involvement in the design of the laboratory practical is also desirable [35] [36]. As they can point out some problems that the professors and staff are unable to spot. The possibility of actively participating in the process of developing the laboratories will also give them a sense of ownership of the programme as it should be. Meanwhile the professors and staff will make sure that the technical requirements are met and will also give their opinions to help build up the curricula. Finally, the safety of the laboratory is always an essential topic, especially in engineering laboratories due to the number of accidents that occur, and the severity of them [37] [38] [39]. Great progress is being achieved in this area [40], and the need for teaching the students how they should behave during the practices is clear [41]. Moreover, the time of COVID-19 has also brought some challenges to the laboratory safety requirements.

This project explores the design and implementation of the thermodynamics and fluid mechanics laboratory practices and tries to make them as student-centred as possible, to ensure that the learning experience of the students is improved. This is the first year in the engineering laboratory (which is the second year of a 5-year degree programme) in a university based in Nigeria.

II. JUSTIFICATION OF THE PROJECT

The necessity for this project arose as this is the first year the laboratory practices are to take place at the school of engineering of a university based in Nigeria which is just starting its engineering programme. Therefore, the programme educational objectives of the university must be met and that the mission of this organisation fulfilled when the laboratory practices are designed. A correct design and implementation of laboratory practices that helped teach the students what they saw in class must also be assured. The mission of this university is "forming competent and socially responsible science and engineering professionals who are committed to the promotion of the common good of society and the advancement of the scientific and engineering profession" it then specified that in order to achieve this it is necessary to "Provide practice-based, student-centred and industry-relevant programs that address technical expertise, industrial management and ethical responsibility".

To make sure that this part of the mission is completed, the school has as their four programme educational objectives four areas, namely [43]:

a. Start-ups and innovative Entrepreneurs
b. Researchers
c. Lifelong learning
d. Ethical Professional Engineer

Therefore, the laboratory practices should adhere to these mission statement and objectives that have been defined beforehand. That is why the first set of thermodynamics and fluid mechanics laboratory practices must be designed with these things in mind. To achieve this, it is mandatory to adopt a student-centred mentality and let the practices be student driven, with the professors and staff working as coach to their work. This was strictly followed during all the laboratory exercises conducted in fluid mechanics. Apart from introductory remarks by the instructors and their intervention when very unique challenges are experienced, students were driving the entire process, running the tests and collecting data for their analysis and report buildup.

III. AIM, OBJECTIVES AND RESEARCH QUESTIONS

The aim of this project is to ascertain the effect of the use of videos and simulations in the students' performance in thermodynamics and fluid mechanics theory and laboratory practices. The objectives are as follow:

a. Improve the speed, breadth, and depth of learning of the students, through visual aid in the form of videos and simulations.
b. Integrate the students in the laboratory practices, through teamwork and a student-centred approach, to increase their motivation but working in a safe and comfortable laboratory environment.

The research questions are:

a. which approach should universities adopt to improve the speed, breadth, and depth of learning of the students, through visual aid in the form of videos and simulations when designing laboratory practices to keep them student-centred?
b. Are their improvements on the learning experience in courses such as thermodynamics and Fluid mechanics through teamwork and a student-centred approach?

IV. METHODOLOGY

To fulfil the objectives, the experimental design for teaching these experiments were as follows:

a. First set of experiments for all students: No theory seen before the experiment.
b. Second set of experiments for all students: Theory seen in class before the experiment.
c. Third set of experiments for all students: Theory and video and/or simulation seen in class before the experiment.

The practices are student-driven, with the students manipulated the equipment, the professors and staff did interfere with the ongoing experiments except to prevent dangerous situations or if their help is explicitly asked for by the students. They knew what to do by following the laboratory manuals uploaded in the university's e-learning web site. The students were divided in groups of 4, as there were 48 students in the second year engineering at the school, thus 12 groups.

To assess the student understanding of the concept, test questions were given to all students after completion of some topics in the theory segment. They took the form of standard assignment, Quiz, Oral questions and some objective type tests with additional open-ended questions. Feedback was also obtained using Google Form questionnaire. The students submitted a laboratory report that followed the guidelines of a standard research publication, with abstract, aim and objectives, introduction and background, methodology, results and discussion and conclusion. The result of test and laboratory reports were used to assess the level of learning the students achieved, whereas the feedback form was used to find out what the students' experience had been, and how it can be improved.

Another approach was added during this project. A specific thermo-fluids theory was chosen and used as example on programming in another course on fundamentals of computer-aided engineering. Specifically, Bernoulli equation was chosen. In the computing class it was used as an example to create an overloaded function using Arduino C programming. The equation format used is shown figure 1 and two examples drawn from the students' textbook were used as test cases. At approximately the same period, the Bernoulli theorem was fully introduced in the Fluid Mechanics course.

$$\frac{P}{p} + \frac{V2}{2} + gz = Constant$$

Formal Examination was used as the evaluation method, with the results of Bernoulli Equation compared to results from other course where there were no simulations before theory. Note that both for the theory and practical, all students participated simultaneously in the exercise to eliminate any possibility of non-compliance to ethics with regard to giving undue advantage to any student or group of students above others.

Bernoulli equation states that the sum of the kinetic, potential, and flow energies of a fluid particle is constant along a streamline during steady flow. The two cases used were examples from the Fluid Mechanics textbook [42]. The students were encouraged to vary the parameters of pressure, velocity, height and even density of fluid types. However, during the Fluid mechanics experiments, only water was used using the equipment in the Thermo-Fluids laboratory.

The C programming exercise illustrating the concept of Bernoulli equation was a large tank open to the atmosphere and filled with water of 5 metres from an outlet tap. The tap near the bottom of the tank is opened, and water flows out from the smooth and rounded outlet. The C programme with an overloaded function developed, was used to determine the maximum water velocity at the outlet, assuming the flow was incompressible, irrotaional and quasi-steady state and losses in the tap negligible.

The second programming exercise was a typical children water fun with water flowing from a garden hose. A child places his thumb to cover most of the hose outlet, causing a thin jet of high speed water to emerge. The presuure in the hose just upstreamn of his thumb was given as 400Kpa. The same C Programme, with an overloaded function, was used to determine the maximum height that the jet could achieve, if held upright by the child.

V. LIMITATIONS

This project had some limitations. The first limitation was the equipment, as the school was just getting started, the equipment though of good quality was still being augmented. There was only one unit for each set of equipment. This means that only one group a week were able to carry out the experiments. This was the biggest limitation, as it limited the desired plan to perform the experiment soon after the theory was discussed in class.

The second limitation was the time that the students had at their disposal to carry out and report the practices. They also had other lectures to attend to and complete the assignments, time to relax and time to get involved in other university activities.

Finally, the third limitation was the number of students that attend the laboratory experiments. There were 12 groups of four students each, that take turns for a particular engineering experiment. This means that every week each group did a different experiment to complete the mandatory 12 experiments in the semester for introductory Thermodynamics or Fluid Mechanics.

VI. RESULTS AND DISCUSSIONS

As research has suggested in the past, it was expected that both the simulation and the videos used in preparation for the experiments [25] [26] will help the students understand the laboratory practices and therefore score well in the tests than the ones that lacked the video and simulation background. Following the same reasoning, the students that performed the experiments before having seen the videos and simulations in class were expected to have lower test results than the ones that did. The students were also expected to feel a bit at a loss at the beginning of the practices, as they were given the freedom to conduct the experiment using the laboratory manual only.

The feedback results of the laboratory practice engagements are shown in the Table 1

TABLE 1: *Student Feedback on laboratory engagements*

	INTERVENTIONS							
Level of Agreement	Visuals: Students (%)		Theory: Students (%)		Teacher: Students (%)		Freedom: Students (%)	
Strongly Disagree	56	40	10	7	10	7	47	34
Moderately Disagree	11	8	10	7	18	13	28	20
Disagree	18	13	18	13	15	11	25	18
Agree	31	22	45	32	35	25	23	16
Moderately Agree	14	10	30	21	28	20	12	9
Strongly Agree	10	7	27	19	34	24	5	4
Total	**140**	**100%**	**140**	**100%**	**140**	**100%**	**140**	**100%**

Legend:
Visuals – Do you feel that the videos/simulation you watched helped you in this practice performance?
Theory – Do you feel that you needed more theory to better understand what you were doing?
Teacher – I need more teacher guidance during the practice.
Freedom - I need more freedom during the practice, too much teacher interference.

From the feedback, it was not very clear if the video and visuals assisted learning but did to some extent. Similar results were seen from the quiz, the score just marginally improved. We also observe as follows:

a. Fluid mechanics, before theory, videos, or simulation:

The average mark on the exam was 4/10, and the feedback form was only filled by 6 out of the 12 students that performed the experiments. The students were not able to complete all the experiments. This practice had six of them, and the group that got the furthest only got to the second one, which indicates that they are quite at a loss. This can also be seen in the results of the feedback.

b. Thermodynamics 1, before theory, videos, or simulation:

The average mark of 5.4/10, seemed that this practice was simpler than the fluid mechanics one. All the groups managed to perform 3 out of the 6 experiments of this practice. We also had a bigger participation in the feedback form with 8 out of 12 students filling it out. The results were like the ones obtained in the fluid mechanics practice; the students seemed to be lost with the experiment. But unlike the previous one there was no clear demand for more teacher assistance, or for more interference.

c. Thermodynamics 2, before theory, videos, or simulation The average mark of 5.4/10 was like the earlier experiment. However, all the experiments were completed by all the groups. Unfortunately, the participation in the feedback form was of only 6 out of 12. In this practice seemed to be surer of the need for more theory and more teacher guidance and interference during the experiments.

The results obtained for the use of video did not back up the hypothesis stated earlier, as no results of the test or the feedback form showed any significant improvement on the previous approach, it even showed a poorer performance in some practices. However, there was not enough data to show that there was no relationship between the videos and a better performance in the laboratory.

d. Fluid Mechanics on Bernoulli equation C Programming:

The results using the Fluid mechanics Bernoulli equation are presented for the mechanical engineering and the electrical engineering students in Figure 1.

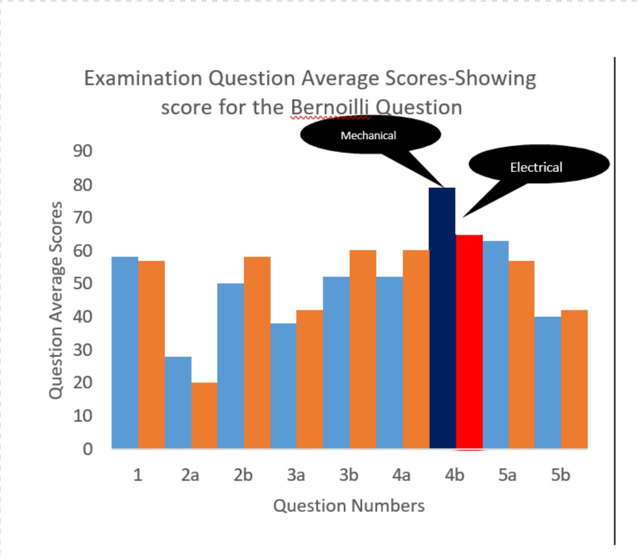

FIGURE 1: *Fluid Mechanics on Bernoulli equation C Programming Mechanical & Electrical Engineering students*

For the performance of students with hands-on C programming experience, the result clearly showed that hands-on computer programming prior to the tests significantly improved the understanding of the theory as evidenced by the test scores. The mechanical engineering students did a little better than the electrical/electronic engineering students possible due to their interest in Fluid Mechanics which is mandatory for them in the higher programme levels.

VII. CONCLUSIONS, IMPACT ON ENGINEERING EDUCATION AND FURTHER WORK

The conclusions that can be drawn from this research are firstly, the students seem to be lost without any visual aid facilitated before the laboratory practices. Their test scores are low, and they ask for more teacher assistance and for more theory before the experiments. Secondly, the effect of the videos is still unclear, as the data obtained in this research so far is inconclusive. The data obtained so far does not show an improvement on the performance of the student who had not seen the video. Thirdly, it clear that with more engaging simulation such as was done using the Arduino C programming exercises, the students understood the concept a lot better.

The impacts on engineering education are many. Firstly, this will motivate faculty members to invest time is providing visual and relevant engaging simulations for their courses. Secondly, the need for faculty to work as a team by exploring the possibility of teaching difficult theories by innovative approaches other than the traditional class lectures, such as programming projects. Finally, dropouts of students from engineering programmes due to difficulties in understanding theories of the fundamental courses could be reduced as interest is generated by student-centred activities.

Further work needs to be done in this research. First, more data is needed to ascertain the effect of showing videos before the experiments. Secondly, to study the effect of simulations on the students before they carry out the practices is the necessary in to ascertain if the simulations are more beneficial than the videos or if they do not contribute to the improved students' experience. Lastly, it would be good to obtain data from 2-3 academic calendar of laboratory practices and carry out a statistical test to explore their correlation.

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REFERENCES

[1] Sokrat, H., Tamani, S., Moutaabbid, M., & Radid, M. (2014). Difficulties of Students from the Faculty of Science with Regard to Understanding the Concepts of Chemical Thermodynamics. Procedia - ocial and Behavioral Sciences, 116, 368–372. https://doi.org/10.1016/j.sbspro.2014.01.223

[2] Ahmed, S. (2018). TEACHING AND ASSESSING LIFELONG LEARNING IN LABORATORY COURSES. Proceedings of the Canadian Engineering Education Association (CEEA). Published. https://doi.org/10.24908/pceea.v0i0.10140

[3] Budihal, S., Patil, U., & Iyer, N. (2020). An Integrated approach of course redesign towards enhancement of experiential learning. Procedia Computer Science, 172, 324–330. https://doi.org/10.1016/j.procs.2020.05.052

[4] Hayes, J., Maslen, S., Holdsworth, S., & Sandri, O. (2021). Defining the capable engineer: Non-technical skills that support safe decisions in uncertain, dynamic situations. Safety Science, 141, 105324. https://doi.org/10.1016/j.ssci.2021.105324

[5] Burkholder, E., Hwang, L., & Wieman, C. (2021). Evaluating the problem- solving skills of graduating chemical engineering students. Education for Chemical Engineers, 34, 68–77. https://doi.org/10.1016/j.ece.2020.11.006

[6] Lyu, W., & Liu, J. (2021). Soft skills, hard skills: What matters most? Evidence from job postings. Applied Energy, 300, 117307. https://doi.org/10.1016/j.apenergy.2021.117307

[7] López-Fernández, D., Ezquerro, J. M., Rodríguez, J., Porter, J., & Lapuerta, V. (2019). Motivational impact of active learning methods in aerospace engineering students. Acta Astronautica, 165, 344–354. https://doi.org/10.1016/j.actaastro.2019.09.026

[8] Castaldi, P., & Mimmo, N. (2019). An Experience of Project Based Learning in Aerospace Engineering. IFAC-PapersOnLine, 52(12), 484–489. https://doi.org/10.1016/j.ifacol.2019.11.290

[9] Lenihan, S., Foley, R., Carey, W., & Duffy, N. (2020). Developing engineering competencies in industry for chemical engineering undergraduates through the integration of professional work placement Thermodynamics equipment 2 and engineering research project. Education for Chemical Engineers, 32, 82–94. https://doi.org/10.1016/j.ece.2020.05.002

[10] Joshi, A., Desai, P., & Tewari, P. (2020). Learning Analytics framework for measuring students' performance and teachers involvement through problem based learning in engineering education. Procedia Computer Science, 172, 954– 959. https://doi.org/10.1016/j.procs.2020.05.138

[11] Spearrin, R. M., & Bendana, F. A. (2019). Design-build-launch: a hybrid project- based laboratory course for aerospace engineering education. Acta Astronautica, 157, 29–39. https://doi.org/10.1016/j.actaastro.2018.11.002

[12] M., K. (2020). Evaluating a First-Year Engineering Course for Project Based Learning (PBL) Essentials. Procedia Computer Science, 172, 364–369. https://doi.org/10.1016/j.procs.2020.05.056

[13] Mahmoud, A., Hashim, S. S., & Sunarso, J. (2020). Learning permeability and fluidisation concepts via open-ended laboratory experiments. Education for Chemical Engineers, 32, 72–81. https://doi.org/10.1016/j.ece.2020.05.008

[14] Singh, R., Devika, Herrmann, C., Thiede, S., & Sangwan, K. S. (2019). Research- based Learning for Skill Development of Engineering Graduates: An empirical study. Procedia Manufacturing, 31, 323–329. https://doi.org/10.1016/j.promfg.2019.03.051

[15] Ballesteros, M. N., Sánchez, J. S., Ratkovich, N., Cruz, J. C., & Reyes, L. H. (2021). Modernizing the chemical engineering curriculum via a student-centered framework that promotes technical, professional, and technology expertise skills: The case of unit operations. Education for Chemical Engineers, 35, 8–21. https://doi.org/10.1016/j.ece.2020.12.004

[16] Chen, W., Shah, U., & Brechtelsbauer, C. (2016). The discovery laboratory – A student-centred experiential learning practical: Part I –Overview. Education for Chemical Engineers, 17, 44–53. https://doi.org/10.1016/j.ece.2016.07.005

[17] Burkholder, E., Hwang, L., Sattely, E., & Holmes, N. (2021). Supporting decision-making in upper-level chemical engineering laboratories. Education for Chemical Engineers, 35, 69–80. https://doi.org/10.1016/j.ece.2021.01.002

[18] Negro, C., Merayo, N., Monte, M., Balea, A., Fuente, E., & Blanco, A. (2019). Learning by doing: Chem-E-Car® motivating experience. Education for Chemical Engineers, 26, 24–29. https://doi.org/10.1016/j.ece.2018.12.003

[19] Rossiter, J. (2020). Blended Learning in Control Engineering Teaching; an Example of Good Practice. IFAC-PapersOnLine, 53(2), 17252–17257. https://doi.org/10.1016/j.ifacol.2020.12.1797

[20] Rossiter, J., Barnett, L., Cartwright, E., Patterson, J., Shorten, N., & Taylor, J. (2017). Encouraging student learning of control by embedding freedom into the curriculum: student perspectives and products. IFAC-PapersOnLine, 50(1), 12149–12154. https://doi.org/10.1016/j.ifacol.2017.08.2155

[21] Shah, U., Inguva, P., Tan, B., Yuwono, H., Bhute, V. J., Campbell, J., Macey, A., & Brechtelsbauer, C. (2021). CREATE labs – Student centric hybrid teaching laboratories. Education for Chemical Engineers, 37, 22–28. https://doi.org/10.1016/j.ece.2021.07.004

[22] Shah, U. V., Chen, W., Inguva, P., Chadha, D., & Brechtelsbauer, C. (2020). The discovery laboratory part II: A framework for incubating independent learning. Education for Chemical Engineers, 31, 29–37. https://doi.org/10.1016/j.ece.2020.03.003

[23] Zhang, M. J., Newton, C., Grove, J., Pritzker, M., & Ioannidis, M. (2020). Design and assessment of a hybrid chemical engineering laboratory course with the incorporation of student-centred experiential learning. Education for Chemical Engineers, 30, 1–8. https://doi.org/10.1016/j.ece.2019.09.003

[24] Gómez-Tejedor, J. A., Vidaurre, A., Tort-Ausina, I., Mateo, J. M., Serrano, M. A., Meseguer-Dueñas, J. M., Martínez Sala, R. M., Quiles, S., & Riera, J. (2020). Data set on the effectiveness of flip teaching on engineering students' performance in the physics lab compared to Traditional Methodology. Data in Brief, 28, 104915. https://doi.org/10.1016/j.dib.2019.104915

[25] Fermigier, M. (2017). The use of images in fluid mechanics. Comptes Rendus Mécanique, 345(9), 595–604. https://doi.org/10.1016/j.crme.2017.05.015

[26] Granjo, J. F., & Rasteiro, M. G. (2020). Enhancing the autonomy of students in chemical engineering education with LABVIRTUAL platform. Education for Chemical Engineers, 31, 21–28. https://doi.org/10.1016/j.ece.2020.03.002

[27] Thees, M., Kapp, S., Strzys, M. P., Beil, F., Lukowicz, P., & Kuhn, J. (2020). Effects of augmented reality on learning and cognitive load in university physics laboratory courses. Computers in Human Behavior, 108, 106316. https://doi.org/10.1016/j.chb.2020.106316

[28] Domínguez, J., Miranda, R., González, E., Oliet, M., & Alonso, M. (2018). A virtual lab as a complement to traditional hands-on labs: Characterization of an alkaline electrolyzer for hydrogen production. Education for Chemical Engineers, 23, 7–17. https://doi.org/10.1016/j.ece.2018.03.002

[29] Falloon, G. (2019). Using simulations to teach young students science concepts: An Experiential Learning theoretical analysis. Computers & Education, 135, 138–159. https://doi.org/10.1016/j.compedu.2019.03.001

[30] Seifan, M., Robertson, N., & Berenjian, A. (2020). Use of virtual learning to increase key laboratory skills and essential non-cognitive characteristics. Education for Chemical Engineers, 33, 66–75. https://doi.org/10.1016/j.ece.2020.07.006

[31] Chowdhury, H., Alam, F., & Mustary, I. (2019). Development of an innovative technique for teaching and learning of laboratory experiments for engineering courses. Energy Procedia, 160, 806–811. https://doi.org/10.1016/j.egypro.2019.02.154

[32] [32] Pawar, R., Metri, R., Sawant, S., & Kulkarni, S. (2020). Evolving Product Development Skills Through Group Based Activity Instructions in Engineering Exploration Course. Procedia Computer Science, 172, 314–323. https://doi.org/10.1016/j.procs.2020.05.051

[33] Najdanovic-Visak, V. (2017). Team-based learning for first year engineering students. Education for Chemical Engineers, 18, 26–34. https://doi.org/10.1016/j.ece.2016.09.001

[34] Augusto, P. A., Castelo-Grande, T., & Estevez, A. M. (2019). Practical demonstrations designed and developed by the students for pedagogical learning in transport phenomena. Education for Chemical Engineers, 26, 48–57. https://doi.org/10.1016/j.ece.2018.10.002

[35] Balamurugan, V., & Uppalapati, D. (2020). Effects of regular feedback on adaptive teaching. Procedia Computer Science, 172, 811–816. https://doi.org/10.1016/j.procs.2020.05.116

[36] Inguva, P., Lee-Lane, D., Teck, A., Anabaraonye, B., Chen, W., Shah, U. V., & Brechtelsbauer, C. (2018). Advancing experiential learning through participatory design. Education for Chemical Engineers, 25, 16–21. https://doi.org/10.1016/j.ece.2018.10.001

[37] Amaya-Gómez, R., Dumar, V., Sánchez-Silva, M., Romero, R., Arbeláez, C., & Muñoz, F. (2019). Process safety part of the engineering education DNA. Education for Chemical Engineers, 27, 43–53. https://doi.org/10.1016/j.ece.2019.02.001

[38] Moreira, F. G., Ramos, A. L., & Fonseca, K. R. (2021). Safety culture maturity in a civil engineering academic laboratory. Safety Science, 134, 105076. https://doi.org/10.1016/j.ssci.2020.105076

[39] Pollock, M., & Sorensen, E. (2021). Reflections on inherently embedding safety teaching within a chemical engineering programme. Education for Chemical Engineers, 37, 11–21. https://doi.org/10.1016/j.ece.2021.07.001

[40] Yang, Y., Reniers, G., Chen, G., & Goerlandt, F. (2019). A bibliometric review of laboratory safety in universities. Safety Science, 120, 14–24. https://doi.org/10.1016/j.ssci.2019.06.022

[41] Viitaharju, P., Yliniemi, K., Nieminen, M., & Karttunen, A. J. (2021). Learning experiences from digital laboratory safety training. Education for Chemical Engineers, 34, 87–93. https://doi.org/10.1016/j.ece.2020.11.009

[42] Yunus Cengel, John Cimbala, (2020), Fluid Mechanics: Fundamentals and Applications, 4th Edition, McGraw-Hills

Technical papers

Continuous assessment in a large first-year engineering mechanics course: The effect of participation and performance in compulsory and voluntary assessments on final grades

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***Abstract* — This paper presents a study on continuous assessment (CA) in a first-year engineering course at a South African University. CA is widely used to encourage active learning and keep students up to date with work. The use of CA has largely been shown to result in an improvement in student performance when compared to the use of final examinations only. This study showed that performance in low-stakes, formative automatically assessed online quizzes had a moderate positive correlation with the semester grade, and weak positive correlation with overall final results. This indicates that the assessments are performing well in keeping students up to date with work, and thus preparing them for higher stakes, summative assessments. The ability to use CA results to flag students early in the semester with a medium to high-risk of not achieving exam entrance or failing the module was noted. Students that participated in additional voluntary CA activities showed a significant improvement in success in the module. Student perceptions identified the CA quizzes as overall the most beneficial activity to improving performance; comments on reasons for this align to the instructive nature of this assessment technique.**

Keywords — continuous assessment, student performance, online quizzes

I. INTRODUCTION

Continuous assessment (CA) refers to the process of assessing students throughout the duration of a module or course, instead of using only a test or exam on completion to assess knowledge. This can take the form of quizzes, weekly class tests and mid-term tests/exams, amongst others [1]. CAs are widely used to encourage active learning and keep students up to date with work; these assessments allow close alignment between instructional and assessment methods thus enhancing students' learning and creating an opportunity for reflective practice for staff to drive decision making for improvement [2,3]. CA is important in engineering programmes as both local [4] and international [5] engineering degree accreditation criteria and international agreements such as the Bologna Process [3, 6] require the inclusion of a continuous process to assess learning progress and student achievement.

The use of continuous assessments has largely been shown to result in an improvement in student performance when compared to the use of final examinations only. [1] conducted a review of 88 papers on the use of CA and the influence on student grades across disciplines in higher education. A vast majority of the studies (77) found positive results of either the influence of CAs on student performance (compared to use of final assessments only) or correlations between CA performance and final grades. Additional engineering-specific examples of improvement in student performance due to continuous assessment are given by [3, 7, 8].

This study considers the use of multiple weekly automatically assessed online quizzes as a form of continuous assessment; the two main advantages of these quizzes are the ease of large group assessment and the ability to keep students on track [1]. The impact on instructor effort due to continuous assessment is noted in [3]; online quizzes mitigate this, particularly if these can be reused from year to year.

II. BACKGROUND

This research focuses on the presentation of a compulsory first-year engineering statics module with large student numbers. The module is termed a "high-impact module" as the consequence of failure is significant; for the majority of students (depending on degree programme), failure in this module would add an extra year to the duration of their degree. Strategies to ensure student success and identify students needing additional assistance early on are therefore key. The presentation of the module in 2021 was used for this research.

This module was presented over 12 teaching weeks with two test weeks when the semester tests are written (after Week 4 and 9). Multiple continuous assessment methods were used including weekly online quizzes, class tests and semester tests. All the assessments contribute to the semester grade, with the bulk of the contribution from the semester tests (75%) and class tests (15%). Tests and exams aim to assess conceptual understanding. The online quizzes contribute 8% to the semester grade, with the final 2% from attendance in tutorials. These quizzes are considered low-stakes assessments as the student's performance in each quiz has marginal impact on the student's grade [9]. The semester grade and exam grad contribute equally to the final grade.

Two types of compulsory online quizzes were used: lecture assignments (LAs) and tutorial preparations (TPs). LAs assess fundamental concepts and theory for each lecture unit; these involve multiple choice answers or simple calculations. TPs assess basic principles and problems; these involve slightly more complex calculations. For each LA and TP, a student has two available attempts contributing to the formative nature of these assessments; the attempt with the higher score is used for the semester grade. The questions ar selected from a pool of available questions, and the variables in calculation-based questions are randomized, thus ensuring that even if students are working together, they still need to complete their own set of questions.

Voluntary practice worksheets were made available to students; these did not contribute to the semester grade. These worksheets have the same examples discussed in the weekly tutorial sessions where students complete a set of example problems with guidance from tutors where required. The variables were randomized and the worksheet is provided in an online, automatic format. Students enter the solutions into the quiz and receive an immediate indication of whether the solution is correct or not and can opt to reveal the actual answers. The worksheets thus do not offer the opportunity to test conceptual knowledge with new problems, but rather to revise calculation procedures that would have been reviewed in the tutorial sessions. As the worksheets were an adaptation of existing tutorial worksheets, the time required to set up these online worksheets was not extensive (4 – 5 hours per worksheet). The value of these worksheets is that they can be reused for as long as the course content remains similar.

The objective of this research was to study the effect of formative assessment on student learning by determining relationships between participation and performance in various CA activities to module outcome. Grades were used as a proxy for learning according to the philosophy noted by [1]. The research questions asked:

a) How does a student's participation and performance in low-stakes CA quizzes correlate to overall module performance and likelihood of success?
b) To what extent can these results be used as a tool to provide early identification of poorly performing students that are likely not to succeed with the module?
c) How are the voluntary practice worksheets being used, and does this contribute to student learning and performance?
d) What are the student's perceptions of the CA activities?

III. METHODOLOGY

The number of students registered for the module changes during the semester. This is due to students either being removed from the class list due to not meeting the prerequisites or choosing to deregister before the last day of classes due to poor performance. Historically there is a large drop in registered students in the last week when semester grades are finalized. An overview of the number of registered students at key points in the semester is shown in Figure 1.

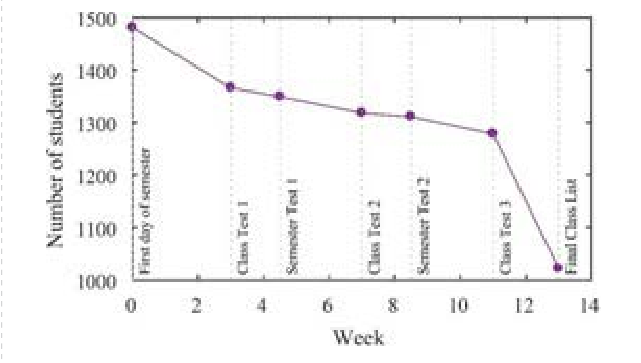

FIGURE 1: *Students enrolled in module over the course of the semester*

The evaluation of the CA relationship to student performance was conducted using the list of registered students on the date of Class Test 3 (Week 11). Students still registered for the module at this point were deemed most likely to be actively participating in the module until this date. Using this class list ensures that predictions of module performance using continuous assessment results can capture the likelihood of students not succeeding due to choosing to deregister whilst having fully participated in the module. Additionally, students with a semester grade of 0 (21 students) and students with pending disciplinary investigations (26 cases) were removed from the sample set to prevent artificial skewing of the results. The total number of students used in the further analysis of results was 1231. Each student's module outcome was categorized as either: pass (minimum final grade of 50%), fail (achieved exam entrance with a minimum semester grade of 40%, but did not pass), no exam entrance (semester grade below 40%) and deregistered (student does not appear on final module class list).

A quantitative data analysis was conducted using the results of 24 LAs (approx. 2 per week), 12 TPs (1 per week), and final semester and exam grades. For each CA activity, the number of attempts made per student and the performance in each attempt was extracted. Where there were multiple attempts at an activity, the higher result was used. These results were assimilated into a weekly participation rate (number of attempts in all CAs to date divided by the total number of available attempts, expressed as a percentage) and performance (average of all CAs to date) for each student. Spearman's rank correlation coefficients, p, were calculated between CA participation and performance, and overall module performance [10]. This measures the strength and direction of the relationship between two parameters; [10] uses p = 0.7-0.9 as indicative of a high variable correlation, with 0.5-0.7 moderate, 0.3-0.5 weak and <0.3 no correlation. Participation data from 11 voluntary practice worksheets (1 per week, excluding final week) were evaluated to determine how these practice worksheets were being used by the students, and if there was any impact on student performance. The number of total attempts on all worksheets made by each student, as well as the number of separate worksheets attempted was determined. Student scores in the worksheet were not considered, only participation was. Correlations between participation in voluntary activities and semester grade and module outcome were made.

Qualitative data from the open-ended questions in two student feedback surveys conducted during and on completion of the module were used to identify student perception of contributions to success. The survey was anonymous; all registered students at the time of the survey were invited to respond. These students are thus not exactly correlated to the students in the CA sample set. The first question asked, "What worked for you in the module?" and the second requested students to "Elaborate on which topics, materials, online activities and assessment tasks that contributed to your learning and development in this module." The first survey was completed by 284 students (1376 registered students); the open-ended questions were answered by 104 and 92 students respectively. The corresponding numbers for the second survey were 232/1315, with 95 and 79 open-ended responses. The responses were analysed through a preliminary content analysis method; the frequency and content of responses within identified categories were noted [10].

IV. RESULTS

A. CA correlation to module performance and success

The student participation and performance in the CAs over the course of the semester is shown in Figure 2. A participation of 100% indicates that both available attempts for all the assessments were used. Participation in TPs was marginally lower than LAs, with corresponding but slightly more marked behaviour in the performance. The TPs require more time and effort to complete, thus lower participation (due to increased time requirement) and lower performance (due to higher level of understanding required to complete) are expected. As the semester progresses there is a marginal decline in participation, except for a jump in the TPs after the completion of the first semester test (after Week 4). For all assessments, there is a steady decline in performance over the semester; this corresponds to generally weaker understanding as the content progresses and builds on prior knowledge.

The correlations of CA participation and performance to semester and final grades are shown in Table 1 for the combined CA results (50% LA; 50% TP). The correlations are all positive; CA participation has a weak correlation to semester grade, but no correlation to final grade. CA performance correlates moderately to semester grade and weakly to final grade. These correlations indicate that the combined results could be a useful tool to predicting overall module performance. The correlations for the combined results are shown in Figure 3. As there is a stronger correlation to the semester grade, the CA results are more likely to give a better indication of if student is likely to make exam entrance or not (based on a minimum semester grade of 40%), than give strong indication of overall success in the module (based on a minimum final grade of 50%). The improvement in student performance using CA is consistent with literature on this topic [1, 3, 7, 8].

B. Module outcome as a function of CA performance

The combined CA mark was grouped according to the final module outcome to determine if any trends that distinguish the groups are visible. The final outcomes as discussed previously were: pass, fail, no exam entrance and deregistered. This is key to identifying potential ways to use the continuous assessment results as an early warning flag for students that are needing more support.

The distribution of final CA marks for each category of students is shown in Figure 4. There appears to be a clear separation in performance between the students who were likely to achieve exam entrance and either subsequently passed or failed, and those who deregistered and did not achieve exam entrance. Students that passed had a mean CA performance of 70%, with low numbers of students with marks below 60%. On the contrary, students that did not achieve exam entrance were fairly evenly distributed across the range of possible marks up to approximately 70%, with only one student with a mark above 70%. If these results are to be used to flag students, then it is important to identify if the trend remains noticeable across the semester. The results of the cumulative combined CA performance over the semester for each group are shown in Figure 5. These show that the separations in performance are maintained throughout the semester, with consistent differences from Week 4 onwards.

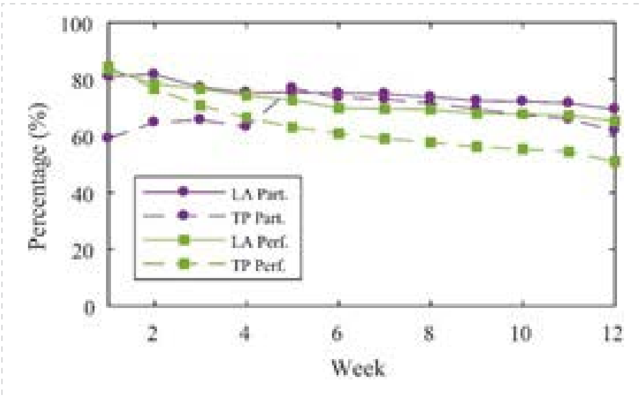

FIGURE 2: Cumulative average participation rate and performance in continuous assessment activities

TABLE 1: Spearman's rank correlation coefficient (ρ) for correlations between CA participation & performance and semester & final grades

	Semester grade	Final grade
CA participation	0.330***	0.088
CA performance	0.610***	0.365***

***p<0.001

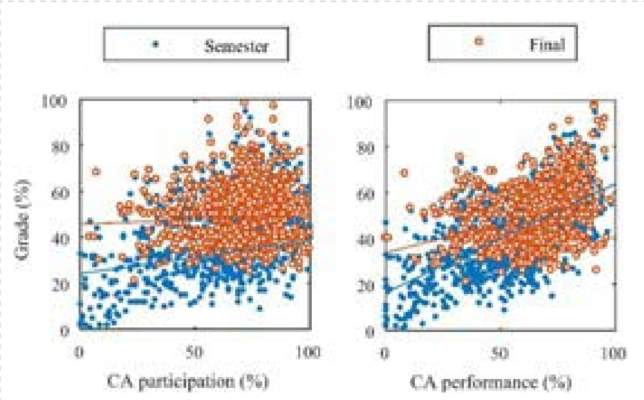

FIGURE 3: Correlation between participation & performance in combined continuous assessments and semester grades (SG) & final grades (FG)

These results were used to determine if there were thresholds of performance that could be used as an early warning mechanism to flag students needing support. This exercise should not result in flagging excessive numbers of students such that it would cause unnecessary alarm and/or result in large numbers of students being nudged thereby rendering the effect negligible. From the histograms, thresholds of above 80%, between 60 and 80%, between 40 and 60% and below 40% were identified. The likelihood of a student either gaining exam entrance or passing the module according to these categories is shown in Figure 6.

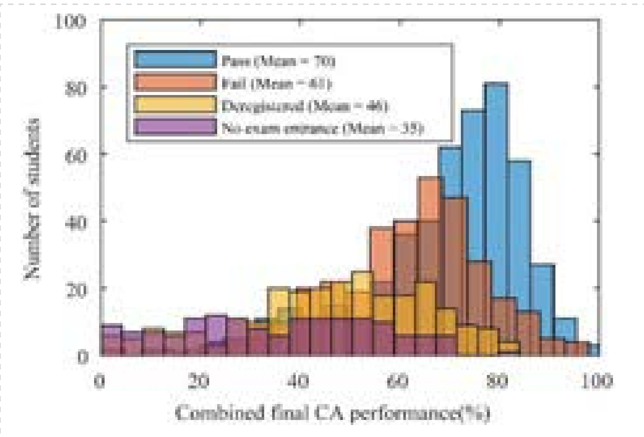

FIGURE 4: Histogram of final combined CA performance according to module outcome

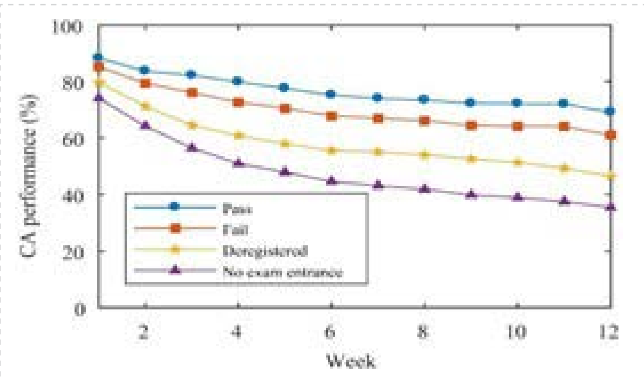

FIGURE 5: Combined CA performance across the semester according to module outcome

These results show that throughout semester, students that have a combined CA performance mark of less than 40% can be identified as having a high risk of not gaining exam entrance (entrance rate approximately 30%) and a very high risk of not passing the module (pass rate approximately 15%). Students with performance from 40 to 60% can be identified as having a medium risk of not gaining exam entrance (entrance rate approximately 50%) and a high risk of not passing the module (pass rate approximately 20%).

The two semester tests are written after Week 4 and 9 respectively; students can thus potentially be flagged as having a reasonable likelihood of "lack of success" in the module after the completion of the Week 3 and 8 CA activities to give time for any intervention to be effected. This would result in 97 students flagged in the high to very high-risk group and 149 students in medium to high-risk group in Week 3. 264 and 165 students would be flagged in the corresponding groups in Week 8. Note that this uses the class list at the end of the semester; more students that deregistered between the start and end of the semester would also potentially be flagged (see Figure 1). Table 2 highlights the continuity of the flagged students; only 18 students flagged in Week 3 improved their performance such that they were not flagged again in Week 8. If a similar exercise is extended to the end of the semester, only 4 students flagged in Week 8 would not classify as either medium or high-risk. On average, 20% of students initially flagged as medium risk in Week 3 or 8 increase to high risk at the subsequent hurdle. This gives an indication that it is largely the same group of students at risk throughout the semester with a significant portion able to be identified as early as Week 3. This gives confidence in the use of these thresholds as an early warning mechanism. This would need to be used with caution in an active presentation of the module as it would not be possible to determine beforehand exactly where the appropriate thresholds lie.

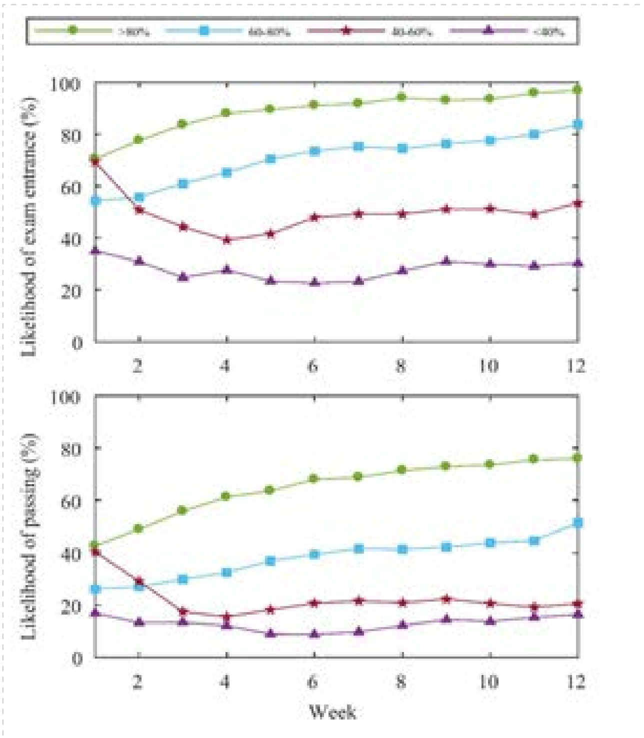

FIGURE 6: Likelihood of gaining exam entrance or passing the module according to groups of combined CA performance

TABLE 2: *Number of medium & high-risk flagged students at Week 3 & 8*

		Week 8			
	Risk	Not flagged	Medium	High	
Week 3	Not flagged		177	24	
	Medium	17	78	54	149
	High	1	9	87	97
			264	165	

C. Participation in voluntary practice worksheets

For the 11 voluntary practice worksheets, the attempts as a function of time where compared to higher-stakes class and semester test dates. It was immediately clear that these worksheets were being used to test knowledge prior to tests and exams with sharp increases in the number of attempts of all relevant worksheets prior to the assessments. The majority of students attempted at least one of the additional worksheets, with 777 students (63%) attempting 1 or more worksheets, 299 (24%) attempting 6 or more, and 67 (5%) attempting all 11. The average number of attempts per worksheet was 1.45 per participating student. This highlights that students were using these worksheets multiple times for additional practice.

Evaluation of the performance of students who completed the additional practice worksheets against those that did not shows a significant improvement in both the semester grade and pass rate. The more additional worksheets a student attempted, the better their performance. Students attempting 6 or more separate worksheets achieved an average semester grade of 51% and pass rate of 57% compared to a semester grade of 44% and pass rate of 40% for students completing 1 to 5 worksheets, and semester grade and pass rate of 39% and 28% respectively for students with no attempts. Slight decreases in the failure rate and significant decreases in the deregistration rate were noted as the number of attempted worksheets increased.

This correlation should be treated with caution, as it is likely that students who were engaged with the module content sought out these additional opportunities to test their knowledge and prepare further for tests and exams. This is in line with the caution noted by [1] to consider "selection effects" when correlating voluntary assessments to student results. Nonetheless, it is interesting to show the value of making additional voluntary practice opportunities available as students are using this resource. This result is interesting in comparison to literature reported by [1] where it was noted that whether or not assessment is mandatory or voluntary did not influence student results. The current research shows a clear correlation between the participation in voluntary continuous assessment activities and student performance.

These results highlight the benefit of making additional practice resources available to students; using the online quiz format allows students to get immediate feedback on whether or not their solutions are correct, and students can test their understanding in a non-threatening environment where their performance is not recorded or used to form part of the module assessment. More emphasis should be placed on mechanisms to guide students that are not sufficiently engaged to use this resource such as signposting the availability and value of these resources during lectures or tutorials, or advising individual students in consultations to make use of them. Furthermore, the creation of a wider set of online questions where students can test their knowledge using new questions would further enhance the benefit of this resource, although setting this up would increase the time burden for academic staff.

D. Student perception on continuous assessment activities

The results of the coding from the surveys showed that students consistently report the use of CAs as being beneficial to the successful completion of the course. On average across the two questions in the two surveys, 35% of respondents highlighted the positive contribution of CAs. This was the most prevalent activity noted, followed by tutorials at 27% and lectures or pre-recorded lectures at 22%. A general overview indicates that students found that CA activities assisted in: understanding topics/concepts, testing basic knowledge, staying up to date, identifying and sorting out issues early on, preparing for class and tutorials, and contributing to learning and development. The low-stakes nature of the assessment and fact that a second chance is available were noted as positive aspects. This corresponds well with the identified benefits of CA noted in the literature. responses highlighting the positive CA contribution include:

"The lecture assignments give a quantifiable method of personally assessing whether I understood the unit's concept which helps identify and resolve pre-lecture misconceptions and errors."

"The continuous evaluations succeeded to keep me up to date and show me whether it was necessary to improve my knowledge or that I had a sufficient understanding of the work covered."

It should also be noted that the responses also indicated some negative perceptions of the CAs. Some of these relate to misconceptions on the purpose of these assessments, e.g. *"I don't think it provides enough preparation for tests."* The volume of work required due to the multiple assessments was also noted: *"The tons of LA's and TP's were a bit too much to handle."* These highlight how these can be more effectively administered, for example combining various assessments to reduce load, and ensuring that students are aware of how these assessments are structured within the framework of other learning and assessment activities.

V. CONCLUSIONS

This paper aimed to investigate the relationship between continuous assessment participation and performance and individual student achievement considering both compulsory CA activities and additional voluntary activities. The key conclusions are listed below:

- Both participation and performance in compulsory continuous assessment show a positive correlation with semester grade and overall module performance. The

strongest correlation existed between CA performance and semester grade, indicating that these results may be most useful for identifying likelihood of exam entrance.
- The grouping of results according to module outcome showed distinct differences in CA performance. Thresholds for flagging students requiring interventions were identified, and it was noted that medium and high-risk students were able to be flagged as early as Week 3 in a 12-week semester.
- Participation in the voluntary worksheets showed a positive and compelling correlation to improved module outcomes, although causation is not necessarily implied.
- Student perception of the CAs is largely positive, with these activities identified as the most beneficial activity to the successful completion of the course.

In conclusion, it is clear that continuous assessments, both mandatory and voluntary, play an integral role in module success. The results from these assessments are a useful tool for both students and staff to monitor performance and design intervention mechanisms to be used in future presentations of the module and create a nudge to highlight the importance of active participation in CA activities. The high usage of the voluntary worksheets is a clear indicator that this is a valuable resource. The potential influence on improved performance presents a strong rationale to make more additional online practice resources available as this was shown to be a valuable learning and revision exercise. Next steps in the research would be the implementation of recommended interventions and flagging mechanisms, and monitoring the impact of this on student engagement and performance.

ACKNOWLEDGMENTS

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REFERENCES

[1] I. N. Z. Day, F. M. van Blankenstein, M. Westenberg & W. Admiraal (2018) "A review of the characteristics of intermediate assessment and their relationship with student grades", Assessment & Evaluation in Higher Education, 43:6, pp. 908-929.

[2] S. Myllymäki (2013) "Incorporation of continuous student assessment into lectures in engineering education", European Journal of Engineering Education, 38:4, pp. 385-393.

[3] J. L. Poza-Lujan, C. T. Calafate, J. L. Posadas-Yag, and J. C. Cano (2016) "Assessing the Impact of Continuous Evaluation Strategies: Tradeoff Between Student Performance and Instructor Effort." IEEE Transactions on Education 59 :1, pp. 17–23.

[4] Engineering Council of South Africa (2020) "Criteria for Accreditation of Engineering Programmes; E-03-CRI-P". Revision No. 4: 15 October 2020

[5] Engineering Accreditation Commission, "Criteria for Accrediting Engineering Programs", Accreditation Board for Engineering and Technology (ABET), Baltimore, Maryland, 2022.

[6] M. Llamas-Nistal, M. Caeiro, M. Castro, I. Plaza, and E. Tovar. (2013). "Engineering education in Spain: One year with the Bologna process", in Proc. EDUCON, Berlin, Germany, 2013, pp. 566–572.

[7] R. Tuunila & M. Pulkkinen (2015) Effect of continuous assessment on learning outcomes on two chemical engineering courses: case study, European Journal of Engineering Education, 40:6, pp. 671-682.

[8] J.S Col. & S.W.T. Spence (2012) "Using continuous assessment to promote student engagement in a large class", European Journal of Engineering Education, 37:5, pp. 508-525.

[9] B. Finn (2015) "Measuring Motivation in Low-Stakes Assessments". ETS Research Reports Series. Princeton, NJ: Educational Testing Service.

[10] E. S. Sanz-Pérez (2019) "Students' performance and perceptions on continuous assessment. Redefining a chemical engineering subject in the European higher education area." Education for Chemical Engineers 28. pp. 13-2

Technical papers

Teaching data science programming skills to diverse student cohorts

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Abstract — **In response to the industry demand for data science skills, universities have created new data science degrees and integrated new data science courses into existing degrees. While data science is now being taught at several universities, there is still limited consensus among instructors on the best way to teach data science. Interviews and surveys with data science instructors revealed that they find it difficult to accommodate diverse student cohorts. Students that enrol in data science courses or degrees have differences in background knowledge, are at various stages of their careers, have various levels of commitment and prefer different learning styles. Although the challenges of teaching data science to diverse student cohorts are often stressed, limited methodologies or guidelines have been developed in response. This paper presents the design of a scaffolding framework developed to teach data science programming skills to a diverse student cohort. The scaffolding framework outlined can be used by instructors to design a project-based data science course that progressively challenges the development of data science programming and self-scaffolding skills.**

Keywords — data science, programming, instructional scaf- folding, course design, diversity

I. INTRODUCTION

Activities in numerous fields and industries have become more data and computationally driven [1]. The term data sci- ence has recently been defined to summarise the skills required to extract insights from large data sets, and the skills required to develop robust software to perform data analysis [2]–[4]. While degrees such as chemical and industrial engineering historically covered data science skills, these degrees did not cover the data science skills to the extent required by industry [5], [6]. To address the data science skill gap, universities have implemented, or are planning to introduce, new data science courses and degrees. For example, Stellenbosch University has introduced a bachelor's degree in data engineering [7], while the University of California San Diego has presented an undergraduate course in data science to over 3300 students in the first three years since the inception of the course [1]. Apart from offering data science education at an undergraduate level, there is also a need to provide data science education to graduates in industry [8].

Because data science is a new field, the best approach to teaching data science has not been established [3]. In the meantime, interviews and surveys have been conducted with data science instructors to understand the approaches used to teach data science and the common challenges that instructors face in the teaching thereof. Kross and Guo [3] interviewed 20 data science instructors from academia and industry in 2019 and found that instructors must accommodate a diverse array of students. Students that enrol in data science courses and degrees have differences in background knowledge, are at various stages of their careers, have various levels of commitment and prefer different learning styles. For example, an undergraduate data science course offered by the University of California San Diego is typically presented to students from 15 different academic fields [1]. Schwab-McCoy, Baker and Gasper [9] surveyed 69 data science instructors from academia in 2019 and found that one of the biggest challenges that data science instructors face is teaching computing to diverse student cohorts.

While data science instructors have highlighted the chal- lenge of teaching data science to a diverse array of students, limited solutions to accommodate diverse students have been proposed. In 2021 the Association for Computing Machinery published a 130-page report that lists the computational skills required by a data scientist [10]. Chapter five of the report outlines the need and advantages of broadening participation in data science from underrepresented groups. Yet, in the 27 data science course examples provided in the annex [11], none of the instructors mentioned how diverse student cohorts are currently accommodated in their course in response to the question of why a course is taught in a specific manner. To accommodate the diverse array of students that enrol in data science courses, courses must be designed with diversity in mind, *but how can an inclusive data science course be designed?*

This paper presents a scaffolding framework that can be used by instructors to design a data science course that accom- modates novice students while keeping experienced students engaged. The framework is based on flow channel theory and scaffold learning and supported by the observations of ten related data science education case studies. The theoretical background of flow channel theory and scaffold learning is discussed in Section II followed by an analysis of the case studies in Section III. The principles and observations discussed in Sections II and III are used to formulate a scaf- folding framework which is presented in Section IV. Section V provides an example of how the scaffolding framework was applied to design a postgraduate data science course.

II. THEORETICAL BACKGROUND

Flow channel theory describes the relationship between the skill level of a student and the difficulty level of a task [12]. When a student possesses the skills to perform a task, the learning opportunity presented by the task is limited and the student consequently loses interest in it [12], [13]. On the other hand, when a student does not possess the skills to perform a task, they can experience frustration. When the difficulty level of a task is much higher than the skill level of the student, the student tends to lose motivation and abandon the task altogether [12], [13]. To keep students motivated while providing them with the opportunity to learn, tasks should be designed to match their skill level.

The skill level of students in a diverse student cohort will differ to a large extent. To keep students motivated, tasks should be designed to match the skill level of all students, but designing tasks for every student is impractical. Designing tasks based on the average skill level of students are common but fails to accommodate novice and experienced students [4], [14]. To accommodate novice students at the expense of experienced students, the general difficulty level of tasks can be reduced. Brunner and Kim [15] reduced the difficulty level of tasks in their data science course but as a result struggled to motivate students with prior experience. Rather than reducing the general difficulty level of tasks, novice students can be accommodated by providing them with additional support. Baumer [16] observed that data science students are willing to accept some frustration during a course, but require support to prevent them from feeling helpless.

According to the theory of learning defined by Vygotsky [17], learning can be enabled by recognising the zone of proximal development of a student and how far an instructor can stretch a student within this zone. With appropriate sup- port, students can be stretched to carry out tasks which would normally be beyond their capabilities. In other words, novice students can be accommodated in a course by providing them with additional support.

Instructional scaffolding refers to the process of initially supporting a student to complete tasks with the eventual goal of enabling them to perform tasks independently in the future [18]. In the context of flow channel theory, scaffolding can be viewed as a tool to prevent students from feeling helpless and ultimately abandoning tasks. As the skills of a student develop throughout a course, the amount of scaffolding is reduced while the difficulty of tasks is progressively increased to maintain interest. The relationship between skill level and difficulty level within the context of scaffolding is illustrated in Figure 1.

To design a data science course based on the concept illustrated in Figure 1, difficulty within the context of data science must be established. Once the concept of difficulty is established, tasks with progressive difficulty levels can be defined. For each task, the support provided must be defined, keeping in mind that scaffolding should be faded over time.

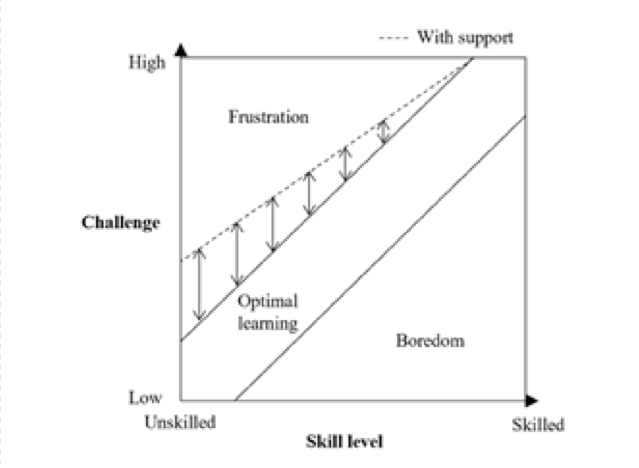


FIGURE 1: *The relationship between skill level, difficulty, motivation and support*

III. RELATED CASE STUDIES

Case studies are a crucial part of the data science education literature [9]. Case studies typically document the teaching approach followed by an instructor at a single institution. Ten case studies [1], [4], [15], [16], [19]–[24] were examined to determine how instructors accommodate diverse students in data science courses. While the courses covered in the case studies were taught at different educational levels and had a wide range of different pre-requisites, several common teaching approaches emerged.

In all of the case studies, data science is taught as an applied subject. Instructors frame data science as a field to answer questions using data from a diverse range of fields. When instructors teach students how data science can be applied, they use imperfect data sets and aim to closely mimic the process that a data scientist would perform in practice. Students are taught to use the computing tools that data scientists use, think critically, communicate findings to a non-technical audience, and to embrace the fact that the data science process is iterative with no distinctive answer.

The case studies examined revealed several methods that can be used to support novice students. Instructors typically started a course with either a topic that required limited background knowledge or used the first part of the course to develop fundamental skills. Several instructors reduced the complexity of the course to accommodate students with different backgrounds. Strategies to reduce the complexity of the course included removing mathematics where possible and removing the challenges related to installing software. Support was provided to students by instructors, teaching assistants and peers throughout the courses. Peer support was often used in larger classes where it became impractical to rely solely on instructors and assistants. The use of online forums allowed students to ask and answer questions and helped to reduce repetitive questions. Videos were provided for revision and to increase the amount of time available for instructor- student interactions. Instructors used illustrative examples in all of the courses. Some instructors noted that students can fall behind and used or suggested using regular quizzes for self-assessment. Tabel I summarises the different methods used among data science instructors to support students.

TABLE I: *Support mechanisms used in data science courses*

Support mechanism	Description
Course sequence	• Start with a topic that is accessible to all students to allow broad participation and time for novice students to develop skills [16], [20], [21], [24] • Use the first portion of the course to develop fundamental skills [15], [20], [21], [23]
Reduce complexity	• Allow students to select a problem they want to work on [1], [4], [16], [20], [21], [23], [24] • Avoid mathematical notation where possible [4], [20] • Provide pre-installed software solutions to avoid the challenges that students experience with installing software [15], [20], [23], [24]
Progress monitoring	• Use quizzes or exercises to determine how to adjust the course pace [4] • Use quizzes or exercises to help students identify gaps in their knowledge [1], [20] • Monitor progress made by students [24]
Instructor support	• Set office hours [1], [15], [16], [20], [24] • Employ teaching assistants [1], [4], [15], [16], [24]
Peer support	• Use group projects or assignments [4], [16], [22]–[24] • Encourage students to assist each other [1], [20], [22] • Use peer grading or student presentations to allow students to learn different solutions [15], [21], [22], [24]
Online forums	• Use online forums or message boards to allow students to ask and answer questions [1], [4], [15], [22]–[24]
Videos	• Provide recorded videos for revision and improved accessibility [1], [4] • Provide recorded videos to increase instructor-student interaction time [20], [23], [24]
Examples	• Provide examples of how to use specific tools [1], [4], [15], [16], [20]–[24] • Provide starter code, prompts and test cases [1], [15], [20], [22]

Although mechanisms to support students were frequently listed in case studies, key scaffolding questions were seldom discussed. Where supporting mechanisms were discussed in detail, it was discussed within the context of the specific course. As long as the field of data science keeps evolving and a consensus data science curriculum has not been defined, support mechanisms designed for a specific course will have limited benefit for other instructors. In the absence of a con- sensus data science curriculum, a course agnostic scaffolding approach is required. A course agnostic scaffolding framework will allow the framework to apply to a wide range of data science courses as opposed to a specific course.

IV. COURSE DESIGN FRAMEWORK

To aid instructors in designing inclusive data science courses, a three-step framework was developed. The first step guides instructors on the critical skills to consider when developing a data science course. In the next step, a list of parameters is provided that allows instructors to define data science projects at incremental difficulty levels. Developing data science projects at suitable difficulty levels throughout a course keeps students engaged and motivated. Lastly, to accommodate diverse students, guidance on how to design a scaffolding system is provided.

Step 1: Define skills

Data science courses are designed for different audiences, and even when the audiences are similar, the topics covered in courses differ. Schwab-McCoy, Baker and Gasper [9] asked 68 data science instructors to indicate whether 34 predefined topics were covered in their data science curriculum; not one of the 34 topics was covered in any of the curriculums. In the absence of a specific list of topics, a general definition of data science student skills is used: *Data science students should be able to authentically execute a data science project.* The ability to execute a data science project authentically was highlighted in all ten of the case studies reviewed and was often reinforced in these courses by asking students to complete a data science project at the end of the course.

Using a high-level definition of data science skills allows the statement to apply to a wide range of courses but requires interpretation from the instructor. When an instructor determines the scope and depth of topics to include, care should be taken to include teaching self-learning.

When mentioning the ability to authentically execute a data science project, most educators focused on using data from real-world problems and teaching students the tool and methods that data scientists use. However, the ability of data scientists to learn new skills and tools on the job was mostly omitted. According to the data science task force established by the Association for Computing Machinery [10], a graduate data scientist should possess the ability to continuously learn. Because data science keeps developing at a rapid pace, the ability to continuously learn is critical in the field.

Step 2: Develop tasks

If the end goal of a data science course is to teach students how to execute a data science project authentically, then the course can be designed as a series of progressively challenging data science projects. To conceptualise a course as a series of progressive challenging data science projects, the concept of difficulty within the context of a data science project must be defined.

A data science project can be described as a set of tasks that must be executed to answer a question using data. Several frameworks exist that outline the tasks of a data science project, however, the cross-industry standard process for data mining (CRISP-DM) is the most commonly used in practice [25]. The CRISP-DM outlines a data science project in six phases, namely business understanding, data understanding, data preparation, modelling, evaluation and deployment. Given the six phases of a data science project, the difficulty of a data science project can be defined either as the difficulty of the most difficult phase or as the total difficulty of all six phases. Either of these definitions requires difficulty to be defined for each phase of a data science project.

In computer games, the difficulty of a game can be set with configurable parameters [15]. For instance, to increase the difficulty of a game the number of opponents faced by a player can be increased. In this example, the number of opponents is a parameter that can be configured to adjust the difficulty of the game. The concept to define and adjust the difficulty in computer games can be applied to a data science project. For each phase of a data science project, parameters exist that influence the difficulty thereof. For example, in the data preparation phase of a project, the number of data sources considered is a configurable parameter. A data science project with one data source is easier to execute than a data science project with multiple data sources. When multiple data sources are considered, a student needs to understand how data sources can be combined. A non-exhaustive list of parameters that should be considered when defining the difficulty of a data science project is presented in Table II. When establishing difficulty with the configurable parameters listed in Table II, a distinction between effort and difficulty must be made. Combing more than two data sources, as opposed to only two data sources, will increase the amount of effort required to complete a data science project, but not necessarily the difficulty of the project.

The computational thinking skills required in a data science project should also be considered when defining the difficulty of a project. Students enrol in data science courses with a variety of computational thinking skills and therefor computational thinking should also be incrementally developed and evaluated. Computational thinking skills can be segmented into three stages, namely: problem formulation, solution expression and execution and evaluation [26]. Each of the three stages of computational thinking should be considered as a configurable parameter that influences the difficulty of a data science project. For instance, students can be provided with pre- developed test cases to reduce the difficulty associated with code evaluation. When determining the difficulty of a data science project from a computational thinking point of view, current data science software libraries should be considered. Data science software libraries have made it easy to express a solution using code. For example, the machine learning li- brary, scikit-learn, provides several different machine learning algorithms that can be applied to a data set with minimal effort [27]. Using a pre-developed function is much easier than implementing a function from scratch.

TABLE 2: *Data science project complexity*

CRISP-DM Phase	Configurable parameters
Business understanding	• Objective(s) ambiguity • Problem familiarity
Data understanding and preparation	• Data availability • Data storage format • Number of data files • Size of data set • Number and type of data features • Data cleaning requirements
Modeling	• Model assumptions • Data pre-processing requirements • Number of model hyperparameters • Sensitivity of model hyperparamaters
Evaluation	• Model interpretability • Evaluation process requirements
Deployment	• Integration requirements • Monitoring and updating requirements

To define data science projects of incremental difficulty, instructors should consider the computational thinking skills required in the project and the parameters listed in Tab. II. In practice, defining a data science project of any difficulty level is best achieved by starting with a complex problem and reducing the difficulty of the project as needed. For example, if a data science project with multiple data sources is selected, the project can be simplified by providing students with one data set that the instructor combined.

Step 3: Provide scaffolding

Once the skills of a data science course are defined and data science projects with increasing difficulty have been developed, support has to be designed to accommodate the diverse array of students. Developing support for each data science project involves answering key scaffolding questions such as what to scaffold, how to scaffold and when to scaffold [18], [28].

At the start of the course, student skills will be the most diverse and therefor the need for scaffolding will be the greatest. After an initial introduction to data science and the CRISP-DM methodology, it is recommended to start the course directly with a project. The project should be viewed as a mastery assignment that aims to build universal fundamental skills among students, thereby reducing the diversity gap. Practically, this implies that students should be provided with a mechanism of immediate feedback to allow students to reattempt the project until they have mastered the specific skill. To support students in mastering the specific skills, pre-recorded videos and course material that covers the topics should be made available to students. Using pre-recorded videos and course material allows students to self-regulate the time they spend on the course material, keeping students with different levels of experience motivated and engaged.

Once the initial diversity gap between students is reduced, the amount of support provided should be faded. Where the support previously focused on helping students to master con- cepts, support should now focus on teaching students to self- scaffold. Self-scaffolding, defined by Holton and Clark, refers to the process where the student, as opposed to the instructor, determines when and how to scaffold [28]. In practice, a wide range of data science resources such as textbooks, websites, videos and forums are available to learn data science from [9], [22]. Teaching students how to navigate and learn from these resources are key to teaching them continuous learning.

Multiple scaffolding platforms should be introduced in a course for students to choose from. These scaffolding plat- forms include textbooks, online help files, illustrative ex- amples, an online forum and non-compulsory question and answer sessions. However, if a student is not aware that they require support, they will not utilise these platforms. Booysen and Wolff [29] observed that the perception and actual performance of engineering students are misaligned. Students should therefore explicitly be taught how to self- assess and therefor when to scaffold. Time should be dedicated to teaching students how the output of their code can be evaluated within the context of the problem. As a course progresses, the responsibility of self-assessment should be transferred to students by explicitly requiring students to illustrate how they self-assess their projects.

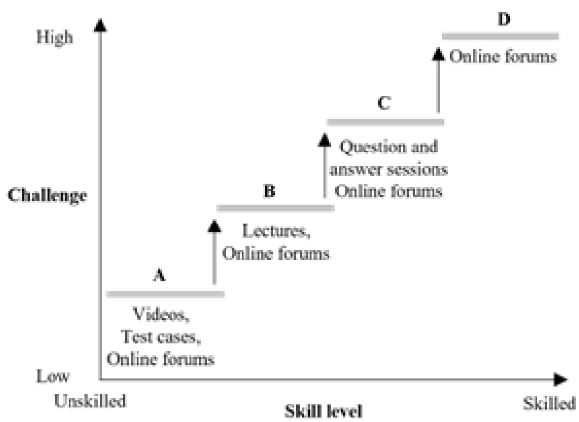
When students engage with the instructor or teaching as- sistants through scaffolding platforms, the instructor should focus on answering questions by teaching students how to self-scaffold. For example, in question and answer sessions, the instructor can demonstrate to students how an answer to a question can be found online. Helping students to self-answer their questions transfers this responsibility of learning back to students and helps instructors accommodate larger classes.

V. IMPLEMENTATION EXAMPLE

After developing the scaffolding framework discussed in Section IV, the framework was used to develop a postgraduate data science course. The course is taught at a content- based, research-intensive university in the global south where the faculty of engineering has a developmental approach to programme renewal and innovation. As part of the ongoing programme renewal aimed at building capacity in emerging markets and developing economies, the university has in- troduced a postgraduate diploma in data science. The first course of the postgraduate diploma in data science focuses on teaching data science programming skills. Teaching data science programming skills as part of the diploma allows the postgraduate diploma to be inclusive to students with no prior programming experience, such as students from social sciences [15].

A pre-course survey was used to establish the diversity of students and subsequently used to inform the design of the course. Students enrolled in this course ranged from 21 years to 59 years old, originated from five different countries, held several different undergraduate degrees and had a wide range of programming experience. Some students enrolled in the course with no programming experience while other students had more than five years of programming experience. Almost half of the students enrolled in the course were part-time students with different levels of commitment and availability. The different levels of student commitment and availability made peer-based scaffolding impractical.

Using the framework, four projects were designed in incre- mental difficulty levels. The first project consisted of structured questions and aimed to develop basic programming skills. Students were provided with test cases for each question which allowed them to self-evaluate their answers. To support novice students, pre-recorded videos which covered the specific skills required for the project were provided. In the second project, students were tasked to analyse the occurrences of fires in the City of Cape Town using four data sets. The project could mostly be solved using the data science libraries introduced in lectures. The data set size and analysis required were simplified to allow students to easily evaluate their work. For example, students were asked to analyse the data visually as opposed to using more complex analytical techniques.



Projects

A - Lay foundations:
Mastery assignment; builds basic programming skills such as data structures, control flow and functions

B - Brick work:
Introduce and teach students how to use common data science libraries. Build self-assessment skills by providing students with small data sets that can be easily analysed in various ways

C - Details:
Let students develop their own data science functions, but provide support on how these functions can be tested

D - Hand-over:
Provide students with a new problem; and specifically expect from students to illustrate that they can learn and use data science libraries not discussed in class

FIGURE 2: *Example course design*

In the third project, students were tasked to build a machine learning algorithm that can classify a code contained in a file as either Python or R. Students had to implement their own machine learning algorithm and compare their code to existing implementations online. Asking students to compare their code to existing solutions online reinforced self-assessment skills. In the final project, students were tasked to develop a machine learning model that can predict the daily demand for bicycles. The data set provided was too large to analyse in memory and therefore required students to find alternative solutions. The project was considerably more difficult than previous projects since the software that students needed to use was not explicitly taught. The different projects provided in the course and the support provided during the course are illustrated in Figure 2.

VI. CONCLUSION

This paper presented a scaffolding framework that can be used to develop data science courses for diverse student cohorts. The scaffolding framework was subsequently used to develop a data science course for postgraduate students. Initial evaluation of the course, which consisted of surveys, observation and the evaluation of online forums, indicates that students with no prior programming experience learn how to self-scaffold during the course and therefore manage to complete the course successfully. Future work will examine the effectiveness of the framework in detail.

REFERENCES

[1] T. Donoghue, B. Voytek, and S. E. Ellis, "Teaching Creative and Practical Data Science at Scale," Journal of Statistics and Data Science Education, vol. 29, no. sup1, pp. S27–S39, 2021, doi: 10.1080/10691898.2020.1860725.

[2] J. West, "Teaching data science: an objective approach to curriculum validation," Computer Science Education, vol. 28, no. 2, pp. 136–157, 2018, doi: 10.1080/08993408.2018.1486120.

[3] S. Kross and P. J. Guo, "Practitioners Teaching Data Science in Industry and Academia," in Proceedings of the 2019 CHI Confer- ence on Human Factors in Computing Systems, 2019, pp. 1–14. doi: 10.1145/3290605.3300493.

[4] S. C. Hicks and R. A. Irizarry, "A Guide to Teaching Data Science," The American Statistician, vol. 72, no. 4, pp. 382–391, 2018, doi: 10.1080/00031305.2017.1356747.

[5] T. A. Duever, "Data Science in the Chemical Engineering Curriculum," Processes, vol. 7, no. 11, 2019, doi: 10.3390/pr7110830.

[6] S. M. Sackey and A. Bester, "Industrial engineering curriculum in industry 4.0 in a South African context," South African Journal of Industrial Engineering, vol. 27, no. 4, Dec. 2016, doi: 10.7166/27-4- 1579.

[7] L. Koch, "Stellenbosch University Starts with the Training of Data Engineers," Jun. 13, 2019. https://www.eng.sun.ac.za/news/stellenbosch- university-starts-with-the-training-of-data-engineers/ (accessed Jan. 12, 2022).

[8] N. Pillay, B. T. Maharaj, and G. van Eeden, "AI in Engineering and Computer Science Education in Preparation for the 4th Industrial Revolution: A South African Perspective," in 2018 World Engineering Education Forum - Global Engineering Deans Council (WEEF-GEDC), 2018, pp. 1–5. doi: 10.1109/WEEF-GEDC.2018.8629703.

[9] A. Schwab-McCoy, C. M. Baker, and R. E. Gasper, "Data Science in 2020: Computing, Curricula, and Challenges for the Next 10 Years," Journal of Statistics and Data Science Education, vol. 29, no. sup1, pp. S40–S50, 2021, doi: 10.1080/10691898.2020.1851159.

[10] ACM Data Science Task Force, Computing competencies for under- graduate data science curricula. New York, NY, USA: ACM, 2021. doi: 10.1145/3453538.

[11] ACM Data Science Task Force, "Computing Competencies for Under- graduate Data Science Curricula." https://dstf.acm.org/ (accessed Dec. 10, 2021).

[12] F. J. Gallego-Dura´n, R. Molina-Carmona, and F. Llorens-Largo, "An Approach to Measuring the Difficulty of Learning Activities," in Learn- ing and Collaboration Technologies, vol. 9753, P. Zaphiris and A. Ioannou, Eds. Springer International Publishing, 2016, pp. 417–428. doi: 10.1007/978-3-319-39483-1 38.

[13] S. W. Vann and A. A. Tawfik, "Flow theory and learning expe- rience design in gamified learning environments," in Learner and User Experience Research: An Introduction for the Field of Learn- ing, M. Schmidt, A. A. Tawfik, I. Jahnke, and Y. Earnshaw, Eds. EdTech Books. Accessed: Dec. 10, 2021. [Online]. Available: https://edtechbooks.org/ux/flow theory and lxd

[14] R. P. Medeiros, G. L. Ramalho, and T. P. Falcao, "A systematic literature review on teaching and learning introductory programming in higher education," IEEE Transactions on Education, vol. 62, no. 2, pp. 77–90, May 2019, doi: 10.1109/TE.2018.2864133.

[15] R. J. Brunner and E. J. Kim, "Teaching Data Science," Pro- cedia Computer Science, vol. 80, pp. 1947–1956, 2016, doi: 10.1016/j.procs.2016.05.513.

[16] B. Baumer, "A Data Science Course for Undergraduates: Thinking With Data," The American Statistician, vol. 69, no. 4, pp. 334–342, Oct. 2015, doi: 10.1080/00031305.2015.1081105

[17] A. Kozulin, "Vygotsky's theory in the classroom: Introduction," Euro- pean Journal of Psychology of Education, vol. 19, no. 1, pp. 3–7, 2004, [Online]. Available: http://www.jstor.org/stable/23421397

[18] M. Y. Doo, C. Bonk, and H. Heo, "A Meta-Analysis of Scaffolding Effects in Online Learning in Higher Education," The International Review of Research in Open and Distributed Learning, vol. 21, no. 3, Mar. 2020, doi: 10.19173/irrodl.v21i3.4638.

[19] M. Majumder and X. Cheng, "Focusing on the Needs: Experiences of Developing a Data Science Program," Journal of Computational and Graphical Statistics, vol. 26, no. 4, pp. 779–780, Oct. 2017, doi: 10.1080/10618600.2017.1385475.

[20] D. White, "A Project-Based Approach to Statistics and Data Sci- ence," PRIMUS, vol. 29, no. 9, pp. 997–1038, Oct. 2019, doi: 10.1080/10511970.2018.1488781.

[21] D. Yan and G. E. Davis, "A First Course in Data Science," Journal of Statistics Education, vol. 27, no. 2, pp. 99–109, May 2019, doi: 10.1080/10691898.2019.1623136.

[22] T. Zheng, "Teaching Data Science in a Statistical Curriculum: Can We Teach More by Teaching Less?," Journal of Computational and Graphical Statistics, vol. 26, no. 4, pp. 772–774, Oct. 2017, doi: 10.1080/10618600.2017.1385473

[23] F. G. Yavuz and M. D. Ward, "Fostering Undergraduate Data Science," The American Statistician, vol. 74, no. 1, pp. 8–16, Jan. 2020, doi: 10.1080/00031305.2017.1407360.

[24] M. C¸ etinkaya-Rundel and V. Ellison, "A fresh look at introductory data science," Journal of Statistics and Data Science Education," vol. 29, no. sup1, pp. S16–S26, 2021, doi: 10.1080/10691898.2020.1804497.

[25] V. Kotu and B. Deshpande, Data science: concepts and practice. Morgan Kaufmann, 2018.

[26] A. Repenning, A. Basawapatna, and N. Escherle, "Computational thinking tools," in 2016 IEEE Symposium on Visual Languages and Human-Centric Computing (VL/HCC), Sep. 2016, pp. 218–222. doi: 10.1109/VLHCC.2016.7739688.

[27] F. Pedregosa et al., "Scikit-learn: Machine Learning in Python," Journal of Machine Learning Research, vol. 12, pp. 2825–2830, 2011.

[28] C. Vieira, A. J. Magana, A. Roy, and M. Falk, "Providing students with agency to self-scaffold in a computational science and engineering course," Journal of Computing in Higher Education, vol. 33, no. 2, pp. 328–366, Aug. 2021, doi: 10.1007/s12528-020-09267-7.

[29] M. Booysen and K. Wolff, "Exclusion from constructive alignment unmasked by emergency remote teaching," in Research in Engineering Education Symposium and Australasian Association for Engineering Education Conference (REES AAEE), Perth Australia, Dec. 2021.

Technical papers

Self-efficacy in engineering design through peer review, self-review, and interactive online tutorials

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***Abstract* — Self-regulated learning is a key attribute in tertiary engineering education, and forms the basis of engineering judge- ment. The experience of remote learning during the COVID-19 era revealed particular challenges in self-regulated student learning practices, but also resulted in a number of systemic, technology-based interventions to enable improved student learning. Drawing on a 3rd-year electronic design course case study at a contact-based engineering faculty in South Africa, this paper presents an approach to bridging the gap between student perceptions and their actual assessment performance during independent, remote learning. Using scaffolded reflective and peer learning strategies, the research team sought to answer the question: What is the impact on self-efficacy of frequent self- and peer-assessment opportunities across a range of project- based learning tasks? Results were analysed using Bandura's four self-efficacy 'mastery' and experiential domains, and indicate an improvement in alignment between perceptions and actual performance. We suggest that a well-designed, scaffolded set of assignments with reflective and peer-learning opportunities can contribute significantly to the development of student confidence and mastery.**

I. INTRODUCTION

The ability to independently source, manage, interpret and appropriately apply information to particular problem contexts is the foundation for engineering decision making. The problem contexts of our 21st century world have become increasingly complex, and as such, the development of engineering judgement is a priority in engineering education. The COVID-19 era learning conditions presented educators and students with precisely the kinds of complexity in 21st century socio-technical industrial contexts, conditions during which innovative and viable solutions needed to be put in place in order to sustain Higher Education's mandate. For residential engineering students, the immediate challenge was the loss of direct access to equipment and laboratories, as well as the dependence on their own devices, infrastructure and connectivity to be able to switch to remote learning. Although scantily reported to date [1], over and above the initial systemic challenges, there has been significant anecdotal evidence of problematic self-regulated learning practices during Emergency Remote Teaching (ERT) [2]. Effective independent and self-regulated learning is closely related to motivation, and entails metacognitive strategies, time management, self-reflection, help seeking and peer learning [1, 3, 4].

One of the affordances of online systems is the ability to productively and constructively monitor, support and evaluate teaching, learning and assessment practices. The research study in this paper reports on a contact-based engineering faculty's feedback-feedforward approach to improving engineering education. Drawing on lecturer observations, student performance, online forum engagement and regular feedback, the faculty continues to implement pedagogical initiatives to improve student outcomes. As part of a Recommended Engineering Education Practices (REEP) project, continuous evaluation of the faculty's initiatives has enabled key insights into student learning challenges and support needs. One REEP initiative has focused on improving the learning experience for 3rd-year electronic design students. A key observation during ERT was the disjuncture between the electronic design course student perceptions and their actual assessment performance during independent, remote learning. Although reported as a common phenomenon among tertiary students, particularly during their first two years of study [5, 6], over- or under-estimation of one's abilities [7] prevents the development of effective engineering judgement. So, a key task for engineering educators is to enable students to better align their perception of requirements, expectations and capabilities to the criteria made explicit in course outcomes.

This paper follows on from a recent paper by Booysen et al. [8], in which the question of self-efficacy was explored among 2nd-year computer systems engineering students. With initiatives such as the increased and improved use of Learner Management Systems (LMS) under ERT conditions across different courses, the course facilitator began to use the LMS environment to encourage self-reflection and elicit learning feedback over a series of surveys during the semester, along with a weekly facilitator-led online question and answer (Q&A) session. In the case of the computer systems students, these initial strategies served to improve alignment between expectations and student perceptions of their own performance. In 2021, these strategies were extended to the 3rd-year electronic design course, with the additional implementation of a scaffolded self- and peer-learning approach. This approach was intended to specifically target the development of self- regulated and reflective learning habits as a budding engineer- ing community of practice approaching their final year. In this paper, we ask the question:

What is the impact on self-efficacy of frequent self- and peer-assessment opportunities across a range of project-based learning tasks?

We present an impact evaluation of the students' shifting perceptions of their performance. We also evaluate their expe- rience of interactive student-led online tutorials, in which their problems were shared and in which they received facilitative guidance - seen by all who watched.

II. CONTEXT

The research study on which this paper reports forms part of an ongoing programme renewal initiative at a contact-based, research-intensive university in South Africa. The faculty of engineering has practised a feedback-feedforward approach to improving engineering pedagogy through theoretically-supported, interdisciplinary and community-of-practice approaches [9]. One of several faculty projects under the umbrella of a REEP initiative involved a survey to determine how undergraduate engineering students were experiencing ERT. The survey echoed national findings of students experiencing significant systemic challenges, particularly with regard to efficient information management and different levels of digital fluency [10].

A key concern, however, was the reported levels of stress and anxiety, and their impact on student confidence and pro- ductivity [11]. Engineering education during the COVID-19 era saw a rapid shift to integrating remotely-accessed virtual and simulated systems into courses which would traditionally have entailed face-to-face practical or laboratory sessions. Another widespread COVID-19 era educational practice was the more strategic use of Learner Management Systems (LMS) to enable peer engagement, learning and assessment practices. The course in question is 3rd-year analogue electronic design. For the 128 enrolled students, this is only their second en- counter with electronic design, and arguably their first with free-form design. Each student had to individually complete their own circuit design that formed part of a bigger system built up over the semester. Each week's assignment brief was presented as a list of functional requirements and sub-circuit objectives at the interface level.

To achieve these, they were given a range of components from which the had to select resistors, capacitors, transistors, and integrated circuits based on rational design principles. The finite range of available components did constrain the design options to some extent, but the assignments were set up to offer substantial flexibility, and consequential unknowns for the student to figure out, technical hurdles to overcome, and interface-level complexity to grapple with. For example, in one assignment the students had to develop a battery charging circuit that interfaces with a solar panel on the input, and a battery and circuit on the output. These interfaces impose limits that include power, temperature, current, voltage, and temporal constraints. Although some of the principles of electronics would be familiar to the students, most of the components and devices, and some of the principles, would be foreign at 3rd-year level. For example, they should already be familiar with resistors, capacitors, current and transistors, but they should not yet have encountered batteries, solar panels, current-limiting voltage regulators, thermal dissipation, for ex- ample. Non-typical batteries and solar panels were prescribed to limit web support. To demonstrate design proficiency, each student is required to submit in a report (1) an individually completed literature survey, (2) detailed and systematic design with justifications drawing from fundamental scientific, mathematical, and electrical principles with justifications; (3) circuit schematic (4) computer-aided circuit simulation output that demonstrates compliance to the requirements; (5) photos of the physical circuit that has been implemented; (6) measured output demonstrating compliance of the physical circuit.

Before ERT, the course was assessed with three assessments over the course of a semester, each based on a test, a physical demonstration of the circuit, and the report described above. The learning curve in this course pre-COVID-19 had already suggested students were experiencing significant challenges. This observation, together with the widely reported systemic and affective challenges during ERT, led to the implementation of a number of innovations and interventions to better support student learning [11]. The first innovative initiative was to introduce a remotely accessed simulated environment using LTspice® - both for student circuit design tasks as well as ease of assessment. This systemic intervention was further supported through improved use of the LMS in order to address student affective needs (such as peer engagement and facilitator support). Course design over the ERT period (2020 – 2021) saw students accessing all recorded lectures via the LMS, along with tutorial exercises and simulated practicals. The scaffolded course assignments cover a broad spectrum of engineering skills, and the students' journey presents a good opportunity to assess their growth along this trajectory. The development of more independent learning practices, confidence and realistic capability perception (self-efficacy) were considered to be especially important after two years of ERT.

III. THEORY

Self-efficacy is defined as the belief in one's capability to exercise control over one's functioning and cope with events that can affect one's life [12]. Self-efficacy development is influenced by four kinds of experiences: mastery, vicarious, social and emotional states. Improved self-efficacy is linked to resilience, coping with stress, improved performance and educational achievement. Although dependent on differentiat- ing between intrinsic and extrinsic motivation [13], improving self-efficacy can contribute to confidence, which, in turn, can positively impact on motivation. Self-efficacy (and the accompanying experiences of confidence-building and motiva- tion) is a key concept underpinning engineering professional practice [8]. One of the specified Graduate Attributes in the engineering standard is the demonstration of the development of independent learning strategies, which is essential to be able to inform autonomous and collaborative ethical decisions in the solution of complex socio-technical and economic challenges. Self-regulated independent learning practices are not accidental. They need to be explicitly developed over time, built into curricula in such a way as to stretch students into more complex, open-ended problem-solving capabilities [14]. Self-regulated learning (and the development of improved self- efficacy) functions as a 'mediator' [15] of the development of students' metacognitive strategies "to monitor, control, regulate, and adjust their learning to reach . . . goals" [15, p.303]. There is extensive literature on the value of self- assessment and peer-learning/assessment strategies to improve overall student learning and academic achievement [16, 17]. If we see the mediation of self-regulated practices using Bandura's [12] four experiential influences, then an effective approach to developing student capabilities would include: i) building mastery through regular scaffolded practice; (ii) enabling vicarious experiences through peer learning and peer assessment opportunities; (iii) anchoring the social experience of engineering identity formation through broader contextual, peer and facilitator support initiatives; (iv) allowing for dif- ferent emotional states which take workload and exam stress periods into account, by scaffolding self-regulated learning opportunities across the semester. This paper conceptually frames the development of self-efficacy against these princi- ples, which can also be regarded as the design of pedagogy using sociocultural mediated learning theory [18, 19].

V. METHODS

A mixed-method survey-based approach was used to assess the students' perceptions of, and performance in, the design-based course. The course was set up to explicitly introduce self-review, peer review, and interactive student-centric online tutorials to stimulate and assess self-efficacy. These reviews and tutorials were done for each of the first three weekly assignments, which coincided with the acquisition of design skills. Every week, the students would complete the assign- ment by a Monday deadline. The assignment was uploaded to the LMS as a demonstration video of the circuit performing a list of required operations, a simulation circuit, and a report that contained evidence of all the steps from survey to results. The students were provided with a rubric with broad criteria to guide their assignments, and then a detailed rubric to self- and peer-assess three randomly assigned reports.

After completing the online peer-review, the students then re-assessed their own report against the same rubric. The self- and peer-assessment grades gave us two samples of quantitative data with which we could assess the students' perspectives on their own performance before and after their engagement in the peer-review process. Their self-assessments before and after the peer review were evaluated and compared for the three assignments. In addition to these quantitative data, we also captured qualitative data. Immediately after submissions, students accessed an online reflective feedbacksurvey on the LMS in which they were asked whether they thought they had enough time, and questions around the level of difficulty in the literature and report tasks. Immediately after the peer reviews, the students were asked to re-assess their reflective responses by answering similar questions in hind- sight. The questions are listed in Table 1, and include asking the students if they learned anything in the peer review process, and whether they would have done things differently. These survey responses gave us a view of the students' perception of difficulty, available time, and critical assessment of their design choices before and after the peer review process.

TABLE 1: *Responses to before and after peer review surveys.*

Statement before assessment	**A1**	**A2**	**A3**
I had enough time for the assignment.	36%	48%	51%
The literature survey was easy.	37%	69%	65%
Writing the report was easy.	29%	60%	55%
Statement after peer-review	**A1**	**A2**	**A3**
In hindsight, I did have enough time for the assignment.	41%	55%	55%
After reviewing the other reports, I better understand what was expected of me.	68%	62%	57%
After reviewing the other reports, it's easier to know what to include in the literature survey.	65%	59%	60%
My understanding of the content has improved after reviewing other reports.	53%	56%	47%
I would approach the design differently after reviewing the reports.	44%	29%	17%
The questions Q&A lectures helped me bridge the gap between theory and practice.	–	81%	83%
The practicals helped me bridge the gap between theory and practice.	–	62%	58%

V. DISCUSSION OF FINDINGS

The findings are reported in two sections. The first section reports on the qualitative results, which capture the students' responses to questions that aim to measure self-efficacy before peer-review and after the peer-review, which was measured at three points. The second section describes the quantitative results that are based on the students' self-assessment marks before and after peer-review.

A. Qualitative results

Before the peer-review of Assignment 1, only 36% of stu- dents said they had enough time to complete the assignment. When asked the same question after the peer-review, this number increased to 41% of respondents. For Assignment 2, those who thought they had enough time to complete the assignment before peer-review was 48%, and after the peer review this increased to 55%. For Assignment 3 the trend continued, with 51% reporting they had enough time before the peer-review, and 55% reporting they did in fact have enough time in hindsight. Therefore, for each of the assignments, an increasing number of students report that they had enough time in which to complete the assignment. Moreover, after completing each assignment's peer review, a marked increase in students report that they realise now that they did in fact have enough time. When asked whether they understood what was expected of them, 64%, 84%, and 67% responded in the affirmative for Assignments 1, 2, and 3 respectively. More importantly, approximately two thirds of students reported after each assignment's peer review that the peer reviews helped them understand better what was expected of them. Interestingly, as time progressed, this benefit of peer review was reduced by 11 percentage points of respondents from Assignment 1 to 3. This appears to indicate an increase in self-efficacy. This was the first time these students had to do a literature survey to acquire and integrate external knowledge. It is understandable that this foreign challenge was difficult for them, and therefore growth in this aspect offers a good proxy of progress. Initially, before Assignment 1, a mere 37% of respondents found the literature survey part of the design easy. A clear increase of almost double from the first assessment – 69% and 65% – indicated that the literature survey had become easier for A2 and A3. We believe that this is indicative of increased self-efficacy. This is further supported by the approximately two thirds of respondents saying the peer- review was helpful in understanding what to include or exclude in the literature survey. Although this was not the first time the students had to write a technical report, the scope and complexity exceeded that of any reports they had written to that point. We found that only 29% of them found writing the report easy before the first Assignment's peer review. Similar to doing the literature survey, this number jumped to 60% and 55% for Assignment 2 and 3. Interestingly, this is also one of the main academic stressors for engineering students [11]. Part of this stress will be due to having to report on content that the students are still grappling with. It is therefore important to note that approximately half of students reported that the peer review led to improved understanding of the technical content – a major benefit of peer review. These growth indications are mirrored by a stark decrease in the number of students reporting that they would have done the design differently after completing the peer review: from 44% to 29% to 17%. Design thinking – a key objective of the module – had clearly improved, as students found their feet and felt they would not have done it differently.

Based on these results, we observe interesting shifts taking place. We observe an improvement in the students' confidence in their ability to navigate the design process. This is evident in that they increasingly found the design process easier, and became less likely every week to have made changes to their design after reading other reports. This is evidenced in the overwhelming number of students who said the online tutorials and peer review helped them understand and apply the design process. It would be reasonable to deduce that their anxiety would have reduced accordingly, especially since writing reports and practical examinations – the bedrock of this challenging course – was explicitly highlighted as sources of anxiety by our engineering students [11]. It would also appear as if the peer assessment process helped the students mediate their standards, given the increase in the number of students reporting they had enough time both after each peer review and with each assignment. In brief, the students became more aware of what they had to do, understood better the standard of work they needed to deliver, and felt more able and confident doing it.

B. Quantitative results

Figure 1a shows histograms of the change in the students' estimates of their own work before and after each of Assignments 1, 2, and 3. This provides temporal insight into the effect of the peer-review process on the students' confidence in their ability to assess their own work. For Assignment 1, most students exhibited increased confidence in their own work after reviewing the work of their peers. As this was the first assessment of the module, it was possible that the students underestimated their own abilities (relative to their peers), until scrutinising the work produced by their peers - thereafter developing an increased level of self-confidence. When analysing the same results for Assignment 2, it does, however, appear that the students may have over-corrected for their lack of initial confidence in Assignment 1. With this assignment, students projected overly-optimistic results, which were then partially corrected by the peer review process. By Assignment 3, most students were attune to the standard of work produced by their peers, as well as their ability to gauge their own relative performance. This increase in confidence and self-awareness is illustrated by the increasingly narrowed histogram for this assessment, in which most respondents changed their estimated mark by less than ±10%.

Figures 1b to 1d show histograms of the error between the students' estimated marks and their peer-review-obtained marks, before and after the peer review process - for Assignments 1, 2, and 3. The histograms in Figure 1a should be examined along with the corresponding histograms from Figure 1b to 1d. For Assignment 1, the increase in confidence provided by the peer review process was well-founded, as the bulk of the shift in the (initially negatively-centred) error distribution was positive, approaching (but not reaching) an expected value of zero. This indicated increased accuracy in the students' ability to assess themselves. For Assignment 2, however, the aforementioned correction for this assignment provided by the peer review process somewhat overshot the mark - decreasing the expected value of the error. By As- signment 3, most students had developed not only increased confidence, but also increased accuracy, in their ability to assess their own work. This is reflected in the error distribution for this assignment, which is narrow and centred around a slightly negative expected value near zero - indicating the remainder of a slight underestimation, on average. The overall result is a temporal decrease in the error of the estimates produced by the students - indicating an increase in both confidence and self-awareness.

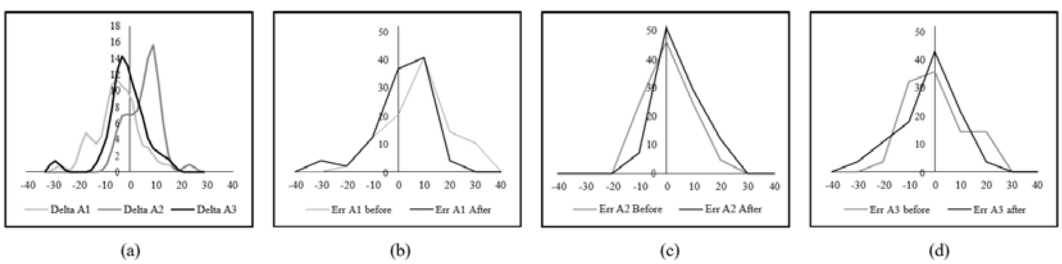

FIGURE 1: Self-assessment results before and after each assignment's peer review. (a) shows a histogram of the difference (delta) in self-assessment before and after doing others' peer review (before - after). (b) to (d) show the difference in self-assessment and awarded peer-review mark, for the mark given to self before and after doing peer-review of others.

C. Self-Reflective and Peer Engagement Feedback

On reviewing the student reflective feedback, it is clear that the majority saw key lessons learnt as improvement in time management, academic literacies practices and digital skills. Bandura's [12] first self-efficacy influence - mastery - is facilitated through scaffolded and repeated practice. The self-reported improvements in independently sourcing relevant information and constructing a technical report are a key Graduate Attribute in the engineering qualification [20]. Along with the opportunity to improve their digital literacies practices (LaTeX report platform), the scaffolded assignments clearly contribute to confidence-building in the "demonstration of . . . appropriate ... professional discourse" [20]. We suggest that this mastery is in fact what manifested as improved time management with each subsequent assignment. An interesting observation is the impact of 'vicarious learning' through engagement with each other's work. Several students appear to have better aligned their expectations by being able to measure their own standard against both the work of their peers as well as the detailed rubric, as indicated in the following feedback (FB):

- *Reading a peer's report makes it easier to identify when sections are irrelevant or incorrect, as you read them without any bias.* [FB194]
- *Giving Constructive feedback and to be able to see the design from another point of view.* [FB220]
- *You can win a lot of marks just by reading the rubric ... and if you actually understand what you're writing.* [FB317]

The vicarious influence on self-efficacy development extends to the social experience of engineering identity formation through peer support. In contrast to a previous initiative in which the facilitator himself led key online Q&A sessions [8], the student-led Q&A sessions in this course speak directly to the value of peer-learning as a mediated sociocultural strategy [18]. More than 80% of the electronic design students reported that the interactive online problem-solving and student-led tutorials [8] helped them to bridge the gap from theory to practice, while less than two thirds reported it for the actual scantily staffed practicals. There were several references to improved understanding through peer-learning:

- *"Asking questions is the way to go. The people who didn't go through the work early enough and didn't make proper use of the practical session really missed out."* [FB43]
- *"I need to participate more in discussions"* [FB85]

Perhaps the most significant feedback on 'lessons learnt' from the scaffolded, self- and peer-assessment assignment strategy, is the number of references to improved conceptual grasp:

- *Small changes in resistor values have a big impact* [FB90]
- *Better understanding of thermal properties of components* [FB118]
- *This is the first time we designed circuits with OpAmps, this opened my eyes to how useful they can actually be* [FB149]

VI. CONCLUDING COMMENTS

The initiative described and evaluated in this paper has sought to contribute to the development of engineering student self-efficacy. Having observed the various challenges engineer- ing students experienced during ERT, a number of initiatives were implemented to support student learning in a 3rd-year electronic design course at a research-intensive, residential institution in South Africa. Drawing on Bandura's [12] four influences, the paper has presented an evaluation of:

1) the building of mastery through a scaffolded set of e-design tasks and accompanying reports across the semester;
2) enabling vicarious experience through the use of peer-review processes;
3) the social experience of supporting each other's learning in peer-led online Q&A sessions;
4) accommodating the different emotional states implied in the shift in workload and exam stresses across the semester by offering self-reflective learning opportunities.

Although not intended to be a 'victory narrative', it is clear that a well-designed, scaffolded set of assignments in which students are encouraged to reflect and engage in peer-learning opportunities can contribute significantly to the development of student confidence and mastery. These attributes are essen- tial if we are to effectively support engineering undergraduate learning that results not only in improved performance and academic success, but in the potential graduation of engineers who can confidently tackle the challenges of our time.

REFERENCES

[1] M. L. Gaeta, L. Gaeta, and M. d. S. Rodriguez, "The Impact of COVID-19 Home Confinement on Mexican University Students: Emotions, Coping Strategies, and Self-Regulated Learning," Frontiers in Psychology, vol. 12, 2021. [Online]. Available: https:// www.frontiersin.org/articles/10.3389/fpsyg.2021.642823

[2] C. Hodges, S. Moore, B. Lockee, T. Trust, and A. Bond, "The Difference between Emergency Remote Teaching and Online Learning," Educause Review, vol. 27, 2020.

[3] B. J. Zimmerman, "Investigating self-regulation and mo- tivation: Historical background, methodological devel- opments, and future prospects," American Educational Research Journal, vol. 45, no. 1, pp. 166–183, 2008.

[4] J. Broadbent and W. Poon, "Self-regulated learning strategies & academic achievement in online higher edu- cation learning environments: A systematic review," The Internet and Higher Education, vol. 27, pp. 1–13, 2015.

[5] D. Grant, A. Malloy, and M. Murphy, "A comparison of student perceptions of their computer skills to their actual abilities," JITE, vol. 8, pp. 141–160, 01 2009.

[6] G. K. Tippin, K. Lafreniere, and S. Page, "Student perception of academic grading: Personality, academic orientation, and effort," Active Learning in Higher Edu- cation, vol. 13, pp. 51 – 61, 2012.

[7] O. Gulacar and C. R. Bowman, "Determining what our students need most: exploring student perceptions and comparing difficulty ratings of students and faculty," Chem. Educ. Res. Pract., vol. 15, pp. 587–593, 2014.

[8] M. J. Booysen and K. E. Wolff, "Exclusion from constructive alignment unmasked by emergency teaching," in REES 2021. Perth, Australia: REES Conferences, Dec 2021. [Online]. Available: https://doi.org/10.31224/osf.io/cxmht

[9] K. Wolff, D. Blaine, and C. Lewis, "A cumulative learning approach to developing scholarship of teaching and learning in an engineering community of practice," in 2021 World Engineering Education Forum/Global Engineering Deans Council (WEEF/GEDC), 2021, pp. 310–318.

[10] L. Czerniewicz, N. Agherdien, J. Badenhorst, D. Bel- luigi, T. Chambers, M. Chili, M. de Villiers, A. Felix, D. Gachago, C. Gokhale, E. Ivala, N. Kramm, G. M. Matete Madiba, E. Mgqwashu, N. Pallitt, P. Prinsloo, K. Solomon, S. Strydom, M. Swanepoel, F. Waghid, and

G. Wissing, "A Wake-Up Call: Equity, Inequality and Covid-19 Emergency Remote Teaching and Learning," Postdigital Science and Education, vol. 2, p. 946–967, 2020.

[11] N. Korsten, K. Wolff, and M. Booysen, "Time for men- tally healthy engineering students," in 2021 World En- gineering Education Forum/Global Engineering Deans Council (WEEF/ GEDC), 2021, pp. 101–109.

[12] A. Bandura, "Self-efficacy: Toward a unifying theory of behavioral change," Advances in Behaviour Research and Therapy, vol. 1, no. 4, pp. 139–161, 1977, perceived Self-Efficacy: Analyses of Bandura's Theory of Behavioural Change. [Online]. Available: https://www. sciencedirect.com/science/ article/pii/0146640278900024

[13] E. L. Deci and R. M. Ryan, "Self-determination theory," Handbook of Theories of Social Psychology: Volume 1, pp. 416–437, 2012.

[14] R. W. M. Pott and K. Wolff, "Using legitimation code theory to conceptualize learning opportunities in fluid mechanics," Fluids, vol. 4, no. 4, 2019. [Online]. Available: https://www. mdpi.com/2311-5521/4/4/203

[15] C.-H. Wang, D. M. Shannon, and M. E. Ross, "Students' characteristics, self-regulated learning, technology self-efficacy, and course outcomes in online learning," Dis- tance Education, vol. 34, no. 3, pp. 302–323, 2013.

[16] H. Andrade and A. Valtcheva, "Promoting learning and achievement through self-assessment," Theory Into Practice, vol. 48, no. 1, pp. 12–19, 2009. [Online]. Available: https://doi. org/10.1080/00405840802577544

[17] D. W. Johnson, R. T. Johnson, and K. Smith, "The state of cooperative learning in postsecondary and professional settings," Educational Psychology Review, vol. 19, no. 1, p. 15–29, 2007.

[18] A. Kozulin, "Sociocultural theory and the mediated learning experience," School Psychology International - SCHOOL PSYCHOL INT, vol. 23, pp. 7–35, 02 2002.

[19] J. Lave, E. Wenger, E. Wenger, J. Brown, C. Heath, and R. Pea, Situated Learning: Legitimate Peripheral Participation, ser. Learning in Doing: Social, Cognitive and Computational Perspectives. Cambridge University Press, 1991. [Online]. Available: https://books.google. co.za/ books?id=CAVIOrW3vYAC

[20] ECSA, "Qualification Standard for Bachelor of Science in Engineering (BSc(Eng))/ Bachelors of Engineering (BEng): NQF Level 8," 2019. [Online]. Available: https://ecsa.co.za

Technical papers

Developing a sustainability culture in LATAM: A case study of a strategic inter-university alliance

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***Abstract* — The last two years the environment has shown us the strong connection between countries, companies and people, and has demonstrated the importance of the supply chain: as an impact on the environment, as well as its impact on economic, social and health stability. Developing a sustainability culture in the day-to-day practices of business, educational institutions, government and society has become global objectives, such as the Sustainable Development Goals. In particular, in higher education institutions, the commitment to develop a culture of sustainability plays a dual role: educational and sustainable practices as an internal community, and an external role in promoting this culture in society. The purpose is to share the case study of an alliance of universities in LATAM, which seeks to create awareness of a sustainable culture in the industry through an efficient supply chain using a survey that is applied annually in LATAM countries with its respective report of results, and how this initiative promotes a culture of sustainability in the professors and students involved in the project. The methodology has 3 phases: a) Description of the alliance between universities and the initiative that unites them, b) instruments such as surveys and reflections of students and professors participating in the project, and c) the analysis and reflections of the main learnings. The participation of students and professors from 13 universities in 10 countries, offers us a motivation in strengthening this culture of sustainability from a strategic collaborative work between universities, it is observed with hope the development of this culture, for the impact on the environment and the welfare of society, through these practices of linkage, research and development for the common well-being.**

Keywords — Sustainability, International Collaboration, Educational Innovation, Higher Education

I. INTRODUCTION

Today's environment is increasingly demanding a sustainable culture in our society, from the personal to the business and public spheres. This priority has been framed in the Sustainable Development Goals , with several of them linked to the impact on the environment such as SDG 7 Ensure access to affordable, reliable, sustainable and modern energy for all, SDG 11 Make cities and human settlements inclusive, safe, resilient and sustainable, SDG 12 Ensure sustainable consumption and production patterns and SDG 13 Take urgent action to combat climate change and its impacts (4 of the 17 Goals are linked to this culture) [1]. These goals are influential in considering that fostering a sustainable culture is not a simple problem to address, and because of its complexity, different perspectives of both stakeholders and disciplines or specialties must be considered [2, 3]. It is important to consider what sustainable development means for a common framework [2], "is the development which meets the needs of the present without compromising the ability of the future generations to meet their own needs".

The demand for a culture of sustainable development has become an urgency, which must be developed from all areas and at all levels of society. Therefore, the need to consider as an emergence of education for sustainability [4], which should have multidisciplinary perspectives and from different sectors, in addition, this education should be beyond a formal education but should be a professional practice and a lifelong learning process. Considering the urgency of promoting and strengthening this culture of sustainability in all stakeholders, higher education institutions, as creators and disseminators of knowledge, as well as trainers of future professionals and / or entrepreneurs, have a dual role in this co-responsibility.

This study shows how, through initiatives based on international collaboration, they promote, create and strengthen this culture. The questions to be answered, related to this culture of sustainability and a strategic alliance between universities, considering the role of the university as a promoter of this sustainable culture, is: Do the initiatives developed in inter-university collaboration generate an impact on the culture of sustainability in the groups involved (professors and students)?, and do the initiatives of the academy towards the industry allow to promote this culture of sustainability in both ways?

II. LITERATURE REVIEW

Among the main stakeholders to promote (and develop) the culture of sustainability with actions are universities, companies and governments, with active roles, encouraging the involvement of all, continuously, holistically and with clear and concrete activities [2]. This research addresses the role of the university as a stakeholder involved and committed to promote and live this sustainable culture. The role of universities in promoting this culture of sustainable development has been considered according to studies in aspects such as the operation of the university, impacting educational programs, research and collaboration [3,5]. This considers two relevant environments of impact on their role: (1) their commitment as an institution to promote with actions and policies the culture of sustainability in their daily work, and (2) the promotion of this culture of sustainability both in their internal community (students, teachers, staff) and in the external community: companies, organizations, society.

The strategies developed in universities to generate this culture of sustainability are affected by external and internal factors. The internal ones are linked to values, knowledge and emotions, while the external ones are related to infrastructure, institutional culture and economy. And among the main actions taken to promote this culture are: recycling and water saving, water and energy management, promoting cooperative and creative environments, until consolidating an institutional strategy with policies related to sustainability [2,6]. One of the external impact strategies of universities in promoting this sustainable culture is to share the lessons learned with the academic community (students, professors, staff) and with society (companies, government). As indicated by [6], Universities "might share knowledge, research, methods and experiences to disseminate and promote sustainable practices; stimulating environmental awareness of the community, the students, the professors and other staff; and promoting shared learning and cooperation with other stakeholders" disseminating and promoting sustainable practices, to be agents of change for sustainability in the different sectors of society [7].

Additionally, the invitation to universities and companies to collaborate and align themselves with the achievement of the SDGs established for global benefit implies both awareness and a series of actions that have a direct impact on the environment and on the operation of the companies. In order to favor this involvement, strategic alliances between companies, between universities and between companies and universities are a contributing factor. As indicated in the literature "SDGs are addressed to all actors in society, but both academia and professional recognize the particular importance of businesses" [8], in recognition of this importance, an initiative arose from a university in Argentina, which seeks to create awareness in companies and their supply chains, generating knowledge through a consultation, which over the years has spread to other countries thanks to international alliances between universities.

Considering that universities play a key role in the generation and dissemination of knowledge, as well as an agent of cultural change both in their internal community and in society, capable of generating models as well as diagnosing best practices in key issues such as sustainability in our countries[3,5,7,8,9], we share the experience, as study case, of an alliance between Latin American universities, that seek to promote awareness in the industry of sustainable practices that are most applied in the supply chain, making the dissemination of this knowledge, and in turn promote through this linkage and development of joint project a creation of awareness among professors and students from 13 universities.

III. METHODOLOGY

The methodology is qualitative [10,11] with the case study, and with the use of surveys as an instrument to obtain qualitative information that allows us to obtain the ideas and perceptions of those involved, in this case students and teachers. The methodology consists of 3 phases: a) description of the alliance between universities and the initiative that unites them, b) instruments such as a survey with reflections of students and professors participating in the project, and c) the analysis and reflections of the main learnings. The methodology is based on a case study describing the initiative that impacts not only companies but also the universities themselves, the use of instruments that allow obtaining qualitative and quantitative data, and concluding on the basis of the analysis that is developed.

The description of the initiative that promotes the alliance between universities is made up of: its origin and objectives, integration process, progress up to 2021. This helps to understand how an initiative, with an academic leadership, that seeks to influence the industry to raise awareness of a sustainable culture, can lead to create an internal awareness in its academic community and in other academic communities.

In order to determine the impact of being part of this alliance between universities, as well as of the activities linked to the initiative, a survey is applied to determine the previous sensitivity of the participants in the project on sustainability issues, and the extent to which it has an impact on promoting this culture of sustainability in themselves (students and professors). The sample of those who participated in the study consisted of teachers and students from:

- Industrial engineering (90%), environmental engineering and business areas (see Figure 1).
- 10 different Latin American countries (including Perú and Republica Dominicana, see Figure 2).
- 40% of the participants are students, and 60% are researcher and/or professors.

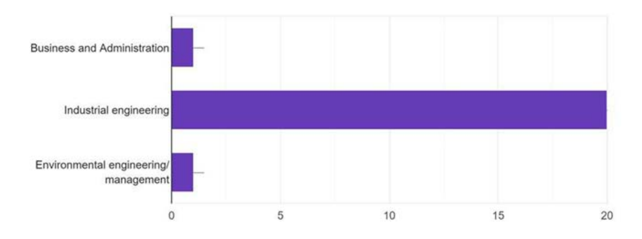

FIGURE 1: Discipline of survey participants (professors and students).

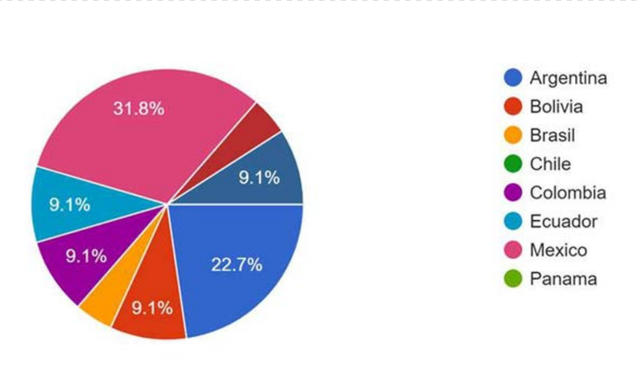

FIGURE 2: Country of survey participants are currently living

Finally, the qualitative and quantitative analysis of the key elements of the survey linked to the creation or strengthening of this culture of sustainability of students and professors is presented as an example of a practice that can impact different stakeholders from our role as an institution of higher education.

IV. RESULTS

The following is presented based on the phases of the proposed methodology: the description of the alliance between universities to promote a culture of sustainability, and the findings of how participating in this initiative has an impact on promoting this culture of sustainability among professors and students.

A. Study case

Since 2014, the Center for Integrated Logistics and Operations of the Instituto Tecnológico de Buenos Aires has been developing a strategic initiative to promote a culture of sustainability in companies [12], through the dissemination of the results of a survey it applies annually to the industry, to learn about their practices in sustainability issues in the supply chain, which impacts the environment.

The general process consists of Step 1. Design or review of a survey, which considers the following elements:

- Significance that the company gives to sustainability
- Training on environmental management issues
- The use of regulations and their management plans.
- Sustainability practices in resource management, transportation and management of the company.
- Documentation and measurement of the impact of sustainability actions in the supply chain.

Step 2. Dissemination of the survey to companies through social networks and other formal and informal means of communication.

Step 3. At the end of the application period, analysis of results and generation of executive reports

Step 4. Dissemination of results through presentations at events, social networks, and on the Center's website.

With the interest of increasing the impact of this consultation, the leading team sought alliances with colleagues from other universities, and year after year teams of professors and students have been integrated, who are the ones who develop this same process in their country of origin, with the leadership of the team that designed and developed this initiative.

Currently, 13 universities from 10 Latin American countries are participating in the initiative in order to raise awareness in the industry of this culture of sustainability in its supply chain (see Figure 3 & 4), and to learn about the current state of sustainability in the logistics activity, and to identify best practices that can be shared. The main characteristics of the alliance are:

- The network´s leadership as well as the annual call to develop the initiative is led by the University of Argentina. It is a participatory and co-development leadership to improve the impact of the initiative.
- Every member has a commitment with the main goal: to raise awareness of sustainable logistics for LATAM.
- Invitations emerge from the network members themselves who know other colleagues from universities in other countries, who freely invite them to participate.
- Teams of professors and students are integrated on a voluntary basis with a commitment to develop the initiative for at least one cycle, the expectation is that they will continue in the following applications.
- The integration of the inter-university network is strengthened through: start-up meeting, follow-up meetings (which are held every two weeks), analysis of results, and closing session for dissemination. At least one member of each team participates in these sessions, which use synchronous digital media. The objective of the bi-weekly sessions, in addition to monitoring the progress of the initiative, is to share best practices in liaising with companies to increase their participation in the survey.
- The results of the consultation are shared among the members of the network for analysis of results, design of executive reports and publications.

FIGURE 3: *Follow up reports and social media flyers.*

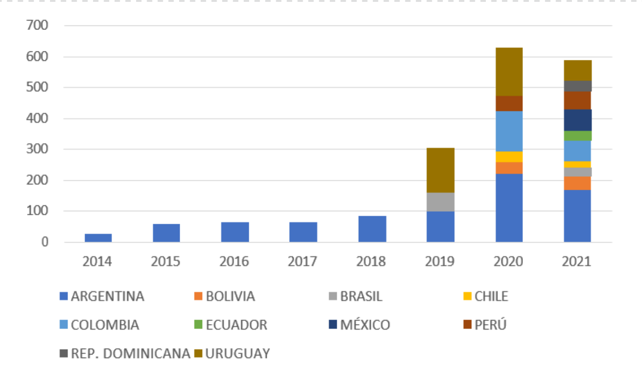

FIGURE 4: *Number of surveys answered per country.*

The increased participation of professors and students allows for consultations in other countries in the Latin American region, aimed at companies of all sizes (see Figure 4). In this way, the diagnosis is closer to reality, and allows to generate comparisons between countries. Another result is the publication of the results through meetings, presentations, congresses and publications in the universities' web pages. This initiative strengthens the role of the university to generate and promote knowledge, in this case of sustainable culture.

Each university develops its own executive report, and the universities share them with the companies that voluntarily participate in the consultation. The finale goal is to incentives them to continue participation in the survey initiative sharing their experience in sustainable practices in their supply chain activities, that could help to another companies as example and inspiration.

Among the results of this consultation is to identify the main sustainable practices that LATAM companies carry out, the standards they follow and the way in which they communicate and document them. The increase in the participation of companies in the survey suggests that the interest in knowing the most common practices that have an impact on a sustainable environment is on the rise. And this awareness of what the industry develops to be sustainable generates an impact among professors and students, creating a double effect in the development of a sustainable culture as will be seen in the results of the survey applied to professors and students that participated in this initiative, and not only to the industry as is part of the objectives of the ITBA initiative.

B. Survey Analysis

A survey was applied to the teams participating in the initiative, both professors/researchers and students, to know the impact of participating in relation to the culture of sustainability that is to be promoted precisely through the network itself.

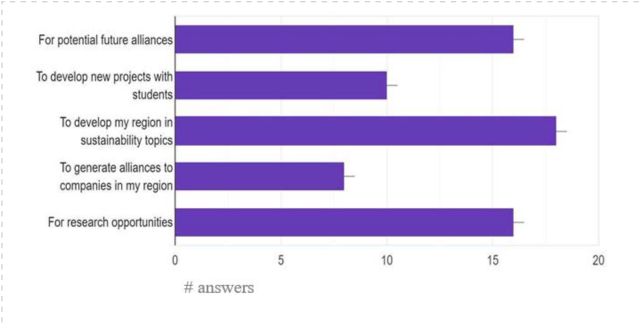

FIGURE 5: *Reasons to join the initiative as interuniversity network*

One of the questions is related to the reasons why they joined the network. It is interesting to find that the main reasons were (see Figure 5):

- To develop my region in sustainability topics (82%)
- For potential future alliances (72%)
- For research opportunities (72%)
- To develop new projects with students (45%)

Recognizing the dual role of universities [2,3,5,6,7], in which the external impact is of relevance with the desire to promote this sustainable culture in society and industry, through generated knowledge that facilitates the implementation of sustainable practices in the supply chain. Allied, with the interest to develop research. In the role of internal impact, the intention to train students through real projects, which allows them to develop competencies and align values such as commitment to the environment.

Participants assessed their learning related with (see Figure6):

- best practices in sustainability
- the existing policies regarding environmental practices in their region.

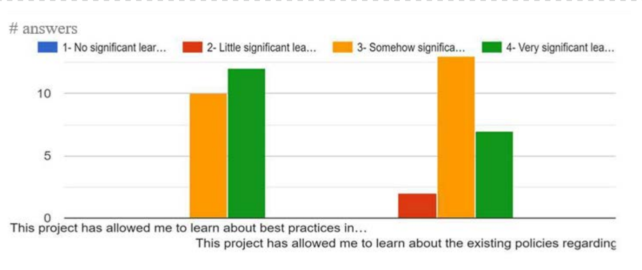

FIGURE 6: *Participants´ Learning through the initiative related to sustainability*

Regarding the impact of their learning, 100% of the participants in the study confirmed that they have significant learning (somehow or very significant learning) from participating in the initiative, in terms of best practices in sustainability. And related to the impact on their learning on topics such as environmental practice policies in their region, it was found that the responses were more distributed where 10% considered little impact on their learning, and the rest (90%) were somehow or very significant.

Among the benefits of participating in these global initiatives is that it allows not only to reach the professors, students and companies that participate, but also to multiply the impact in the classroom through the professor, as indicated by this professor:

"Participating in this project led me to learn more about issues related to the supply chain and its impact on the environment, a topic that I had not addressed so far and that I found very valuable to work on in my classes."

V. CONCLUSIONS

The effects of not having a sustainable culture are increasingly evident in our current environment. Therefore, it has become a necessity for universities to take a leadership role that generates new knowledge as well as integrates current knowledge, and is disseminated to all sectors of society. In addition, it must ensure as a training institution that integrates this sustainable culture not only in its internal operating practices but in the same members of the academic community, students, teachers, researchers and staff in general.

One of the main purposes of higher education is the formation of committed leaders who transform the environment with social responsibility and professional ethics. And in this globalized world, which was confirmed by the pandemic with one of its teachings: we are all connected, we affect each other, and the solutions are also in everyone, individual work is not enough to respond to the challenges we face, so the alliances between different interest groups generate greater impact to the effort made by one alone. Sustainable culture must be present in the individual, in the family, in society in general, in companies and governments. The alliance between universities helps to strengthen and encourage this culture, both internally in their daily operations and in the formation of students and strengthening of professors and researchers, through the generation of new knowledge and sharing best practices through joint initiatives and projects. And also, externally, by carrying out joint initiatives that impact one of the most important stakeholders, the companies, who are increasingly aware of the impact of their supply chain activities on the environment and society, and it is through university-business collaboration that a multiplied impact can be achieved, as we hope it will be for our regions in LATAM.

ACKNOWLEDGMENT

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REFERENCES

[1] "The 17 goals," Sdgs.un.org. [Online]. Available: https://sdgs.un.org/goals. [Accessed: 06-Jun-2022].

[2] W. L. Filho, "About the role of universities and their contribution to sustainable development," High. Educ. Pol., vol. 24, no. 4, pp. 427–438, 2011.

[3] R. Lozano et al., "A review of commitment and implementation of sustainable development in higher education: results from a worldwide survey," J. Clean. Prod., vol. 108, pp. 1–18, 2015.

[4] C. Mio, S. Panfilo, and B. Blundo, "Sustainable development goals and the strategic role of business: A systematic literature review," Bus. Strat. Environ., vol. 29, no. 8, pp. 3220–3245, 2020.

[5] M. Dzimińska, J. Fijałkowska, and Ł. Sułkowski, "A conceptual model proposal: Universities as culture change agents for sustainable development," Sustainability, vol. 12, no. 11, p. 4635, 2020.

[6] Berchin, I.I., Grando, V.d.S., Marcon, G.A., Corseuil, L. and Guerra, J.B.S.O.d.A. (2017), "Strategies to promote sustainability in higher education institutions: A case study of a federal institute of higher education in Brazil", International Journal of Sustainability in Higher Education, Vol. 18 No. 7, pp. 1018-1038. https://doi.org/10.1108/IJSHE-06-2016-0102

[7] J. C. Stephens, M. E. Hernandez, M. Román, A. C. Graham, and R. W. Scholz, "Higher education as a change agent for sustainability in different cultures and contexts," Int. J. Sustainability Higher Educ., vol. 9, no. 3, pp. 317–338, 2008

[8] S.-H. Kang, B. Kang, K. Shin, D. Kim, and J. Han, "A theoretical framework for strategy development to introduce sustainable supply chain management," Procedia Soc. Behav. Sci., vol. 40, pp. 631–635, 2012.

[9] A. Sibbel, "Pathways towards sustainability through higher education," Int. J. Sustainability Higher Educ., vol. 10, no. 1, pp. 68–82, 2009

[10] S. M. Alexander et al., "Qualitative data sharing and synthesis for sustainability science," Nat. Sustain., vol. 3, no. 2, pp. 81–88, 2020.

[11] J.W.Creswell, W.E., Hanson, V.L. Clark Plano, V. L., & A. Morales. Qualitative research designs: Selection and implementation. The counseling psychologist, 35(2), 236-264, 2007

[12] "Encuestas OLS," Edu.ar. [Online]. Available:https://www.itba.edu.ar/centros/clio/encuestas- ols/. [Accessed: 01-Jul-2022].

Technical papers

Skills requirement by industrial engineering students during vacation work

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***Abstract* — Engineering training should prepare students for industry work; hence, it is expected that the academic curriculum should be structured after the requirements of the industry. The objective of this research was to understand what Industrial Engineering (IE) skills are used in the industry by the university students during their vacation work. This may help in determining the level of emphasis placed on some of the skills with which students are imbued, and how soon the exposure to these skills should be during the training period.**

It was found out that the mostly used skills are the soft skills, and not the technical engineering skills imparted into the students. Moreover, even among the engineering skills used, most students make more extensive use of the basic engineering skills acquired earlier in their study years than the more advanced skills taught later in the Universities.

The study indicates that it is important that the training of engineering students should place sufficient emphasis on teaching students on team dynamics and relationship management as this may be more central to their career, especially as they transition from student to working life.

Keywords — engineering training, industrial engineering skills, soft skills, technical skills, vacation work.

I. BACKGROUND

A purpose of engineering education is to prepare students that can make contributions in the society, and adapt to the current global reality with its rapidly changing requirements. It is, hence, important that there is as little gap as possible between what the industry expects of the students, and how the students are prepared in the Universities. The determination of what these requirements are is important in the training of engineering students and has started to received attention from many training institutions, starting from the regulatory bodies.

The University of Pretoria is one of the main universities training engineering students in South Africa, and Industrial Engineering (IE) is one of the engineering fields in which students are trained there. A requirement of all engineering students is exposure to practical work environments for 12 weeks during their training. This requirement was made by the Engineering Council of South Africa (ECSA); hence, all IE students do vacation work. These 12 weeks are broken into two periods, the first 6 weeks usually done after their second year and the remaining 6 weeks after their third year of study. A question of interest is what skills the students need to be equipped with so that they may be well suited for the environment in which they work. While there is no easy answer to this question across all engineering fields, it seems the skills have been broadly classified as being either technical or professional in all engineering professions. Hard skills are generally considered to be those required in the design and analysis of engineering problems, while soft skills help to function in the professional environment, which usually involves people from different backgrounds, a number of which may not be engineering [1].

The technical skill requirement is also diverse, not only across the different engineering fields, but even within a particular field of engineering. While some of these skills make sense to be taught earlier as prerequisite to some other skills, there are, however, a number of skills and techniques whose order may be moved around. This, therefore, begs the question about the order in which students are introduced to each of these skills are and the relative emphasis placed on each of them. This understanding is important both for the long-term performance of the IE graduate as well as the adaptability of students to the work environment after graduation.

ECSA, on another hand, drew a lot of its requirements from those of the The International Engineering Alliance (IEA). IEA is an international cooperation created to enhance the mobility of engineering skills and portability of engineering qualifications. It provides a framework for the mutual recognition of competence of engineers across member nations. The IEA achieves its mandates through its constituents, the oldest of which is the Washington Accord, and which dates back to 1989 and guides the mutual recognition of the training and competency of Professional Engineers. The Engineering Council of South Africa (ECSA) applied for membership in 1993 and became a signatory in 1999 [2] and has since been guided by IEA tenets. The IEA has progressively emphasised more inclusion of soft skills in engineering training, and it is important to understand how relevant this is to the industry as well, particularly as ECSA has adopted the same measures in the definition of engineering requirement. While understanding the long-term relevance of these skills is in IE practice, the focus of this research is to understand how much the undergraduate students of IE in the University of Pretoria use each of these techniques in during their vacation work and possibly infer possible areas that may deserve some more attention in the preparation of the students for industry.

II. RESEARCH AIMS AND QUESTIONS

The aim of this research is to find out how useful the different skills taught to the IE students in the university are when the students are out during their vacation work, hence, to inform how the IE training programme may enhanced to support the students as they transition into practitioners in the industry. In addition, the study seeks to understand how complementary the techniques are, so that plans may be made about how the modules may be structured in a manner that the students may have all the techniques needed for industry practice delivered in an integrated manner. These objectives can be summarised in the following research questions:

How often do the students need to use each of the techniques taught to them in the school during their vacation work in the industry?

How may this assist in preparing engineering students for their future work environment?

This research sought to answer these two questions from the information provided by the IE students as reported after their vacation work experience.

III. LITERATURE REVIEW

The regulation of engineering qualification in order to prepare the engineering professional is done through the use of engineering learning outcomes, and more recently, the graduate attributes [2]. Graduate Attributes (GAs) have been defined as the set of individually assessable outcomes that are the components indicative of the graduate's potential to acquire competence to practice at the appropriate level [3]. These skills are said to be transferable [4], meaning they can be learnt, and their level of acquisition can be measured, hence the definition of range statements made for the different categories of qualification [3]. This range of attributes cover the knowledge needed, not only to solve engineering problems, but to assimilate into society and works with other professionals. For the engineering professional, the skills may be classified into two categories, namely: technical skills (also sometimes called hard skills); and professional skills (also sometimes called soft or generic skills). While every engineering training has usually incorporated the core skills covering areas like the application of the knowledge of mathematical and the engineering sciences, universities seeking to be compliant with the IEA requirements have reported major shift around a significant inclusion of professional skills like communication, team work, ethics and case-based reasoning amongst others (ibid).

Soft skills are the types of skills needed for daily interaction with others and are probably as important as the core skills that are transferred to engineers. Without these skills, they engineers are unable to fulfil their roles [1], and this is a reality dawning on many engineering training institutions. Ng [5] noted that the graduate level engineering applicants in Malaysia are reported by employers not to be wanting in technical skills, but need significantly improved soft skills. The same observation has been made earlier by Katz [6] about entry point engineers in the United states. Of particular importance is the communication skills, which the employers noted was "less than not good" but really bad. Shakespeare et. al. [7] summarised the skills requirements for a professional training succinctly as follows: "Qualifications in the practical professions need to address fitness for award [what the educational establishment wants], fitness for practice [what the professional body wants], and fitness for purpose [what the employers want]. Changes in professional education usually betoken a rebalancing between these three points when one is thought to have become privileged and is producing 'unbalanced' professionals.". Riemer [8] opined that not is communication skills essential for the engineer in the 21st century, but consideration should also be given to learning foreign languages, and emphasising different elements of communication skills like oral, listening, written, visual, interdisciplinary and intercultural.

One definition of Industrial Engineering (IE), amongst others, is that it is the branch of Engineering concerned with the design, installation and improvement of integrated systems of people, material, information, equipment and energy [9]. Another succinct definition provided is that which summarises IE from two main perspectives: human effort engineering and systems efficiency engineering [10]. From these definitions, the scope of the expectations of an Industrial Engineer can be conceptualised, and hence, what constitutes the skills-set of an Industrial Engineer. This skills-set also parallels the development in the industry that the industrial engineer serves. Records for both the second year and third year vacation works were merged. There were 684 records in total, but the actual number of students is a little less than this since some students submit both the second- and third-year reports in the same year, hence, the unit of analysis is record of vacation work and not individual students, per se.

The challenge of the continuous change in the skills requirement of an Industrial Engineer is captured by Du Preez and Pintelon [11], where they surmise that the IE is always in a period of dynamic change in terms of the skills required. They stated that there is the need for the IE to balance between working within the traditional sphere of managing productivity and improving system efficiency, and shifting with the current advances to become the engineer working on virtual and extended enterprise system. They concluded that in reality, the Industrial Engineer needs a mastery of both worlds to remain competitive in today's world. Actually, this conclusion simply emphasise the need to balance between the traditional and evolving technical IE skills. The question is if it is important to place equal (or even more) emphasis on focusing on the softer skills.

IV. METHODOLOGY

This study was conducted in the department of Industrial and Systems Engineering of the University of Pretoria, South Africa and the record of every second- and third-year student that did vacation work was was available. The reporting standardization project started in 2016 and was test-run in 2017. The record of two full years was available before COVID started in 2020, but for the purpose of this work, only the result of the second year (2019) was utilised because by then, the students have become quite accustomed to the use of the submission platforms and the data is more reliable. 2019 had a more representative data for a typical year while the years 2020 and 2021 had COVID infraction which affected how many industry projects were implemented in those year.

Traditionally, vacation work reporting takes the form of essay type documentation, which leads to less standard structure. To assist with this research, the reporting structure was changed in two manners: firstly, it was made to be project based, meaning each student presents their reports based on the list of projects they implemented during their vacation work and the techniques they used in implementing them; secondly, the documentation was divided into two sections a standardised and a customised section. The standardised section is made up of some common data fields that all students always mention in their reports, and which could be converted to standard google form and used to collect some general meta-data related information about the projects implemented, and the custom section is where students may be allowed to write freely about each project's details, the student's learning experience and personal opinion.

To identify the standard fields to be implemented for collection of meta-data in the standard section, previous project report documents were analysed and a list of entries that could be standardised for the students' reporting purpose were identified. These objects were designated as standard text fields and their possible linguistic values were collated from the values provided by the students. This was then implemented in such manner that students could make simple entries such as multiple choice, single choice, or short response fill-ins. This means students only needed to select options from given choices or type short text responses. The standard entries that most students have in their report include number of days worked, number of projects implemented, the type and level of supervision received, industry mentor's details, list of techniques adopted to address the problem that each project is intended to solve, and similar fields.

The students' records of IE skills used in implementing their projects during the vacation work was the field of interest in this study and it was one of the standardised fields. After coding the texts of some previous years' documents submitted by selected students for techniques mentioned in their reports as explained in the previous paragraph, a list of one hundred and eighteen (118) types of skills were identified. Since there was such a large number of identified skills, they were further grouped based on subject categories and similarities of use, and the groups were named as appropriate. Six groups of these skill sets were created, five of which were related to taught IE techniques, and the last group consists of general soft and basic engineering skills. The six groups of skill sets created are as follows: Group 1: Time study, motion study and productivity analysis; Group 2: Project Planning, Statistical Process Control, Statistical Analysis and Computer Programming; Group 3: Process Design, Production Planning, ERP systems and Strategic Planning; Group 4: Facilities Layout and Material Handling; Group 5: Process Diagramming and Modelling, Information System Design, Data Modelling and Analysis; Group 6: Soft and Basic Engineering skills.

The list of all skills collated from previous students' reports were made the possible options (linguistic values) under each of the groups (text fields), and from these, the students could make multiple selections. This was then implemented in the form of google form. A section of the list of IE skills put in Group 1 containing work study and productivity improvement techniques is shown in Figure 1. Students select all skills utilised here, and at the back-end, the students' entries get recorded into a spreadsheet that could be downloaded for analysis. This makes comparison across different units of analysis and trend analysis easier. The category created for the soft skills and general engineering includes techniques such as communication/interpersonal relations skills, presentation skills, use of office applications and engineering drawing amongst others.

Students were required to first complete the standard section before submitting their customised written reports that summarises each of the projects implemented, the problem addressed by the project, how the techniques were utilised in addressing each project, difficulties encountered and how they were surmounted, data related to the projects implemented, reflection of their learning from the projects, perceived learning attained, and other details. This written report is also uploaded in an appropriate section of the university learning platform (called clickUP). The links to both the standard google form section and the document upload section were put together in a landing page on clickUP, a customised version of the blackboard (see Figure 2), and the entries of the standard section gets collated into the background spreadsheet for subsequent analysis of the meta-data collected.

The data needed for this analysis was retrieved from the backend table that stored the submission of each student as a record. For this research, only the fields related to the list of projects implemented and the IE techniques used in implementing them were of interest. These were then selected and downloaded. The data was first cleaned up and prepared for the research. Numerical summary techniques like graphical visualisation and descriptive summary were then used to study the patterns observable in the data.

V. FINDINGS

The result of the frequency count of techniques used is presented in Figure 3. It was found that soft skills (e.g. communication/personal interaction, presentation/speaking skills) were the most pervasively reported by the students, followed by data handling skills (e.g. data capture, data validation, data analysis), the basic engineering skills (e.g. reading engineering drawings, understanding issues related to occupational health and safety, etc), and then others.

It was also found that the IE skills mostly used by the students during their vacation work were the more basic techniques learnt in the early parts of their study for general process improvement (e.g. flow charting, brainstorming, 5S, 5 why etc), and not the more advanced techniques (e.g. mathematical modelling, probability models, simulation modelling, MRP, etc.). While some of the more advanced techniques were also used, the extent of use was far below the basic skills. In fact, techniques like differential equations and matrix analytic techniques were not reported at all. It is interesting that more students reported the use of skills like foundations of law in the business environment than some of the more sophisticated IE techniques they have learnt.

The list of the top forty (40) skills used reported by their frequency of mention is presented in Table 1. It can be seen that communication and interpersonal skills is by far the most mentioned skillset. The students reported participation in (or implementation of) 684 projects in total, and this skill was reportedly used in 603 of these projects, which is 88.2 percent of the total projects reported. The next skillset most mentioned is the use of office applications, mentioned 395 times, which is about 57.1 percent of the total projects implemented. The first set of basic IE techniques mentioned includes brainstorming, flow charting and work sampling, coming in with counts of 278, 203 and 158 respectively, implying 40.6, 29.7 and 23.1 percent of the entire number of projects indicated. In fact, the use of accounting skills came in at 12.4 percent of the total count in position 23, much higher than most advanced core IE techniques (that is the highly specialised ones), almost all of which were mentioned less than 5 percent of the total count. Figure 3 is a distribution plot of the frequency of count of these skills, and it can be seen that it suggests that using ABC classification, only just about 8 to 13 skillsets might be classified in category A of the frequency count, with all others in B or C.

It is not clear at this point what the reason for this count might be, but conjectures can be made: whether it is because those were the techniques with which the students were most comfortable; or that the industry restricts students to only those activities they believe the students are able to handle, although the industry uses the more advanced techniques more frequently while the students were not involved in such; or that the students learnt some important skills rather late, hence, hardly use them during their vacation work; or even that the skills have less applications in the industry. This is an area that would need to be investigated further. Another interesting finding is that the use of soft skills by the students is very high, in fact, higher than the frequency of use of the specialised skills. Precisely, communication skill comes in the first position among the skills the students indicated they always needed to use, even more than presentation skills.

TABLE 1: *The top 40 techniques used*

SNo	Technique/skill	Code	Count	%
1	Communication/ interpersonal	T109	603	88,2
2	Office applications (Microsoft etc)	T114	395	57,7
3	Presentation/speaking	T110	371	54,2
4	Time management	T118	364	53,2
5	Data analysis	T40	323	47,2
6	Administration/People management	T111	288	42,1
7	Brain storming	T8	278	40,6
8	Flow charting	T60	203	29,7
9	Work sampling/Stop watch time study	T3	158	23,1
10	Material handling	T103	157	23,0
11	Data validation	T41	150	21,9
12	Health and safety	T106	150	21,9
13	Standard Operating Procedure	T4	141	20,6
14	Ergonomics	T107	116	17,0
15	Motion study	T2	105	15,4
16	Engineering drawing	T115	102	14,9
17	Time sheet (design/ completion)	T5	101	14,8
18	5 whys	T13	101	14,8
19	Gantt chart	T28	101	14,8
20	Qualitative Analysis	T35	98	14,3
21	5S	T11	92	13
22	Requirement Analysis	T69	90	13
23	Accounting/Finance	T112	85	12
24	Descriptive analysis	T36	82	12
25	R programming	T44	82	12
26	Process Capability	T30	81	12
27	Business Planning	T98	77	11
28	Theory of constraints	T90	71	10
29	Operations analysis chart	T6	65	9,5
30	Operations chart	T10	64	9,4
31	Constraint analysis	T86	64	9,4
32	Cash flow analysis	T34	61	8,9
33	Route sheet (design/ completion)	T7	58	8,5
34	Scenario Modelling	T99	56	8,2
35	Time series analysis	T39	52	7,6
36	Machine/ Activity chart	T15	51	7,5
37	Others	T67	51	7,5
38	IRR/Profitability	T33	49	7,2
39	Capacity Requirement Planning	T93	48	7
40	SWOT/PESTEL	T96	47	6,9

VI. CONCLUSION

This research sought to understand the relative frequency of use of learnt skills by IE students during their vacation work in the industry. The data entry was standardised where necessary and posted as google forms to collect student responses. The list of skills reported by the students was analysed using descriptive statistics. It was found that the use of soft skills were more frequent than the core IE skills, and that the basic skills seem to have found more use than the more advanced skills. The reason for this may need further study, but four possibilities were suggested. This finding seems to be aligned with the importance of soft skills as identified by some other researchers, but also seems to point out the importance of the basic skills that has not been really reported on by researchers. Given this finding, it is important that efforts should be made to ensure that engineering students are properly prepared in the use of many soft skills like communication, relationship management, time management, etc. It is also important to ensure that the basic engineering training provided to students should be reinforced throughout their study programme and linked to other techniques. It may also be helpful for the department to consciously make effort to ascertain why the students have not really been using most of the advanced techniques taught to them at school. This research does not necessarily suggest discountenancing the advanced skills taught, but encourages a discussion on the order or presentation to know how this might affect their effectiveness of use. It is also recommended that the list of skills identified be reviewed for future studies because the current ones used were based on the list of reported skills by students up until 2015. There might have been probable shifts in skills requirement today with possible inclusion of skills like analytics, internet of things and artificial intelligence. Also, since COVID restrictions have now been lifted, it may be time to study if the patterns observed persist or there have been changes.

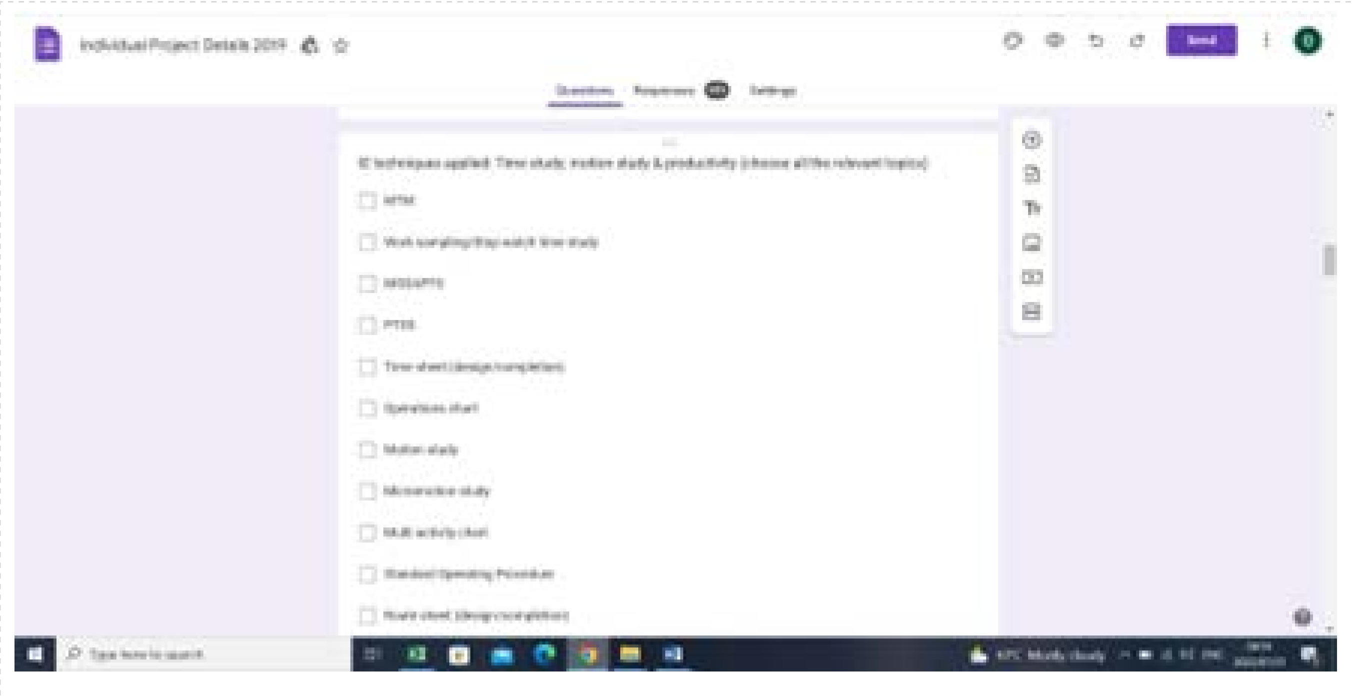

FIGURE 1: *A sample of the data capture screen for Group 1 category of skills set*

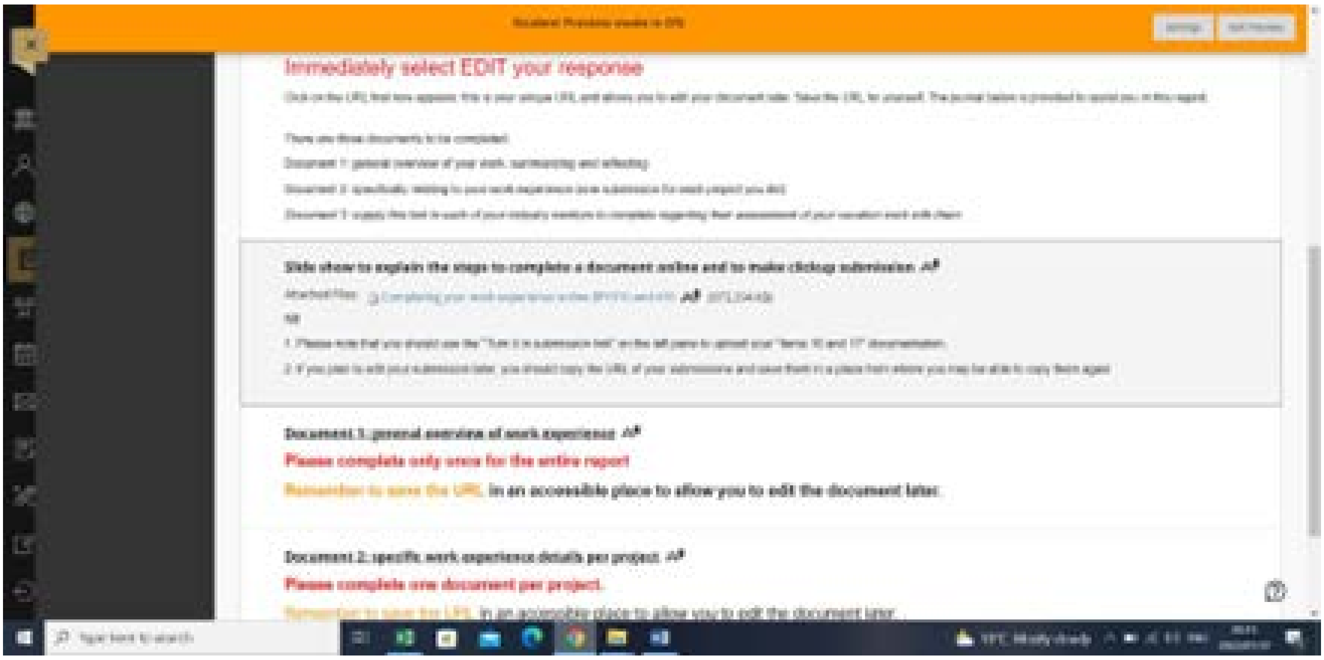

FIGURE 2: Landing page for data entry

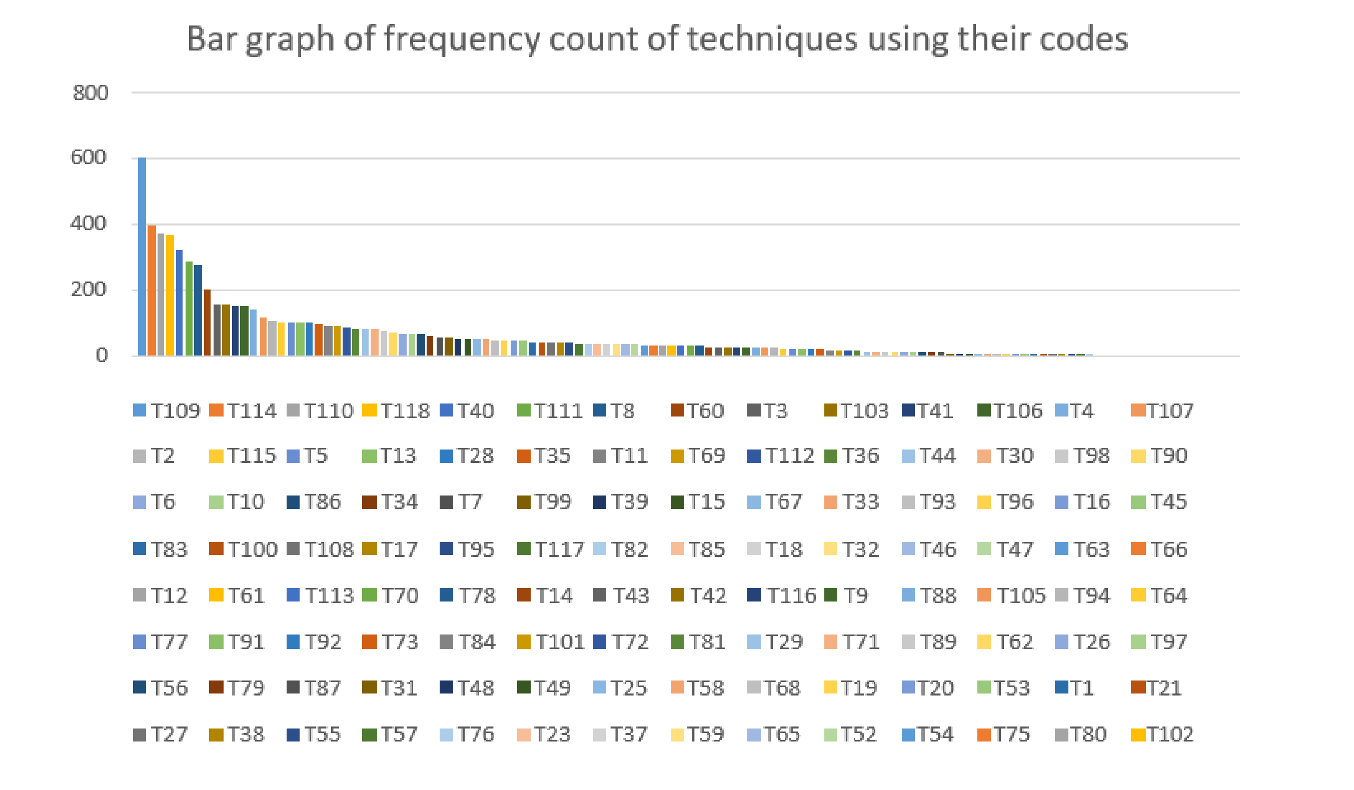

FIGURE 3: Frequency count of use of Industrial Engineering techniques

REFERENCES

[1] M. Orsted (2000) Software Development Engineer in Microsoft: A subjective view of soft skills required, 22nd International Conference on Software Engineering, Dublin, Ireland, June 2000

[2] IEA (2015), A History of the International Engineering Alliance and its Constituent Agreements: Toward Global Engineering Education and Professional Competence Standards

[3] R.K. Dixit and M. Pathak (2012) An Overview of International Engineering Accords with special reference to Washington Accord, J. Engg. Sc. Mgmt. Ed. Vol-5 Issue-II (467–471)

[4] L. Greenbaum and A. Rycroft (2014) The development of graduate attributes: The Book of the Year project, South African Journal of Higher Education, 28(1), 91–109

[5] Y. Ng (2009) Engineering Employability Skills Required By Employers In Asia, Proceedings of the 6th WSEAS International Conference on ENGINEERING EDUCATION, Wisconsin, United States

[6] S.M. Katz (1993) The Entry-Level Engineer: Problems in Transition from Student to Professional, Journal of Engineering Education, 82(3), 171 – 174

[7] P. Shakespeare, P. Keleher and L. Moxham (2007) Soft Skills, Hard Skills and Practice Identity, WACW World conference on work integrated education, Singapore, Singapore

[8] M.J. Riemer (2007) Communication Skills for the 21st Century Engineer, Global Journal of Engineering Education, 11(1)

[9] H.B. Maynard (1963) Handbook of Industrial Engineering, 2nd Edition, McGraw Hill, New York, 1963.

[10] Rao N KVSS (2006) Definition of Industrial Engineering: Suggested Modification, Udyog Pragati, October-December 2006, 1 - 4

[11] N.D. Du Preez and L. Pintelon (1997) The industrial engineer-caught between two revolutions? Production Planning & Control, 8:5, 418- 430

Technical papers

Active student participation and engagement in the virtual classroom during the COVID-19 pandemic

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***Abstract* — Active participation and student engagement in virtual classrooms are fundamental for the student's learning experiences. Online teaching and learning in virtual classrooms may pose the challenge of leaving students behind without the instructor recognizing that students have not grasped the content delivered. Online platforms applied in some higher learning institutions provide one-way communication, whereby a lecturer delivers a presentation and students are allowed to ask questions at the end or during the session. Delivering a lecture where students opt to keep their videos off makes it difficult for the instructor to gauge students' participation and engagement in the virtual classrooms. The transition to online teaching and learning due to the COVID-19 pandemic provides an opportunity for teachers to develop ways to make virtual classrooms more engaging. This study seeks to answer if students that are not visual or audible can actively participate in online activities and be efficient in attending virtual classrooms. In seeking innovative ways to create an engaging environment for students in the virtual classroom, the author presents an online strategy that was designed and implemented. The methods entailed designing a structure and organized online strategy to assist students to navigate the online teaching and learning platforms using discussion forums, and online quizzes without draining their limited data. The results show that students can be present in the virtual classrooms and actively engage without being visually present and audible. Student participation and engagement were directly proportional to graded online activities. Although many online platforms encourage students to be online with their videos to ensure their participation, students can still engage actively even if the instructors do not see them or hear their voices.**

Keywords — active participation, online engagement, virtual classroom

I. INTRODUCTION

A. Context of the study

Active participation and student engagement in the virtual classrooms are fundamental for the students' learning experiences. Online teaching and learning in virtual classrooms may pose the challenge of leaving students behind without the instructor recognizing that students have not grasped the content delivered. Online platforms applied in some higher learning institutions provide one-way communication, whereby a lecturer delivers a presentation and students are allowed to ask questions at the end or during the session. Such an environment does not always encourage students' participation and engagement. There may be challenges with students' preferences when it comes to switching their videos on or off. This also goes beyond the classroom environment and speaks to some of the social issues, where students are not comfortable switching on their videos based on their study environment. As teachers become innovative in the virtual classrooms, they need to be aware of the social disparities. For the context of this study, a virtual classroom refers to an online environment where both the teacher and the student connected online at their respective spaces.

In the face-to-face classroom environment, it is rare for students who are shy to raise their hands to ask questions or engage effectively in the discussions. Some researchers have suggested that the nature of e-learning is less confrontational, thus may encourage the engagement of shyer students and make them feel less pressure than during the traditional face-to-face interaction [1, 2]. The application of techniques and theories for student engagement in online learning environments can enhance student engagement and help higher education institutions to produce graduates that can contribute to the development of societies and the economy [3]. In terms of online delivery, the focus for many institutions is on the effectiveness of the tools used for online teaching [4] and not the strategies to enhance students' engagement. The current situation, which is influenced by the pandemic, pushed higher learning institutions to transition to online teaching and calls for innovative, as well as greater attention to strategies that promote student participation and engagement [4, 5]. The transition to online teaching and learning has provided some teachers with the opportunity to be innovative to improve students' engagement and subsequently student learning outcomes [6, 7]. This, therefore, suggests that online teaching platforms can be used to encourage students to participate, which may be a challenge and time-consuming in a classroom-based environment, depending on the number of students.

Designing lectures that are monologue-based, is a common practice in the online teaching environment [8]. Teachers and students stated that in a remote environment, students are generally passive and learned less [8]. Failure to attend classes and behaviour as if students are watching television in the virtual classroom is a concern that was also raised [8]. The offering of lectures using technology, on its own, presents numerous issues such as access to the internet, connectivity, and high data cost. Because of the nature of online teaching, teachers must be innovative to reduces and combat these effects [9, 10]. In the studies by [11, 12], they suggested a need for a radical shift in the pedagogical methods to accommodate technology, which can be achieved by introducing a synchronous hybrid learning environment [8,13-14]. The synchronous method encourages teachers to design learning activities that enhance student participation [15]. This approach calls for teachers to transform the virtual classrooms, adapt their teaching approach while maintaining acceptable learning standards [16,17]. According to [18], synchronous hybrid tools that mimic face-to-face lecture delivery enhance students' closer connections with their peers. However, this suggests that other than the requirements for good video and audio quality, framing by the teacher may be a challenge [19]. Are all the teachers adequately trained to navigate around the technologies used in higher learning institutions, for effective student learning?. Most of the platforms that may encourage student participation in the virtual classrooms require students to answer questions when asked by the instructors and engage in live activities where they are visible and audible. Students can also experience anxiety and fear to speak to instructors and peers in the virtual classrooms online, just as they do in the traditional face-to-face classrooms. In the methods presented, it is evidence that the primary delivery tool to encourage student participation is through live sessions, where teachers need to see and hear the students.

Student engagement is defined as student involvement in educationally purposeful activities by [20]. The studies by [21-23], show that student engagement is directly proportional to the student learning experience and personal development. Some of the methods that contribute to student engagement are reported by [24]. A positive relationship between engagement and academic success has been reported by some scholars [25, 26]. Positive learning outcomes and high retention rates are also associated with student engagement [27].

Student participation and interaction are important for virtual classrooms, and they facilitate student engagement. The student participation refers to students being present in the classroom and attending the lecture sessions, while engagement, refers to students actively engaging with the content delivered in the classrooms and taking part in the activities conducted in the classrooms through quizzes, discussion forums etc. According to [28], asynchronous oral communication components can be used as a tool to enhance student engagement. Dividing students into smaller groups in the visual classrooms encourages student participation [29]. Another tool commonly used is sharing educational and short videos, making it easy for students to access study material. This has shown to have a significantly increased viewership by students [30]. The study by [31] shows that students preferred using social media such as Facebook, as compared to the platforms provided by the institutions, which led to a high course success rate. Providing and designing a safe online environment through anonymous discussion boards has proved to encourage students who are shy to participate [32, 33]. With the presented strategies, video viewership does not provide evidence that students have actively engaged with the content. Dividing students into groups also require that their videos are switched on, and they are audible to measure their participation and engagement. The use of social media for engagement has its limitation, as it is normally outside the lecturer slots and with minimal monitoring by the instructor.

The current common practices for online teaching platforms present challenges such as; (1) delivering a lecture to students you cannot see because they are not comfortable switching their videos on; (2) not being able to measure or tell if the students on the other side of a computer are fully present in the virtual classroom or have they just logged in; (3) not being able to easily establish if students understand the content presented and if they have engaged with the online content. Although several studies have reported successful strategies for online teaching and learning there is a gap in tools that are effective in encouraging student participation on platforms that are not live (where you cannot see students' faces virtually).

The study was conducted to develop a strategy to encourage active engagement and participation in virtual classrooms. The study seeks to answer the question of how do we ensure our students actively participate in the virtual classrooms even if we do not see them? The aim of the study is to illustrate how teachers can design effective strategies to encourage students' participation in online virtual classrooms, whether they see the students or not. By using discussion forums for engagement, allocating marks to online activities, and designing live online quizzes students are encouraged to participate in virtual classrooms effectively and actively.

II. METHODOLOGY

A. Online platforms used

An online strategy that does not require students to be live on the platform to engage and participate was designed using Blackboard. Blackboard Collaborate was used for the live quizzes designed with Poll Everywhere. Blackboard is a global educational technology service or solution for Higher learning institutions and other industries. It is a technology used at the institution where the study was conducted. Poll Everywhere is an online an "online service for classroom response and audience response systems". It may be freely accessible to instructors and students, depending on the size of the classroom, and the plan selected.

The study was conducted using data generated in 2020, with 38 students in the 3rd year, and in 2021 with 18 students at the Honours level. Both modules were coursework modules. Two online platforms were used in this study, namely, Blackboard and Poll Everywhere. Blackboard was used as it is the tool provided by the university for online teaching and learning. Poll Everywhere was a tool adapted by the instructor to enhance student engagement in the virtual classroom. The attractive aspect of the Poll Everywhere tool is the provision for different types of questions. Instead of the instructor designing only multiple-choice questions to engage students, the Poll Everywhere provides options to develop different kinds of questions, as shown in Figure 1. Through these the variety types of question the lecturer can design, students are encouraged to participate and show their understanding of the modules, as they can also do open ended questions.

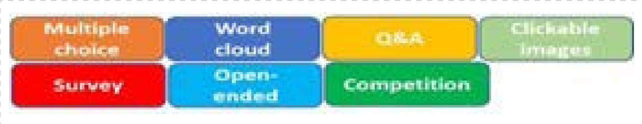

FIGURE 1: Types of questions that can be developed to encourage student participation and engagement.

B. The strategy implemented to guide students in the virtual classrooms

Figure 2 shows the novel online strategy that was developed and implemented to ensure students effectively participated in the virtual classrooms. The novelty in the strategy is to present how going an extra mile in the virtual classroom to care for and ensure students are in class can positively impact students and encourage them to attend online lectures and participate in the activities. With the move to online teaching and learning, and with some students experiencing online teaching for the first time, guidance to make sure students are not confused with navigating the digital platform, has become a priority. It is therefore critical that students are guided in the virtual classrooms so that they actively participate and engage.

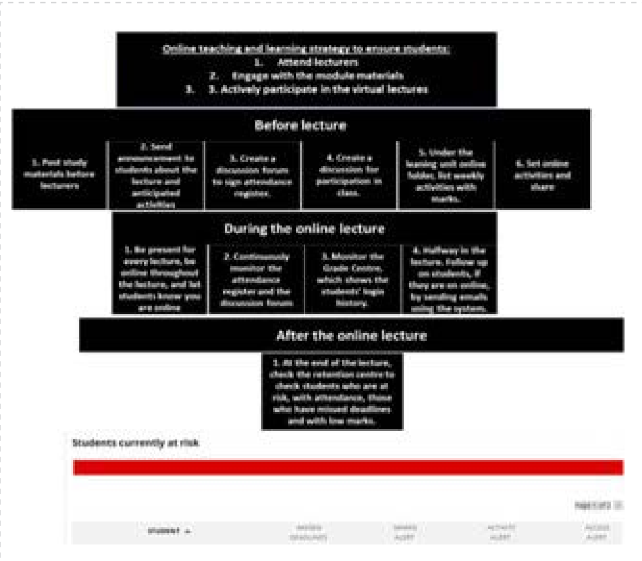

FIGURE 2: Online teaching and learning strategy.

The method presented in Figure 2 is divided into three phases, (1) what the lecturer did before the lecture session, (2) what the lecturer did during the lecture session, (3) what the lecturer did after each session. The two crucial aspects under Phase 1 of the method entailed preparing the students for the online lecture by sending them all the necessary materials to prepare before the virtual class, sending students an announcement to show them the online activities step by step and the instructor's expectations. When students understand what they need to do, they tend to be willing to participate. In most developing countries, issues of connectivity and access to the internet remain one of the biggest challenges. It is therefore important that teachers do constant follow-ups on the students if students have not logged on to the online virtual classrooms. The follow ups were conducted by using the tools avaialble on BB to personalise individual messages or send bulk messages to students, which they would receive in their email addresses. BB allows for an instructor to email the user (student). Through the follow up, students would respond and indicate their reasons for not attending.

Phase 2 of the method involved a teacher checking who has or has not logged on and monitoring the platform and sending emails to students who are not in class to find out if they are experiencing any challenges. Phase 3 of the method entails checking the retention center to check and identify students who may be falling behind with their online activities and then doing a follow-up on the students. The retention centre allow the instructor the instructor to check the students missed deadlines, marks alert (if student is performing below average), activity alert (if a student misses to complete an activity), and access alert (if a student has not logged into BB). The grade centre allow an instructor to access the classlist and directly send messages to students.

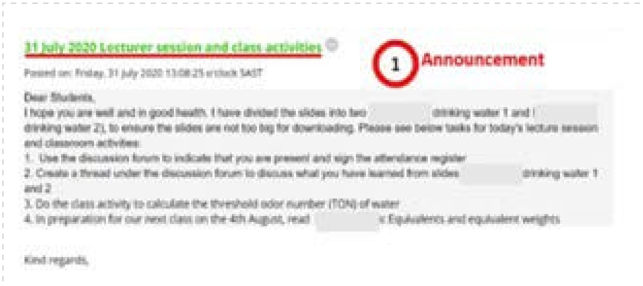

FIGURE 3: Leading students in the virtual classroom for active participation.

Figure 3 shows the process followed with the method implemented on Blackboard. The process emphasizes the importance of organizing content in the online platforms for easy access, guiding, and leading students in virtual classrooms. The steps show what was presented on the announcement for the lecture on the 31st of July 2020, detailed activities for the students with marks allocated for each activity. It is worth noting that the effect of allocating marks to encourage student engagement and participation was also studied by comparing the students who participated in activities with and without marks.

For Poll Everywhere, the process and strategy implemented is presented in Figure 4.

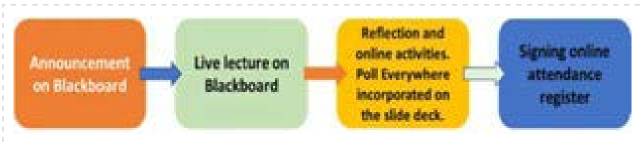

FIGURE 4: Process for Poll Everywhere online platform.

C. Evaluation and data collection

The data was collected by analysing results obtained from the two online platforms used in the virtual classrooms. Blackboard and Poll Everywhere reports showing evidence of students participating on the discussion forums, and on the online quizzes were generated.

D. Data analysis

The data obtained was used to calculate the percentage of students who engaged in online activities. This was done by evaluating the students who contributed to the Blackboard discussion forum and by checking the activity responses on the Poll Everywhere online platform. A statistic on the students who actively participated online on activities with marks and those that were not allocated marks was also generated.

III. RESULTS AND DISCUSSIONS

A. Student response to the strategy developed (Lecturer observation)

The student response to the strategy developed was positive and students indicated it made them be at ease as they were guided throughout the process and the expectations were clear. The method was also applied to assessments and giving students instruction before the assessments reduced the pressure and anxiety from the students. The importance of managing expectations in online environment is highlighted by [34].

B. Student attendance in the virtual classrooms following the strategy implemented

Figures 5, 6, and 7 show the results for student attendance in the virtual classroom, following the strategy implemented. The results for 37 3rd year and 17 Honours students are presented.

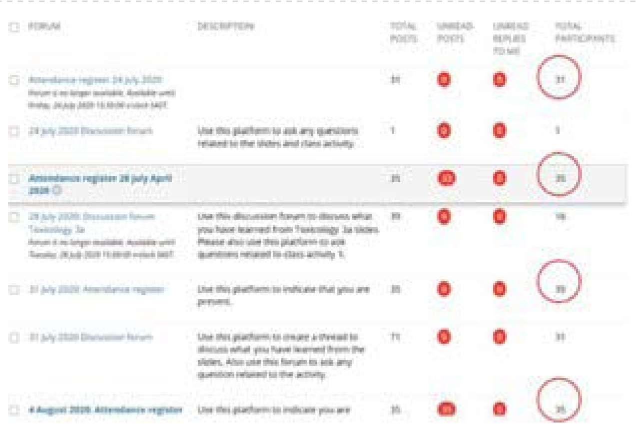

FIGURE 5: Student attendance in the virtual classroom (Blackboard data).

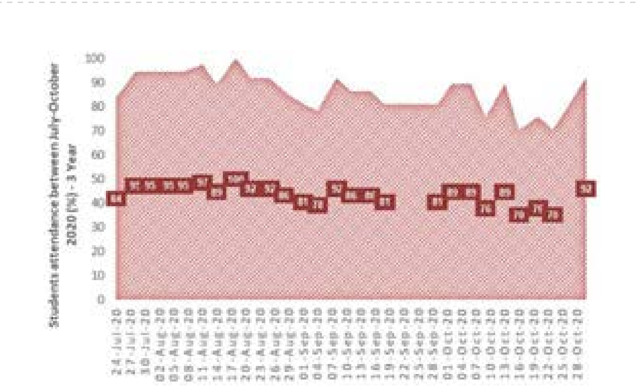

FIGURE 6: Student attendance in the virtual classroom (3rd year students 2021).

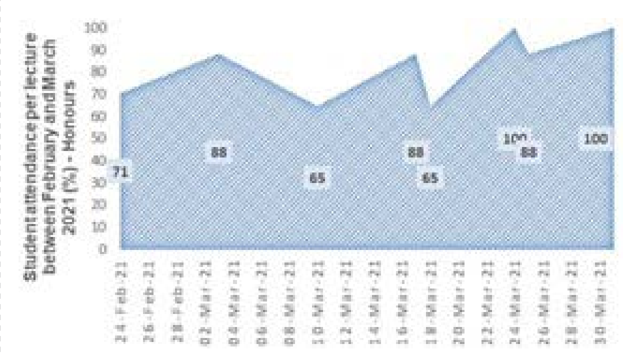

FIGURE 7: Student attendance in the virtual classroom (Honors students 2021.

The Blackboard discussion forum was used to record students' online attendance. The student marked the register by creating a thread that says, I am present. This approach was effective as it makes the student begin to participate in the virtual classrooms, and it was the first activity students had to do after they have logged into the platform.

Several scholars have reported a positive correlation between student attendance and student performance [35, 36]. In the study to investigate the relationship between student engagement and attendance on online learning, [37], showed attendance as a predictor of student performance. With the method implemented most of the students attended the virtual classrooms. In most of the session, more than 80% attendance was achieved in several lectures. The lecturer was also able to identify students who were struggling either with access to the online classes or dealing with personal issues. Through the method designed and implemented, as presented in the methodology section, on the sessions where the attendance was low, the lecturer could account for all the students, either online or offline. Active engagement online cannot be achieved if students are not attending, and this strategy was successful in encouraging online attendance. Most importantly, most student were not left behind because of the transition to online teaching and learning.

C. Student engagement and participation on the online platforms.

Participation on Blackboard discussion forums

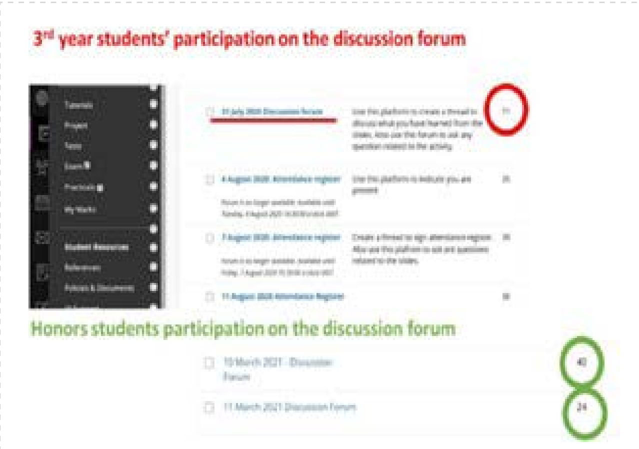

FIGURE 8: Student participation in the virtual classroom (3rd year and Honors students).

Figure 8 shows the results for the methods implemented in the module for honours and 3rd year students. The responses received for the activity on the 10th March 2021 were 40, showing that all students engaged in the activity, and this was also monitored to make sure every student participated. It is evident that a significant number of students participated and were engaging in the virtual classroom, without the instructor seeing them.

Participation on Poll Everywhere platform (live quizzes).

Another method was implemented in the virtual classroom to encourage students' active participation and engagement. Unlike the discussion forum, which was effective even though it is not live, the second method was implemented on a live platform. The live quizzes were designed for the students to determine if they engaged with the content presented. The quizzes were presented to the student at the end of a lecture session and students could carry out the exercise within a specified time. The method was tested with the honors students (17 students) and the results are shown in Figs. 9 and 10. The online platform used is recommended as it also shows the names of students who participated in the activities (Figure 10), providing the instructor with an opportunity to identify students who may be struggling with the content.

FIGURE 9: *Student participation on Live quiz in the virtual classroom (17 Honors students).*

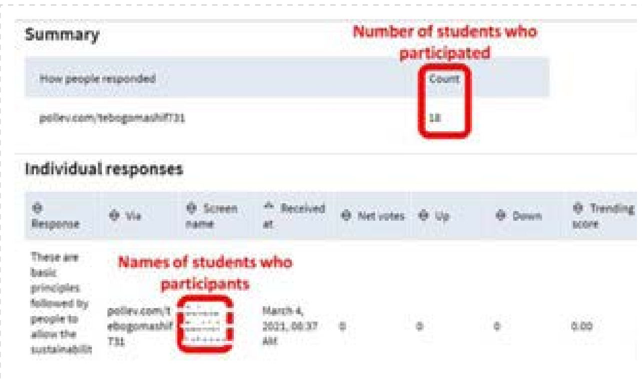

FIGURE 10: *Online platform showing student participation with identity.*

The results presented show that most of the students participated in the online activities. The overall % for students' engagement or participation on the online quiz ranged between 83 – 100 % on some of the activities. The activities with low participation rates were not necessarily because of students not engaging but due to the limited time given to students to complete the exercise. Some students who do not participate indicated that they were experiencing challenges with connectivity, and they were removed from the online virtual platform and therefore could not complete the activity.

D. Student participation on activities with and without marks

There is a direct link between student participation and online activities with marks. Figure 11 exhibits the results for student participation when the online activities were allocated marks. Figure 12 presents results for student participation when online activities were not allocated marks.

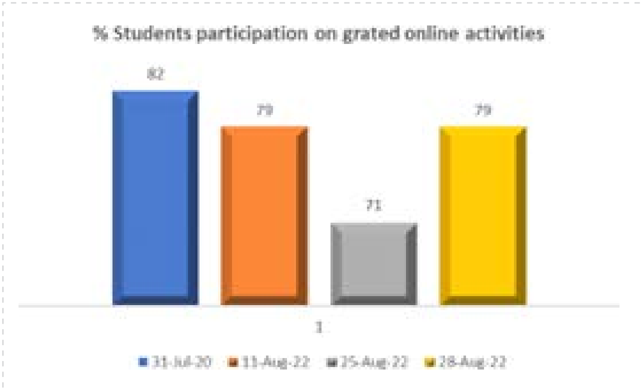

FIGURE 11: *Students' participation on Blackboard discussion forum on activities that have marks.*

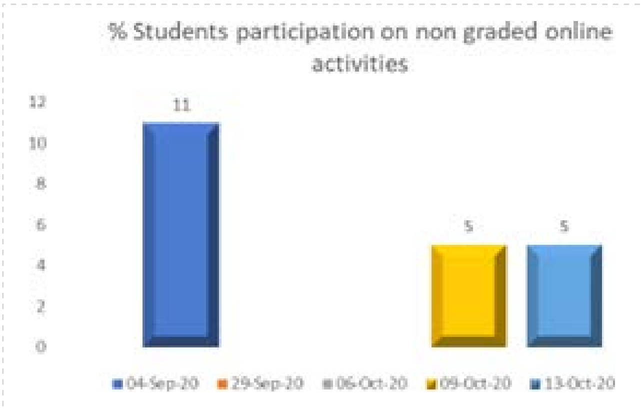

FIGURE 12: *Students' participation on Blackboard discussion forum on activities that do not have marks.*

With the activities that were allocated marks, most of the students actively participated in the classroom. When activities were not graded and were only for learning purposes, students' participation was low. From Figure 11, the responses to the activities were between 71% - 82 %. With the method for follow-ups on the students during lecture sessions, the students that did not participate indicated access to the internet and connectivity as the challenge. From Figure 12, the responses from students were between 0% to 11%. In some of the activities, no students participated in the online activities and the highest students' participation was 11%. This observation is also reported by [38], where there was about 13% performance on voluntary discussion forums. In the study by [39], discussion forums were not graded, but an incentive was provided by advising students that the questions were a guide to prepare for the examination. The approach encouraged students to participate in the forum.

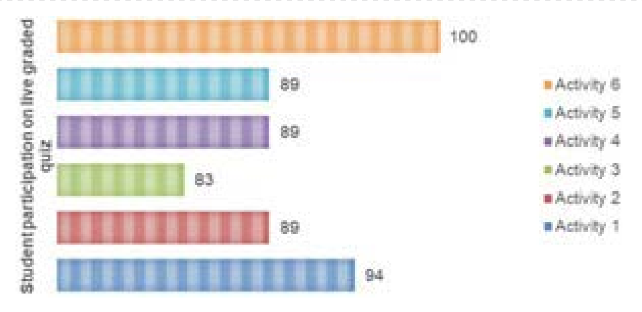

FIGURE 13: Student participation on online quiz on activities with marks.

Figure 13 shows student participation and engagement in the online quiz. According to [40, 41], classroom participation is associated with active student-centered pedagogies. The overall percentage for students' engagement or participation on the online quiz ranged between 83 – 100 % on some of the activities. The activities with low participation rates were not necessarily because of students not engaging but due to the limited time given to students to complete the exercise. As mentioned before some students who do not participate indicated that they were experiencing challenges with connectivity, and they were removed from the online virtual platform and therefore could not complete the activity. The study by [42] reported a positive correlation between performance and student engagement. Therefore, the strategy presented in this study using either discussion forums or online quizzes, can also be used to enhance students' performance, and not only their engagements. The results presented using the strategy that was designed and implemented, the discussion forums, and quizzes have shown that it is possible to effectively enhance students' participation without seeing the students online in the virtual classrooms.

IV. CONCLUSIONS

The transition to online teaching and learning due to the Covid 19 pandemic and the implementation of lockdown in many countries has seen students and instructors dispersed in different spaces and working or attending lecturers from different locations and environments. The argument for this study is formulated and centered around student presence in the virtual classrooms, their engagement, and participation when they are not seen. Instructors must design well-organized online platforms to guide students in virtual classrooms. Several studies have shown that student active participation in the classroom is directly proportional to student success rate, and that students will normally conduct grated activities. Students can actively engage and participate online in virtual classrooms even if their presence is not visual or audible. Graded discussion forums and online quizzes encourage students to engage with the content and participate in online activities. Well-structured and organized online platforms, accompanied by monitoring, and following up on students who are not online, can enhance student attendance in the virtual classrooms. This approach also highlights the importance of designing activities aligned with the outcome and the graduate's attributes. By adapting to the presented methods, issues such as data availability and its consumption, which is higher with a video on, can be addressed.

Students who are shy to speak or ask questions can also participate confidently. Different forms of incentives to encourage students, can be investigated further and be embedded in all the discussion forums to make sure students participate even if there are no marks. Through the results in this study, it is evident that online students' engagement is not dependent on students being visual and audible through videos, and using their voices. Other efficient and cost-effective strategies can be used to successfully enhance students' participation in the visual classrooms. The findings from this study agree with what has been presented by several scholars. A further study is recommended to study the relationship between the strategy implemented and the student's throughput and success rate, and the impact thereof of the study to encourage students participation in the classrooms.

For larger group classes, the presented strategy, monitoring and follow up on students may be applicable if the instructor has tutors assisting her/him to carryout the task, as it may be a tedious exercise without manpower.

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REFERENCES

[1] M. Warschauer, "Computer-mediated collaborative learning: Theory and practice," Mod. Lang. J., 1997, vol. 81, pp.470-481.

[2] D.L. Hobbs, "A constructivist approach to web course design, a review of the literature," Int. J. E-Learn., 2002, vol.1, pp.60-65.

[3] K.A. Meyer, "Student engagement in online learning: What works and why," ASHE High. Educ. Rep., 2014.

[4] T.M. Brinthaupt, L.S. Fisher, J.G. Gardner, D.M. Raffo, and J.B. Woodward, "What the best online teachers should do," 2011.

[5] N.C. Green, H. Edwards, B. Wolodko, C. Stewart, M. Brooks, and R. Littledyke, "Reconceptualising higher education pedagogy in online learning," Distance. Educ., 2010, vol. 31, pp.257-273.

[6] D. Holley, and M. Oliver, "Student engagement and blended learning: Portraits of risk," Comput. Educ., 2010, vol. 54, pp.693-700.

[7] A. Ituma, "An evaluation of students' perceptions and engagement with e-learning components in a campus based university," Act. Learn. High. Educ., 2011, vol. 12, pp.57–68.

[8] C.L. Weitze, "Pedagogical innovation in teacher teams: An organisational learning design model for continuous competence development," Proceedings of the 14th European Conference on E-Learning. Academic Conferences and Publishing International. 2015, pp. 629-638.

[9] N. McGovern, and K. Barnes, "Lectures from my living room: A pilot study of hybrid learning from the students' perspective. In International Conference on Hybrid Learning and Education. Springer, Berlin, Heidelberg, 2009, vol. 40, pp.284-298.

[10] R. Ørngreen, K. Levinsen, V. Jelsbak, K.L. Moller, and T. Bendsen, "Simultaneous class-based and live video streamed teaching: Experiences and derived principles from the bachelor programme in biomedical laboratory analysis," Proceedings of 14th European Conference on e- Learning ECEL-2015. Reading: Academic Conferences Limited, 2015, pp.451-459.

[11] W. Cain, "Technology navigators: An innovative role in pedagogy, design and instructional support. In Educational Innovations and Contemporary Technologies," Palgrave Macmillan, London. 2015, pp.21-35.

[12] D. Ramsey, J. Evans, and M. Levy, "Preserving the seminar experience" J. Political Sci. Educ., 2016, vol. 12, pp.256–267.

[13] C.L. Weitze, R. Ørngreen, and K. Levinsen, "The global classroom video conferencing model and first evaluations, Proceedings of the 12th European Conference on E-Learning: SKEMA Business School, Sophia Antipolis France, 30-31 October 2013. pp.503-510.

[14] L.D. Lapitan Jr, C.E. Tiangco, D.A.G. Sumalinog, N.S. Sabarillo, and J.M. Diaz, "An effective blended online teaching and learning strategy during the COVID-19 pandemic," Educ. Chem. Eng., 2021, vol. 35, pp.116-131.

[15] M. Bower, B. Dalgarno, G.E. Kennedy, M.J.W. Lee, and J. Kenney, "Design and implementation factors in blended synchronous learning environments: Outcomes from a cross-case analysis." Comput. Educ., 2015, vol. 86, pp1–17.

[16] C.A. Lightner, and C.A. Lightner-Laws, "A blended model: Simultaneously teaching a quantitative course traditionally, online, and remotely," Interact. Learn. Environ., 2016, vol.24, pp.224-238.

[17] M.M. Grant, and J. Cheon, "The value of using synchronous conferencing for instruction and students," J. Interact. Online Learn., 2007, vol. 6, pp.211-226.

[18] V. Irvine, J. Code, and L. Richards, "Realigning higher education for the 21st century learner through multi-access learning," J. Online. Learn. Teach., 2013, vol. 9, pp.172.

[19] A. Raes, P. Vanneste, M. Pieters, I. Windey, W. Van Den Noortgate, and F. Depaepe, "Learning and instruction in the hybrid virtual classroom: An investigation of students' engagement and the effect of quizzes," Comput. Educ., 2020, vol.143, pp.103682.

[20] G.D. Kuh, "The National Survey of Student Engagement: Conceptual framework and overview of psychometric properties," 2001.

[21] C.R. Pace, "Measuring the quality of student effort," Curr. Issues Educ., 1980, vol.2, pp.10-16.

[22] A.W. Astin, "What matters in college?," JB, 1997.

[23] E.T. Pascarella, and P.T. Terenzini, "How College Affects Students: A Third Decade of Research", Jossey-Bass, An Imprint of Wiley. 10475 Crosspoint Blvd, Indianapolis, IN 46256, 2005, vol. 2.

[24] A.D. Dumford, and A.L. Miller, "Online learning in higher education: exploring advantages and disadvantages for engagement," J. Comput. High. Educ., 2018, vol. 30, pp.452-465.

[25] E.E. Ketonen, A. Haarala-Muhonen, L. Hirsto, J.J. Hänninen, K. Wähälä, and K. Lonka, "Am I in the right place? Academic engagement and study success during the first years at university," Learn. Individ. Differ., 2016, vol. 51, pp.141-148.

[26] T. Phan, S.G. McNeil, and B.R. Robin, "Students' patterns of engagement and course performance in a Massive Open Online Course," Comput. Educ., 2016, vol.95, pp.36-44.

[27] M.L. Bote-Lorenzo, and E. Gómez-Sánchez, "Predicting the decrease of engagement indicators in a MOOC," Proceedings of the Seventh International Learning Analytics & Knowledge Conference. 2017, pp.143-147.

[28] B. McBain, A. Drew, C. James, L. Phelan, K.M. Harris, and J. Archer, "Student experience of oral communication assessment tasks online from a multi-disciplinary trial," Education+ Training, 2016.

[29] C.C. Wolverton, "Utilizing synchronous discussions to create an engaged classroom in online executive education," Int. J. Educ. Manag., 2018, vol. 16, pp.239-244.

[30] S.A. Ahmed, M.H. Shehata, H.W.A. Malak, S.A. El Saadany, and M.A. Hassanien, 2020. "Use of short videos for faculty development in adaptation of interactive teaching strategies for virtual classroom," J. Microsc. Ultrastruct., 2009, vol. 8, pp.211.

[31] C. Pukkaew, "Assessment of the effectiveness of internet-based distance learning through the VClass e-Education platform," Int. Rev. Res. in Open. Dis., 2013, vol. 14, pp.255-276.

[32] A. Bunker, and R. Ellis, "Using bulletin boards for learning: what do staff and students need to know in order to use boards effectively?," 2001.

[33] T. Douglas, A. James, L. Earwaker, C. Mather, and S. Murray, "Online Discussion Boards: Improving Practice and Student Engagement by Harnessing Facilitator Perceptions," J. Univ. Teach. Learn. Pract., 2020, vol. 17, pp.7.

[34] D. Nandi, M. Hamilton, J. Harland and G. Warburton, "How active are students in online discussion forums?," Proceedings of the Thirteenth Australasian Computing Education Conference. 2011, vol.114, pp.125- 134.

[35] P.T.M. Chou, and Y. Kuo, "Examining factors relating to classroom attendance and performance," J. Stud. Int. Educ., 2012, vol. 2, pp.193- 204.

[36] J.W. Westerman, L.A. Perez□Batres, B.S. Coffey, and R.W. Pouder, "The relationship between undergraduate attendance and performance revisited: Alignment of student and instructor goals,Decision Sciences" J. Innov. Educ., 2011, vol. 9, pp.49-67.

[37] M. Stewart, T. Stott, and A.M. Nuttall, "Student engagement patterns over the duration of level 1 and level 3 geography modules: Influences on student attendance, performance and use of online resources," Journal of J. Geogr. High. Educ., 2011, vol. 35, pp.47-65.

[38] L. Deng, and N.J. Tavares, "From Moodle to Facebook: Exploring students' motivation and experiences in online communities," Comput. Educ., 2013, vol. 68, pp.167-176.

[39] F. Buckley, "Online discussion forums,". Eur. Political Sci., 2011, vol. 10, pp.402-415.

[40] E.J. Dallimore, J.H. Hertenstein, and M.B. Platt, "Classroom participation and discussion effectiveness: Student-generated strategies," Commun. Educ., 2004, vol. 53.

[41] A. Rassuli, and J.P. Manzer, "Teach us to learn: Multivariate analysis of perception of success in team learning," J. Educ. Bus., 2005, vol. 81, pp.21-27.

[42] B.Y. Rajabalee, M.I. Santally, and F. Rennie, "A study of the relationship between students' engagement and their academic performances in an eLearning environment," E-Learn., 2020, vol.17, pp.1-20.

Technical papers

A collaborative autoethnography on cultivating innovative attitudes in undergraduate engineers through a co-curricular initiative

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***Abstract* — Innovative attitudes are critical affective learning outcomes for engineering graduates. However, affective learning requires immersive environments and ill-defined problem contexts which are difficult to create in traditional curricula due to resource and time constraints. The Aircraft for Rhino and Environmental Defense (AREND) project is a longterm, co-curricular learning initiative that has succeeded in cultivating innovative attitudes in students. Through collaborative autoethnography, we identify that immersion in an authentic innovation process and a project-based learning environment foster attitudes of experimentation, risk-taking, adaptation, alternatives seeking, self-reliance, implementation, persistence, user-focus, being visionary, being passionate, leadership, being a team player and being persistent. The paper offers practical insights to educators wishing to create similar experiential learning environments.**

Keywords — innovative attitudes; affective development; cocurricular; project-based learning; collaborative autoethnography

I. INTRODUCTION

In literature, definitions of creativity, innovativeness, and entrepreneurial ability overlap [1],[2]. Ferguson's [3] two-stage innovation process is used to differentiate between these terms in this paper. The front-end stage has two parts. The first relates to the conceptualisation of a creative idea while the second refers to development, feasibility analysis, and testing. The back-end stage refers to the commercialisation of the invention. A high dose of creativity is required during the front-end stage while entrepreneurial capabilities are the currency for the back-end stage.

Ferguson [3] also delineated a set of 20 characteristics of engineering innovativeness based on extensive data collection from industry resonates deeply with descriptions of the key competencies of engineering graduates facing Industry 4.0 [4]-[6]. Yet, in our experience as engineering educators, the dissonance between the recognised need for these competencies and the challenge of cultivating them in traditional engineering curricula is exasperating.

Strategies to hire an innovative workforce, [7] state that a person's innovative potential is a function of knowledge (such as domain-specific knowledge); skills (specific technical skills and creative processing skills); and abilities and dispositions/ motivations. This classification maps to the domains of learning identified in educational psychology over the past sixty years: the cognitive domain (knowledge and skills) and the affective domain [8]. The affective domain spans students' attitudes, values, and behaviour. It also relates to students' motivation to learn and their emotional state while learning. While there certainly are interrelations between the cognitive and affective domains [9], this distinction enabled us to differentiate which of Ferguson's 20 innovation characteristics are more affective in nature: active learner, adapter, experimenter, persistent, risk taker, implementer, self-reliant, visionary, user-focused, leadership, passionate, team player, challenger, and alternatives seeker. These characteristics refer to a state of being and we refer to them as innovative attitudes in the rest of the paper.

Achieving learning outcomes in the affective domain is regarded far more difficult than learning outcomes in the cognitive domain [8]. In fact, [10] proposed that six of the fourteen innovative attitudes are innate while two are primarily innate with some scope for learning. We disagree that any attitude is beyond the reach of those who do not naturally possess it. Instead, we defer to the perspective that attitudes are learned differently [8],[11]-[13], primarily by "learning as becoming" [12].

During this study both of us, the co-authors of this paper, were engineering educators at the University of Pretoria (UP) which has a large and prestigious School of Engineering. Both were also pioneers of co-curricular initiatives that created opportunities for engineers to gain practical experience outside of the classroom. Smith had been the Aircraft for Rhino and Environmental Defense (AREND) keyman for eight years. Trent had piloted the Vertically Integrated Projects (VIP) Programme at UP in collaboration with the Georgia Institute of Technology and the VIP Consortium. At the time, Trent was the VIP Programme coordinator and also led a VIP team in transportation modelling. Our involvement in these co-curricular initiatives exposed us to the benefits of experiential learning. This exposure underscored why traditional curricula could not foster the characteristics that constitute innovativeness: *Most of these characteristics are not born from knowing, but from being.*

Learning that challenges a student to critically evaluate and adjust their attitudes requires 1) ill-defined problems for which the student does not already possess the required competencies [11]; and 2) immersion in a situation that mimics the scenarios in which specific attitudes are required

[12]. In this paper, we explore how the AREND project has provided both these elements and how this has successfully cultivated innovative attitudes in participating students.

This paper (1) offers practical insights to educators who wish to create immersive environments that cultivate innovative attitudes, and (2) suggests to administrators that cocurricular project-based learning initiatives can overcome some of the affective learning gaps of traditional curricula.

II. METHODOLOGY

'Autoethnography is an approach to research and writing that seeks to describe and systematically analyze (graphy) personal experience (auto) in order to understand cultural experience (ethno)' [14]. It is a reflexive, emotional, and subjective methodology which has been legitimised [15] through the diligent effort of social scientists who have addressed issues of relational ethics [14],[16], reliability, generalisability, and validity [14],[17]. This methodology has been used to promote the scholarship of teaching and learning, for example [18] and [19].

There are many pitfalls to using autoethnography [20], and to adhere to the intention of "reflecting the interconnectivity of self and others" collaborative autoethnography is used to unpack our personal experiences of how the AREND project cultivated innovative attitudes in the AREND students and in us. The research started as a conversation between two colleagues in 2018.

Smith's curiosity was piqued by her observations of the accelerated personal development of AREND graduates when compared with their peers. Smith has supervised many final year mechanical engineering students during their individual capstone project journey. Her capstone group included approximately 15 students each year of which at least 1 in 3 students had been involved in the AREND project. Because the capstone project is an individual endeavour at UP, the supervision process is also a personal mentoring experience. Over the past few years, Smith perceived that capstone students who had been committed to the AREND project generally displayed greater maturity, initiative, and selfreliance in their capstone project. Despite the exceptions, the differences between the groups were significant enough to provoke investigation.

Trent's experience within the VIP Programme - first as a student team member at Georgia Tech in 2010/2011 and then as coordinator and team leader at UP between 2018-2020 - aligned with Smith's observations. These experiences, coupled with testimonies from VIP coordinators at other institutions, excited Trent about the educational potential of these co-curricular initiatives.

There are two data sources in this study. The first is Smith's autobiography of the past seven years as AREND's keyman. Smith has been involved in AREND since its inception. In 2014, she immediately stepped into a leadership role on the project as a PhD student and full-time faculty member. She recruited two other staff members who acted as ad hoc mechanical and electronic design supervisors. Towards the end of 2015, she became the project owner. Since 2017, she has been the only faculty member actively involved in a supervisory capacity. Her roles as leader, mentor, and technical supervisor since 2014 makes her the project's keyman. There is no other individual, student or faculty, whose lived experience spans from the project's inception until now. She recalled her experiences and observations from the AREND project through informal conversations, field notes, and previously published work [21],[22]. As one seldom lives one's life with the sole purpose of academic documentation, the autobiography is, by default, retrospective and selective [14].

The second data source was collaboratively produced. Having identified the cultivation of innovative attitudes in AREND as our topic of inquiry, we sought a deeper understanding of innovative attitudes in particular and engineering education in general. We turned to literature to connect our experiences to prevailing theory regarding innovative attitudes and affective learning. This was a joint endeavour. Our journeys into engineering education were more distinct. Trent completed a Postgraduate Certificate in Higher Education while Smith developed an extensive network with scholars involved in project-based learning at University College London and Aalborg University. Throughout this time, we often discussed what we were learning about topics that had direct relevance to this inquiry.

The method used to collate and analyse the two data sources was writing. By using *writing as method* [14],[15], we were able to make sense of our experiences, question our beliefs about our roles as educators, and explore the validity of our "hunches" about cultivating innovative attitudes. This manuscript has crystallised over multiple revisions since 2018. What emerged from this collaborative autoethnography is our personal meaning making regarding two questions:

1. What about the AREND project makes it a good environment to foster innovative attitudes?
2. Which innovative attitudes, in particular, were fostered in the AREND project?

The following sections organise our findings around these questions.

III. WHAT MAKES AREND A GREENHOUSE FOR INNOVATIVE ATTITUDES?

AREND started in 2014 as a short-term student competition project aimed at entering the Wildlife Conservation Unmanned Aerial Vehicle (UAV) Challenge (www.wcUAVc.com). Since then, it has grown into a sustainable, co-curricular initiative through five phases of which the framework, assessment and coordination is described in [22],[23],[24]. The project's roots are in Mechanical and Aeronautical Engineering. The faculty supervisors and advisors have all hailed from this discipline as have the majority of the team members. Multidisciplinary facets were introduced during those semesters when electronic and industrial engineering students participated in the project.

The goal of the AREND project is to develop an innovative UAV design to address a unique problem as described by [21]. However, it isn't the inventive challenge itself that makes AREND an incubator of innovative attitudes. Instead, it is its authentic innovation processes and pedagogical approach that create a fertile environment.

A. Immersion in authentic innovation processes

Every innovation context is different, emphasising different innovation processes [3]. We identified four pertinent processes in AREND.

(1) Exposure to prototyping cycles
Firstly, there is a real client that has a real need that cannot be solved by current products. In engineering curricula, students are taught variants of the product development cycle - also typically called the engineering design cycle. [25] present one such cycle that includes ***planning → concept development → system development → detail design → testing and refinement → production and ramp-up.***

Admittedly, these steps are not strictly linear and there are many iterations in the process. Traditional curricula are bound to academic calendars and throughput targets. Design modules cannot afford the luxury of allowing multiple iterations through this cycle. Contrarily, AREND cannot cease its work until it has developed a viable product. Furthermore, it is free of academic calendar and throughput constraints. Thus the prototyping iterations are innumerable.

(2) Considering social, legal, and cost implications
Secondly, each sub-component must be designed taking into account social, legal, and cost considerations.

Within the AREND project, there is a close link between the team and their client – Kruger National Park (KNP). The nature of the project requires an appreciation of the impact the solution will have on its stakeholders: KNP managers, rangers, and visitors; the poachers and the impoverished communities who depend on their income; the animals in the reserve; and local and international market competitors. These stakeholders introduced unexpected social dilemmas to the design of the product.

The legal considerations that influence an innovation project can range broadly. The Intellectual Property (IP) emanating from an innovation project must be well managed and protected and can be a source of great conflict among parties. Apart from IP, the laws and regulations affecting the industries or countries within which the product will be used need to be accommodated. In the AREND project, both IP management and United States export regulations affects the solution's design.

Cost pressure on design and development are stark realities in innovation projects. There is a limit to AREND's development budget. The cost of materials, machine time, training, transport and more is capped based on the funding and sponsorships secured.

(3) Marketing
The third innovation process in the AREND project relates to marketing. Marketing is not only about selling a product to a customer, it is required to garner shareholder buy-in, to build strategic alliances, and to recruit expertise. One way to ensure that the requisite marketing focus and expertise is to draw advisors and students from both engineering and business majors. AREND does not yet have business majors in the team, thus marketing tasks fall on the engineers.

(4) Managing team diversity
Finally, the fourth innovation process is managing team diversity. Team diversity spans nationality, work ethos, design philosophy, and experience, with undergraduates through to doctoral students participating. This mimics the diversity in industry where '[t]he days of the solo researcher or solo designer have come to an end' ([5], pg. 4).

AREND's team members are immersed in an authentic innovation environment where they participate in iterative prototyping cycles; grapple with social, legal, and cost interfaces; market their altruistic goal, innovative product, and their team; and contribute to and lead diverse teams. This addresses the requirement of immersion for affective learning [11].

B. Project-based learning as pedagogical base

Project and problem-based learning are both based on the ethos of self-direction and collaboration in learning (i.e. active learning) and a multi-disciplinary problem orientation [26]. The students are at the helm of knowledge creation with the lecturer acting as a guide and encourager, rather than an instructor. Literature distinguishes between project and problem-based learning [26]-[28], but in practice, it is difficult to distinguish between purely project and purely problembased approaches [29]. Thus we consider the acronym PBL to reflect a blended approach in this paper.

The suitability of PBL in engineering education has been discussed in literature [26],[27],[30],[31] and empirical studies point to the benefits and practical challenges of PBL, for example [32]. How AREND's co-curricular structure circumvented many of the practical challenges is discussed in [23]-[24].

In the AREND project, PBL poses a series of ill-defined, real-world learning challenges. Working towards the project goal has been a multi-year, multi-disciplinary journey with many intermeshing sub-projects. Progress is student-led with students collaboratively defining the goals and work plans for sub-projects and initiating peer-led learning sessions. All of these elements are classical characteristics of PBL. The PBL pedagogical base thus addresses the requirement of ill-defined problem scenarios to foster affective learning.

IV. INNOVATIVE ATTITUDE DEVELOPMENT IN AREND

Smith recounted many lived experiences and observations to support our belief that AREND cultivates innovative attitudes. We organise the observations here in relation to the four innovation processes identified previously.

A. Exposure to prototyping cycles

Prototyping cycles can be gruelling if one is not comfortable with failure. Unfortunately, the time pressures and high stakes of design projects in traditional curricula seldom allow room for failure, let alone for learning from failure. This is not the case in AREND.

The design challenge posed to the AREND team is unique and "unsolvable" to some degree. Students need to "learn the system" without staff support. With only limited publications and a few presentations and project reports at their disposal, getting up to speed is overwhelming. New team members are forced to engage with older members and learn about the history of the project and the different sub-projects.

There is little faculty involvement during the design process. Design reviews take place every three months. In the meantime, students are expected to prototype and test many possible solutions. Since there are limited risks to experimentation, students make many mistakes. These are easily exposed during reviews. Students are then guided to learn from their mistakes. We've observed how this process cultivates attitudes of *experimentation* and *risk-taking* as the fear of failure is ameliorated.

A good example of learning through failure is that of the first successful test flight in July 2018. This success followed four consecutive failed attempts in April 2018. The failures inspired new sub-projects. Failure also made the students more receptive to the mentorship of an industry sponsor. Students developed a system and pre-flight check procedure that allowed for the eventual successful flight. This experience was transformational for those involved. The goal of conducting a successful flight and the space to learn from their failures fuelled their motivation to *experiment, adapt* and *seek alternatives* in a short timeframe. Although the July 2018 test flight was a prototyping highlight, the same cycles occur in other sub-projects.

When Smith reflects on the informal and formal student feedback she has received over the years, the same theme recurs. Students were initially frustrated by the design freedom they were given. They perceived it as a lack of guidance! However, those who persevered were eventually grateful, noting that the experience increased their confidence and empowered them to make design decisions. At last tally, approximately two thirds of the students who had entered the project in their second year ended up developing their own sub-projects. Many of these students were able to work with Smith to co-develop their engineering capstone project from their innovative ideas instead of needing a prescribed topic.

After considering the role of the continuous prototyping cycles in the development of innovative attitudes, Smith understood better the differentiation observed in her capstone group. She could see how these experiences made students more *self-reliant,* better *implementers*, and more ***persistent***.

B. Grappling with social, legal, and cost considerations

Global trends in engineering education emphasise the social and environmental responsibility of the engineering graduate [5],[33]. Currently, the only way to assess this attribute in the curriculum is theoretically. Students can speculate about the potential impacts of their designs or they could debate the evidence from case studies. However, the best way to become fully aware of the potential impact of your design is through experience. Such experiential learning cultivates the innovative attitudes of being *user-focused* - imagining from the perspective of others - and *visionary* - imagining a non-existent future. Smith 1 recalled a number of relevant scenarios.

At inception, the AREND team conducted interviews with the stakeholders. From these interviews, the students had to define the needs of the client and the constraints of a final solution. This process was a vexing learning opportunity. They went into the interviews thinking that the problem would be easily solved through technology alone. Instead, they realised the mission profile would have to be one-of-a-kind to address the social dimensions at play. These social dimensions translated to a need for a novel UAV design.

At a later stage in the project, a debate regarding IP arose. At the time, multiple universities were involved in the project with design responsibilities split across institutions. Those involved at the time did not anticipate the IP issues. When the need arose to formalise an IP agreement, it had a detrimental impact on the project's momentum and the team's motivation. Inadvertently, the students were involved in dealing with this IP "crisis". They gained first-hand experience of how legal issues can derail a project and relationships if not properly considered. After the issue had been resolved, the feedback Smith received from team members indicated that the experience of working with lawyers was educational and informative. Their ability to think about design from a legal perspective was cultivated.

The International Traffic in Arms and Regulations of the United States of America presented another legal scenario. During international design reviews with the global team, it became clear that these regulations presented design restrictions. This led to a re-assessment of the aircraft and this design adjustments. Students experienced how this nonengineering challenge affected the design space and had to accommodate the restrictions without compromising the final objectives.

Cost considerations are also present in AREND. As the project's funding is channelled through UP, government's procurement policies affect purchases. Smith makes students cognisant of these policies and the budget implications of their designs. Funding is not unlimited and the team members are exposed to the trade-off decisions that result.

AREND is a real project with stakeholders, legal constraints, and a budget. Therefore, team members are involved in many processes that require them to develop their user-focus and visionary abilities.

C. Marketing to different stakeholders

Engineering students easily relegate the idea of marketing to something that someone else does. In truth, any innovator must be a good marketer too. Being *visionary*, *user-focused* and *passionate* is required to "sell your story" to a stakeholder in his language. AREND students have been involved in marketing AREND to public audiences on a number of occasions.

In 2018, AREND's UAV was exhibited at DroneCon and the Electronic Warfare of South Africa conference, the African Aerospace and Defence Expo, and the VIP Poster Exhibition. Smith was present with students for the first two events, but because of research commitments, had to delegate the responsibility of the latter two events to the students. It was a gamble, leaving the public reputation of her project to a group of students. Based on her experience with the students, Smith had confidence that the responsibility and autonomy would inspire them to perform, which it did.

To be impressive at exhibitions, the students needed to appear passionate. This was a challenge for some of the shy and more introverted students who, despite their genuine internal passion for AREND, now had to engage and express their passion publicly. In our experience, students grow in their ability to present passionately as they are given more encouraging opportunities to do so. The exhibitions offered a safer space to practice than an oral exam would.

D. Contributing to and leading diverse teams

'… we have to teach our engineering students to respect the ideas and ways of working that are common in other disciplines and to stay open to other culture and work environments' ([5], pg. 4). The ability to thrive in diverse teams is an indispensable graduate competence. Trent has observed how the teamwork experiences in projects like AREND and the VIP teams are markedly different from what students experience in teamwork projects that are part of modules. She studies teamwork experiences in the classroom [34] and in the VIP Programme. This has led her to a deeper reflection on why teamwork in traditional curricula is different to teamwork in a project like AREND.

Although the classroom teamwork experience is not without merit, it falls short in a couple of ways. The diversity in these teams is limited to the diversity in the cohort. What about diversity in experience levels, age, international diversity, or modes of thinking beyond engineering? Another shortcoming is again the time pressures faced. Classroom teams hardly have the time to develop through the *forming* and *storming* phases to the *norming, performing,* and *adjourning* phases of teamwork first suggested by [35]. This leaves undergraduates with an antagonistic perception of teamwork because their group experiences were stuck in the *storming* phase.

The AREND project addresses both the diversity and time challenges. Specifically, the diversity challenges in the AREND team have been fertile soil for developing leadership and communication skills with no small amount of persistence and tolerance required.

Team members range from second year to postgraduate level. Smith has found that assigning leadership roles can be risky. Most students do not have the professional skills to handle conflict and motivate team members while remaining focused on the project objectives. Instead, she has noticed that some members naturally emerge as managers and mentors. Because AREND has the luxury of time, she can let the team dynamic emerge organically, and then steer and mentor where required. Students who do not immediately stand out as natural leaders need a different type of training to grow. A structure of supervised leadership and a culture of accountability and coaching have worked well to cultivate their leadership abilities. But communication undergirds any form of good leadership and in such a diverse team, communication challenges are vast.

In the early phases of the project, team members were immersed in the challenge of communicating across international boundaries. Language, disciplinary, cultural, and even design philosophy barriers made for arduous meetings and necessitated many clarifying discussions. This was a completely new experience for undergraduates. Later in the project, resident German and French exchange students introduced communication challenges "in the home team". However, the team also experienced communication challenges among the South African members. Differing personalities, management style, and work ethic made clear and thorough communication even more vital.

Communicating well across all of these boundaries requires being a *team player* and being *persistent*. It is evident to us that students grow in these attitudes over time as they become better at understanding and making themselves understood.

V. CONCLUSION

Cultivating attitudes of innovation requires ill-defined problem scenarios and immersion into an authentic innovation project. Such conditions are near impossible to simulate in the current engineering curricula at UP. AREND is a long-term, co-curricular initiative that immerses students into an authentic innovation environment using a PBL approach. Through collaborative autoethnography, we have highlighted its innovation processes and how these contributed to developing innovative attitudes.

Our first practical insight is not to overdesign the learning experience, but rather to make sure that the project resembles an industry innovation project and let the learning experiences follow. Our second practical insight would be to maintain a reflexive posture towards student development and to adapt and grow with the team.

In this paper, we focussed on the cultivation of innovative attitudes using an autoethnographic approach. In ongoing work, we embark on a deeper exploration through student surveys and interviews with AREND graduates in industry. In particular, we are interested in the professional skills developed in AREND team members and the benefits of early cross-subject synthesis.

REFERENCES

[1] D.M. Ferguson, K.W. Jablokow, M.W. Ohland, and S. Purzer. (2017). "The diverse personas of engineering innovators," J. Eng. Educ., vol. 33, pp.19–29, 2017.

[2] I. Badran. "Enhancing creativity and innovation in engineering education," Eur. J. Eng. Educ. vol. 32, pp. 573–585, 2007.

[3] D.M. Ferguson. How engineering innovators characterize engineering innovativeness: A qualitative study. PhD thesis, Purdue University, 2013.

[4] K. Grzybowska and Łupicka, A, "Key competencies for industry 4.0," Econ. and Manag. Innov., vol. 1, pp. 250–253, 2017.

[5] A. Kamp, Science & Technology education for 21st century Europe. Technical report, TU Delft, 2019.

[6] L. Prifti, M. Knigge, H. Kienegger, and H. Krcmar, "A competency model for 'Industrie 4.0' employees," In Proceedings of the 13th Int. Conf. on Wirtschaftsinformatik (WI 2017), St. Gallen, 2017.

[7] S.T. Hunter, L. Cushenbery, and T. Friedrich, "Hiring an innovative workforce: A necessary yet uniquely challenging endeavor," Hum. Resour. Manag. Rev., vol. 22, pp. 303–322, 2012.

[8] K. Shephard, "Higher education for sustainability: seeking affective learning outcomes," Int. J. Sustain. High., vol. 9, pp. 87–98, 2008.

[9] R. Harden, R. "Learning outcomes and instructional objectives: is there a difference?," Med. Teach. vol. 24, pp. 151–155, 2002.

[10] J. Menold, K.W. Jablokow, D.M. Ferguson, S. Purzer, and M.W. Ohland, "The characteristics of engineering innovativeness: A cognitive mapping and review of instruments," Int. J. Eng. Educ., vol. 32, pp. 64–83, 2016.

[11] L. Baartman and E. de Bruijn, "Integrating knowledge, skills and attitudes: Conceptualising learning processes towards vocational competence," Educ. Res. Rev., vol. 6, pp. 125–134, 2011.

[12] H. Colley, D. James, K. Diment, and M. Tedder, "Learning as becoming in vocational education and training: class, gender and the role of vocational habitus," J. Vocat. Educ. Train., vol. 55, pp. 471– 498, 2003.

[13] R. Gagné, "Learning outcomes and their effects: Useful categories of human performance," Am. Psychol., vol. 39, pp. 377–385, 1984.

[14] C. Ellis, T.E. Adams, and A.P. Bochner, Autoethnography: an overview. Hist. Soc. Res., pp. 273–290, 2011.

[15] A.P. Bochner, "On first-person narrative scholarship: Autoethnography as acts of meaning," Narrat. Inq., vol. 22, pp. 155–164, 2012.

[16] M. Tolich, "A critique of current practice: Ten foundational guidelines for autoethnographers," Qual. Health Res., vol. 20, pp. 1599–1610, 2010.

[17] C.S. Le Roux, "Exploring rigour in autoethnographic research," Int. J. Soc. Res. Methodol., vol. 20, pp. 195–207, 2017.

[18] L. Bayerlein and N. McGrath, "Collaborating for success: an analysis of the working relationship between academics and educational development professionals," Stud. High. Educ., vol. 43, pp. 1089–1106, 2018.

[19] S. Trahar, "Autoethnographic journeys in learning and teaching in higher education," Eur. Educ. Res. J., vol. 12, pp. 367-375, 2013.

[20] H. Chang, "Autoethnography as Method: Volume 1 of Developing qualitative inquiry", Universiy of Michigan, Left Coast Press, 2008.

[21] J. Koster, A. Buysse, L. Smith, J. Huyssen, J. Hotchkiss, J. Malangoni, and J. Schneider, "AREND: A sensor aircraft to support wildlife rangers," In 57th AIAA/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, page 0827, 2016.

[22] L. Smith, J. Koster, and J. Schneider, "Experience with international collaborative aircraft design education," In 31st Congress of the International Council of the Aeronautical Sciences, Belo Horizonte, Brazil. ICAS, 2018.

[23] L. Smith, and N.M. Trent, "Student and staff experience of an interdisciplinary, multi- national co-curricular aerospace design project," Flipped IRSPBL 2020/2021, online, Paper 82, 2020.

[24] L. Smith, and N.M. Trent, "A Cocurricular Framework for a Multinational, Vertically Integrated Engineering Design Project" ASEE Virtual Annual Conference, 2021.

[25] A. Silva, E. Henriques, and A. Carvalho, "Creativity enhancement in a product development course through entrepreneurship learning and intellectual property awareness," Eur. J. Eng. Educ., vol. 34, pp. 63–75, 2009.

[26] J. Perrenet, P. Bouhuijs, and J. Smits, "The suitability of problem-based learning for engineering education: Theory and practice," Teach. High. Educ., vol. 5, pp. 345–358, 2000.

[27] J. E. Mills and D.F. Treagust, "Engineering education — is problembased or project-based learning the answer," Australas. J. Eng. Educ., vol. 3, pp. 2–16, 2003.

[28] J. R. Savery, "Overview of problem-based learning: definition and distinctions, the interdisciplinary," J. Probl. Based. Learn., vol. 1, pp. 9–20, 2006.

[29] J. D. Lehman, M. George, P. Buchanan, and M. Rush, "Preparing teachers to use problem-centered, inquiry-based science: Lessons from a four-year professional development project," Interdiscip. J. Probl. based. Learn., vol. 1, pp. 7, 2006.

[30] A. Guerra, "Integration of sustainability in engineering education: Why is PBL an answer?," Int. J. Sustain. High., vol. 18, pp. 436-454, 2017.

[31] R.G. Hadgraft and A. Kolmos, "Emerging learning environments in engineering education," Australas. J. Eng. Educ., vol. 25, pp. 3-16, 2020.

[32] S. Rouvrais, J. Ormrod, G. Landrac, J. Mallet, J. M. Gilliot, A. Thepaut, and P. Tremenbert, "A Mixed Project-based Learning Framework: Preparing and Developing Student Competencies in a French Grande Ecole," Eur. J. Eng. Educ., vol. 31, pp. 83–93, 2006.

[33] M. Murphy, K. Hawwash, M. Vigild, and X. Fouger, SEFI position paper: Developing graduate engineering skills. Technical report, SEFI — European Institute for Engineering Education, 2016.

[34] N.M. Trent, J.W. Joubert, and W.L. Bean, "Engineering students' perspectives on the use of group work peer assessment in two undergraduate Industrial Engineering modules," In 2020 IFEES World Engineering Education Forum - Global Engineering Deans Council, WEEF-GEDC 2020, 2020.

[35] B. Tuckman and M. Jensen, "Stages of small-group development revisited," Group. Organ. Manag., vol. 2, pp. 419–427,

Technical papers

A proposed classification system for online forum content

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***Abstract* — Student engagement with content, each other, lectur- ers and artefacts is a fundamental aspect of an active learning ethic. Covid era remote teaching revealed particular challenges in enabling, sustaining and cultivating forms of engagement. This paper presents a conceptual framework for considering the dimensions of online engagement based on a case study from a research-intensive institution in South Africa. The focus is on a second-year large-class Material Science course with a broad range of content requiring 600 + pages of reading, projects and practicals. The course has seen several innovations over the years. This paper examines forms of student engagement in established, structured online forums pre- and during the Covid era of teaching, and presents an analysis of engagement patterns drawing on a synthesis of learning typologies from a range of educational theories intended to inform possible affordances of online engagement. The data produced by the classification of forum posts under the proposed scheme can highlight their overall structure, monitor changes in posting behaviour over time, and potentially contribute to a more nuanced understanding of the role of online forums in student learning.**

Keywords — Online forums, participant post classification, student engagement

I. INTRODUCTION

Engineering education has seen a significant increase in the use of technologies, both for learning assistive tools and professional applications. However, the onset of Emergency Remote Teaching (ERT) [1] accelerated academics world-wide into rapidly adopting tools and platforms to facilitate technology-based remote learning. Most notably, supporting student engagement with content, each other, lecturers, and artefacts is the fundamental aspect of an active learning ethic citeb2. The shift from the classroom-based, face-to-face engagement where the learning community engaged in tacit forms of mediated support [3] saw significant challenges in enabling meaningful active and sustained forms of engage-ment. In the Global South and resource-constrained contexts, digital access and fluency [4] have proven to be particularly challenging. The question of access to digital resources is further exacerbated by the need to support learners not just academically but with co-curricular engagement and other social supports [1].

In the context of national reports citing challenges of online student engagement during ERT and the increasing need to optimally and efficiently integrate technologies into our education systems, this paper focuses on a research initiative at a higher education institution in South Africa. The engi- neering faculty in question is actively involved in engineering education research initiatives from a scholarly-informed and practice-based perspective [5]. One particular course - a 2nd- year Material Science - has seen several innovations over several years. Facilitators had integrated an active online student forum before the onset of - and sustained throughout - ERT. Initially created to consolidate administrative questions on an open and accessible platform so as to reduce the lec- turing team administrative burden, students were encouraged to answer questions where possible and share course-related topics they found interesting. Informal feedback suggested that the course facilitators and many students found these forums useful. However, this was not the experience of fellow teaching enthusiasts on other courses This raised questions about how and what kind of engagement the forums enabled. With this in mind, the course facilitators and an engineering education advisor collaborated on a research initiative to interrogate the nature of engagement in the Material Science course.

A preliminary literature review revealed little had been published on the educational, theoretical underpinnings of user forum engagement, and there appeared to be no established tools for evaluating the content of an online academic fo- rum. Drawing on the educational theories that support our holistic work in the faculty [5], the research team set out to problematise the features of online forum engagement and develop a conceptual framework to enhance educator insights. Using the Material Science course as a case study, the paper problematises and examines forms of student engagement in established, structured online forums pre-and during the Covid era teaching using a mixed-methods research approach.

II. CONTEXT

The research-intensive institution at which this research is located is in the process of ongoing programme renewal, with funded educational innovation projects in engineering education [5]. Initiatives include meeting strategic objectives such as maximising opportunities for using technology in the online space [3]. This paper reports on one funded initiative examining the theme of online student engagement, using a specific engineering course as a platform through which to develop more nuanced insights into student online behaviour to enable lecturers to address student learning needs and challenges proactively. The Material Science course has, in the past, implicitly required students to have a modest level of experience with various materials and applications. When course facilitators identified shortfalls in this experience, they could address them directly. However, with the increased number of students and the broader range of experience in a more diverse cohort, it is no longer practical to engage with individual students to overcome gaps in their experience. In addition to a growing burden of engaging with students directly on technical content, there is a substantial growth in administrative communication resulting again from a growing and more diverse student group.

Since 2019 this course has been presented with weekly context videos, assigned readings, small projects (with peer-review), and lab practicals (with online virtual preparation). In addition, online student forums were introduced into the course in recognition that a large group of high achieving students is a resource that can become part of our teaching toolset. Our hopes in introducing an online forum are:

- ***To consolidate communication paths.*** Before the student forums, we were aware of multiple communication paths, both person-to-person, via email and messaging services, and person-to-group, via email, messaging service and LMS announcement. Communication is sometimes between students and facilitators and between students, leading to a situation where not all information is available to all participants, disproportionately impacting the most vulnerable students. They are less likely to be part of the student communication groups or communicate directly with the facilitators.
- ***Encourage a realistic learning community.*** Group learning communities have demonstrable benefits for the growth and understanding of the individual participants [6]. However, they need to grow organically and with self-driven engagement to see these benefits. Online fo- rums are a realistic learning community for people to learn outside a classroom environment that encourages engagement and self-reliance. A subject-specific forum is a low-stakes environment to build a life skill that will benefit students long after graduation.
- ***Improve the quality of communication.*** As is typical with email, person-to-person communication has a predictable delay caused by reliance on a single designated responder. Extending communication to an open platform increases the number of potential respondents to all par- ticipants and reduces communication lag. A consolidated communication path further improves clarity, with all facilitators able to comment on any communication or reply to a question, reducing the chances of different information being sent to different people. [7]
- ***Shift the study mechanism to discussion-based learning.*** Discussion-based learning allows students to engage with the course content more individually [8]. The translation and rotation of information and concepts needed when reading and commenting on other participants' posts encourage deeper learning than that provided by self-study alone. Students also benefit from the excite- ment and additional context provided by what their peers discover.

From 2019 through 2021, the course content, presentation method and forum integration have remained consistently an online hybrid format, making the course one of a few courses that remained unchanged in its presentation before, during, and after ERT. Therefore, the course and approach offer an ideal opportunity to evaluate the potential impact of user forum engagement and develop a more nuanced understanding of the nature of online engagement.

Students receive an onboarding lecture during the first week that covers the purpose of each forum, some basic technical coverage of how to construct a forum post, reply to a post, and an induction into the expected 'netiquette'. In addition, we incentivised activity on the forums:

1) All activity on the forums counts towards a class participation mark contributing around 5 % to each student's semester mark. We calculate this forum participation mark as the weighted sum of distinct engagements, with the weightings representing our espoused values, posting new content and replying to posts having a higher value than simply viewing a post.
2) We award additional bonus marks for exceptional contributions. For example, translating video content into some of the other national official languages.
3) All external communication is deliberately redirected to the forums to reinforce its central communication role.
4) Facilitators take time to thank and encourage participation in the forums, especially in the early stages of the semester.

Through monitoring the content of the forums, we note that although it takes some prompting early in the semester, the forums become self-sustaining, with the group taking on the culture enacted by the facilitators. It is worth noting that participation in the online forums develops key engineering graduate attributes, including; professionalism, collaboration, ethics, and problem-solving.

III. THEORETICAL FRAMING

The paper consolidates a number of key educational theories, beginning with a view of curriculum: Barnett [9] produced a precedent-setting publication on the need for a more holistic view of the curriculum over two decades ago, which saw the explicit inclusion of the development of identity and practice-focused 'skills'. Bloom's domains [10], similarly, have been used as guidelines for developmental learning for decades. The holistic features of curriculum and pedagogy promoted by educational theorists see a synergistic relationship between cognitive, *affective and systemic* (CAS) domains. The CAS model has been applied to the analysis of communities of practice [6] as well as the design of simulated learning environments [3]. While using the CAS domains as an over- arching framework, each dimension can be further enriched by drawing on multiple sociological and educational theorists. In the cognitive domain, Bernstein's [11] concept of 'fram- ing' is useful: What is selected, in what order, at what pace, and against what criteria? These features offer a means to categorise the scope of user forum posts. Secondly, Biggs' [12] definition of forms of cognitive engagement enable the interpretation of forum posts according to whether or not the focus is on a deeper understanding, a strategic approach or simply a superficial level of conceptual engagement.

In the affective domain, we draw on the concepts of motivation underpinning levels of social engagement - from the need at an individual level to a cooperative and more socially motivated level of engagement [13]. Motivation is further supported by the interpretation of sentiment - Negative, Neutral, Positive - which are key to understanding if one intends to adopt a community-of-practice approach to learning [14].

The third domain from a learning support perspective is informed by [15] descriptions of the systemic resources that need to be in place to support student learning, from the academic to administrative and supplemental. This category requires differentiating between types of engagement from a logistical perspective, and as such includes whether or not the form of engagement is a question, response, presentation, acknowledgement or correction.

Finally, the implementation of the user forum is underpinned by a principle of orientation to or induction into engineering practices. While the cognitive engagement and the resources supporting such engagement are ostensibly what Bernstein terms 'Instructional Discourse' (2000), the so-called hidden curriculum is constituted by the Regulative Discourse. This represents the often invisible 'rules of the game'. The forum offers an opportunity to induct students into the 'rules of the academic game' and simultaneously introduces them to the epistemic values and practices of a community of enquiry [16]. Drawing on these scholarly principles, and adopting a methodologically pluralist approach, the research team have set out to interrogate, analyse and interpret student engagement in the online forum across a three year period.

IV. METHODOLOGY

The data set for the study comprises all downloaded forum content from the institutional LMS from 2019, 2020, and 2021, representing pre-, during and post-ERT, and which were shared via a spreadsheet system. The individual content for each post was subjectively classified by three collaborating researchers using a mixed approach of induction and deduction, initially using a grounded approach and open coding system. We first explored the post content in terms of systemic utility. For example, were the posts generally academic or administrative, and how many contained supplemental information? Are the posts generally questions and answers, or is there other con- tent? Next, we expected to evaluate the posts on a cognitive level and found that they differed in scope, with some focusing on well-defined topics while others were more general. In addition, some posts indicated a simple shallow understanding of the course material, while others pushed for deeper, more generalised responses. Finally, as we progressed through the posts, we noted that posts varied in motivation and ranged from very positive to very negative.

Our initial observations suggested that several educational models would be useful for analysing and understanding forum engagement patterns. We settled on the holistic educational support model with three domains - the CAS model, subdi- vided into two sub-domains, each with a small number of level indicators.

- Cognitive Engagement: Cognitive framing and learning level
- Affective Engagement: Scope of motivation and post sentiment
- Systemic Engagement: Categorisation of post content and type of post.

V. UNDERSTANDING ONLINE FORUM ENGAGEMENT

A. Cognitive Engagement

Higher education's primary intention is to promote and develop cognitive engagement to prepare our students for lifelong and life-wide learning [16]. The learning opportunities we put in place are intended to enable students to access, process and utilise concepts and their related applications. Learning opportunities are framed along a fairly fixed to more open-ended continuum. The open-ended nature of discussion forums allows us to learn about the current framing a student uses in their studies and their level of learning by interpreting their online behaviour. The analysis of cognitive engagement differentiates between 'framing' and 'learning':

- Framing - [Narrow, Broad, Complex]
  - A narrow framing describes a post constructed with a converging scope limited to a narrow range of responses.
  - A broad framing describes a post constructed with a divergent scope that exceeds an implied limited context.
  - A complex framing extends a narrow and broad framing that brings in additional cognitive aspects such as context and implications.
- Learning - [Surface, Strategic, Deep]
  - Surface learning describes a prima-facie repetition of terms or concepts or utilising formulas and equations in well-established applications.
  - Strategic learning speaks to an economised view of learning beyond surface learning but is aimed at grade achievement rather than understanding.
  - Deep learning speaks to understanding the underly- ing principles of a subject area and generalising those principles.

Examples of the cognitive category (Tables I and II) reveal that narrow framing results in more rapid targeted responses that are particularly effective at communicating administrative information. Broad framing often resulted in more community- building discussions with longer discussion chains. Complex framing generally resulted in responses from the course facil- itators, but the responses were viewed by more of the class and had the highest rate of repeat views.

Surface learning posts are often centred on clarifications, allowing students and facilitators to broadcast additional in- formation to the group. Strategic posts provide a wealth of information regarding how students choose to economise their learning. Observing the trend towards additional supplemen- tal video sources allowed facilitators to identify threshold concepts and initiate a discussion regarding effective study methods. Deep learning posts are often linked to examples outside the official curriculum. Many of these posts resulted in exciting discussions and subsequent interest groups.

TABLE 1: *Cognitive engagement - Framing level indicators*

Narrow	'Yes you may use a tablet to make written notes and hand-drawn graphs.' 'I would like to inquire if the group we select this week will be our permanent group for the term/ semester or will be be able to select a group every week'
Broad	'It is a pretty interesting process too. Gene Roddenberry also used the word in his popular TV show. Any of you know which one?' 'I think that is a choice best left to you. Just keep in mind how long it will take to read through all of the mindmaps.'
Complex	'In order to calculate area under a curve, you are integrating over the curve. With discrete data, or when the curve given cannot be analytically integrated (almost all cases) this is typically done with a quadrature rule, essentially a weighted sum. One that works well here is the trapezoidal rule. XXX. When you post to a forum, be careful not to ask two questions in one post. Typically this will make answering the question too much work for one of your peers to answer (This is what I think happened to your question) or only one part of your question will get answered.'

TABLE 2: *Cognitive engagement - Learning level indicators*

Surface	'In the review session it was mentioned that it was incorrect to provide the monomer (with the double bonds) and that the repeat unit was marked as correct. However, the question explicitly askes for the monomer, not the repeat unit. Am I missing something?' 'Toughness is the total area under the curve.'
Strategic	'This channel I have found extremely useful when it comes to understanding concepts and converting my knowledge of theory into calculations. Youtube channel name: Introduction to material science and engineering Link:' 'From what I know of previous years, the department does not share past papers. I would recommend the example questions and the end of chapter questions for preparation/practise.'
Deep	'Found this short video on how sheet glass is made. Hope this helps with visualizing the process better.' 'Good day, I have seen it noted many times that some materials are soft. What exactly does this mean and how is this beneficial when selecting materials? I have also seen it commonly associated with ductility.'

B. Affective Engagement

The affective engagement category focused on levels and types of motivation and an interpretation of 'sentiment'. These factors are useful indicators of potential student persistence [17]. A positive attitude and cooperative learning approach are key problem-solving attributes in engineering graduates, potentially indicating longer-term success in the world of work. By identifying dominant sentiment trends, staff can intervene, respond or pre-empt dispositional or behavioural engagement patterns. This dimension differentiated between 'motivation' and 'sentiment' as follows:

- Motivation - [Individual, Cooperative, Social]
  - Individual motivation would describe a post that only intends to benefit the person posting.
  - Cooperative motivation describes a post that attempts to elicit an interaction. Though the individual posting will benefit, it is clear that the benefit will extend beyond the posting individual.
  - Social motivation describes a post intended to ben- efit other group members rather than the individual posting.
- Sentiment - [Negative, Neutral, Positive]
  - Negative sentiment describes a post with a negative tone or emotive content.
  - Neutral sentiment describes a post with no emotive content.
  - Positive sentiment describes a post with net positive emotive content.

Examples in the affective category (Tables III and IV) suggest that many students are motivated through self-benefit. However, based on the response rate of these questions, it be- came clear that many other students benefitted from questions framed in terms of self-interest. Interestingly the data shows that the minority of posts are framed solely for individual ben- efit. More often, posts were cooperative or social. Furthermore, cooperative posts tended to have longer discussion threads, indicating a developing learning community. There were more posts with no self-benefit than we would have expected, with some of these posts showing significant social benefit. One powerful example is a student posting a complete preparation exam with annotated marking memorandum they created.

A common experience for the course facilitators was that the group was often negative, affecting their emotional state. This is in contrast to the data that shows a minority of posts were, in fact, negative. This highlights the impact of negative posts and the need to keep the overall group behaviour in perspective.

C. Systemic Engagement

The systemic categories are divided into relatively proce- dural enquiries regarding material and administration and the classification of post types. One central intention of including a forum in the course was to consolidate communication channels and improve communication. Classifying the content by the systematic category provides insight into the nature of what is being discussed on the forums.

- Category - [Academic, Administrative, Supplemental]

TABLE 3: Affective engagement - Motivation level indicators

Individual	'Hi guys, I was wondering about in what order I should revise my work for A2. Would it be suggested to start at chapter 1 and go through the textbook or is it beter to stick to what the study guide says? ' 'Hi, I am struggling to find the correct elastic modulus from my graph, the closest I've been able to get is 230440,203. How does one get a more accurate value from the graph? Also how do we find the resilience, toughness and proof strength from our data. Thanks'
Cooperative	'BTW, Thanks for introducing me to subject tags, the forum will never be the same again. :' 'Trying to figure out the best app to use for the mind map Mini- project. Does anyone have suggestions on which app would be best to use? Thanks in advance!'
Social	'There is no need to use the 8th Edition. You can access a full copy of the 9th Edition at this post:' 'There was a question in today's f2f class about why the atomic % and weight % for the copper nickel binary isomorphous system look to be the same (the x-axis on top lines up with the x-axis at the bottom, approximately). Opposite to this, we have the iron- iron carbide phase diagram where the atomic % C (top x-axis) is greatly different from the weight % C (bottom x-axis). It has to do with differences in atomic weights. See the reasoning behind why this is the case here (under Week 9):'

TABLE 4: Affective engagement - Sentiment level indicators

Negative	'Greetings sir I have encountered an issue with the weekly quiz where it marks correct answers as incorrect. attached below is an example of ONE of the many that I have encountered ' 'So, please note that from this point on, Dr XXX and Prof XXX will NOT be answering any further posts or emails in this regard. Please limit your questions to asking for further explanation or insight into the CONTENT and information of the module, be specific. We are not going to be giving clues as to what is in A2. That is not the point of this module nor should it be the focus of your studies.'
Neutral	'I believe the slides have been added now. ' 'Hi, I just wanted to know if 2 of our lowest quiz marks will get dropped when calculating our final mark?'
Positive	'Wow, thanks XXX. This will really help me with understanding the topics better. ' 'Fascinating stuff XXX, Thank you. It's the medical benefits are amazing!'

- Academic content relates to the course's terms, con- tent, or theories.
- Administrative content relates to how the course is run and may include items such as clarification of deadlines.
- Supplemental content is not directly within the course content. However, it provides additional ben- efits to the group- for example, posting a link to a video describing an exciting application of new material.

- Type - [Question, Response, Presentation, Acknowledge- ment, Correction]

A data review shows that more than half of the forum posts cover administrative issues. Although this does not necessarily benefit the student's learning, it significantly reduces course uncertainty. All these administrative questions are publicly asked and answered. In practice, many of these questions were answered by other students, which reduced the facilitator load and resulted in faster transmission of information. Inter- estingly, there were more supplemental posts than academic posts indicating a meaningful inclusion of information not in the official curriculum, driven by the learners (Table 5). As expected, many of the posts were in the form of questions and responses, but many more than expected were simply presentations not eliciting a response and acknowledgements. We suspect that the high proportion of acknowledgements is how the forums become self-sustaining.

We suspect that the high proportion of acknowledgements is how the forums become self-sustaining.

TABLE 5: Systemic engagement - Category level indicators

Academic	'Thanks XXX. Just to clarify, would the primary alpha then be at a higher temperature than the Eutectic alpha which would always be below the Eutectic isotherm? Or have I misunderstood? ' 'I can across a question in a past paper, where they ask why is stainless screws in an aluminum plate not considered to be susceptible to corrosion but aluminum rivets in a stainless steel plate corrode more easily. Can someone please explain. '
Administrative	'Good Afternoon Sir Would it be possible to see our quiz marks after we have submitted them to see how we are doing? I feel like I could be thinking I'm doing well in the quiz's and have grasped the vocabulary well but could actually be doing really badly and have no idea. Thank you in advance. ' 'Here is the online version of our textbook'
Supplemental	'I don't know, I can't find any details confirming it, but I do know that solid hydrogen has been produced, and longer ago than you would expect. It was first produced in 1899. For context, the second Anglo Boer War started in 1899. ' 'Here is a link to the Fun to Imagine series from 1983. It is presented by Richard Feynman, possible the best science communicator of all time. This series helped me conceptualise how the world works at an atomic level. If you are struggling with the question of why things are the way they are in Chapter 2 and 3 please take a look.'

VI. DISCUSSION

The analysis of forum posts using the CAS model in conjunction with the educational theorist dimensions enables a more nuanced picture of the scope and nature of online engagement. On the one hand, the ERT teaching and learning experience saw course facilitators globally relying on various online strategies, including forum participation, as a key means to drive holistic student engagement. However, generally, poor online participation was reported anecdotally and increasingly in the post-ERT literature as a result of workload and time management [19], which manifest in the systemic (non/) use of such platforms. The sheer predominance of administrative posts in the case study reported in this paper attests to the fundamentally systemic purpose of online forums, and indeed, was the initial intention. We suggest that the overall lower engagement figures in 2021 could be attributed to 'insecurity, lack of confidence and loneliness' as reported in an Australian study [20]. These affective aspects were also a key intention of establishing the online forums in the course in question: to stimulate a community of practice ethic to encourage peer learning strategies. Both systemic and affective intentions, however, are designed to support the ultimate goal of higher education: cognitive development.

From a cognitive engagement perspective, the use of framing and learning level indicators in this study have enabled course facilitators to determine student perceptions of course material content, monitor and intervene when conceptual gaps emerge, and encourage the community to engage both strate- gically and more deeply with the fundamental concepts. What is noteworthy here is the level of cooperative and social forms of engagement demonstrated by students across the three data years included in the study. In addition, the development of professional practices such as appropriate salutation and ac- knowledgement among forum participants suggests the forums are to a certain extent inducting students into the epistemic values of a specialised community of 'inquiry' [16].

Building a sense of community and cooperation lies at the heart of the future engineering graduate's role in addressing socio-technical challenges. What the analysis does not suggest is that online forums can necessarily enable the forms of deeper learning which academics strive to facilitate. We suggest that for online forums to achieve this requires specific user-engagement and design elements to scaffold the required learning. The project team intends to pursue this objective going forward.

VII. CONCLUDING COMMENTS

This paper has presented a conceptual framing for understanding student engagement in online forums, and has drawn on the analysis of a particular set of cohorts from 2019-2021 (pre- and during ERT) to determine the nature of engagement from cognitive, affective and systemic perspectives. While the analysis suggests that online forums are predominantly used to support systemic information management and clarification needs, there are indications that the effective design of such systems can support student affective needs.

The analysis has highlighted two particular factors that may be of use to educators as we return to contact-based instruction, with the intention of retaining good practices acquired during ERT.

- Learner Management Systems may be just that: ways to administratively regulate learning. The use of online forums in this context are a means to reduce the administrative workload of large classes on academic staff, through sharing the responsibility with students for accessing information and managing task requirements.
- Online forums may well be a means to developing the broader range of Graduate Attributes for professional qualifications in that they comprise elements of professionalism, collaboration, ethics, problem solving and appropriate communication strategies. Academic staff focussed on specialised disciplinary content may not have the luxury of curricular space within which to integrate these 'so-skills', and as such, effective online forums can be used to facilitate their development.

REFERENCES

[1] B. Hodges, S. Moore, BB. Lockee, T. Trust, and MA. Bond, "The difference between emergency remote teaching and online learning," 2020.

[2] A. Kozulin, "Psychological tools and mediated learning," Vygotsky's educational theory in cultural context, vol. 4(6), pp. 15–38, 2003.

[3] K. Kruger, K. Wolff, and K. Cairncross, "Real, virtual, or simulated: Approaches to emergency remote learning in engineering," Computer Applications in Engineering Education, 2022.

[4] GL. Czerniewicz, N. Agherdien, J. Badenhorst, D. Belluigi, T. Cham- bers, M. Chili, M. De Villiers, A. Felix, D. Gachago, C. Gokhale, and E. Ivala, "A wake-up call: Equity, inequality and Covid-19 emergency remote teaching and learning," Postdigital Science and Education, vol. 2(3) , pp. 946–967, 2020.

[5] K. Wolff, D. Blaine, and C Lewis, C., "A cumulative learning approach to developing scholarship of teaching and learning in an engineering community of practice," In 2021 World Engineering Education Fo- rum/Global Engineering Deans Council (WEEF/GEDC),pp. 310–318, 2021.

[6] C. Lewis, K. Wolff, and B. Bekker, "Supporting project-based education through a community of practice: a case of postgraduate renewable energy students.," World Transactions on Engineering and Technology Education, vol. 19(1), pp. 35–40, 2021.

[7] N. Peimani, and H. Kamalipour, "Online education and the COVID-19 outbreak: A case study of online teaching during lockdown," Education Sciences, vol. 11(2), pp. 72, 2021.

[8] KA. Smith, SD. Sheppard, DW. Johnson, and RT. Johnson, "Pedagogies of engagement: Classroom-based practices," Journal of engineering education, vol. 94(1), pp. 87–101, 2005.

[9] R. Barnett, "Supercomplexity and the curriculum," Studies in higher education, vol. 25(3), pp. 255–265, 2000.

[10] B. Bloom, "A taxonomy of cognitive objectives," New York: McKay, 1956.

[11] B. Bernstein, "Pedagogy, symbolic control, and identity: Theory, re- search, critique," Rowman & Littlefield, vol. 5, 2000.

[12] J Biggs, "What do inventories of students' learning processes really measure? A theoretical review and clarification," British journal of educational psychology, vol. 63(1), pp. 3-=19, 1993.

[13] KF. Trenshaw, RA Revelo, KA. Earl, and GL. Herman, "Using self- determination theory principles to promote engineering students' intrin- sic motivation to learn," International Journal of Engineering Education, vol. 32(3), pp. 1194–1207, 2016.

[14] J. Lave, and E. Wenger, "Communities of practice," Learning, meaning and identity, 1999.

[15] A. Tait, "Planning student support for open and distance learning," Open learning: The Journal of open, distance and e-learning, vol. 15(3), pp. 287–299, 2000.

[16] WE. Morrow, "Bounds of democracy: Epistemological access in higher education," HSRC Press, 2009.

[17] EL. Deci, and RM. Ryan, "Self-determination theory: A macrotheory of human motivation, development, and health," Canadian psychol- ogy/Psychologie canadienne, vol. 49(3), pp. 182, 2008.

[18] G. Joughin, "The hidden curriculum revisited: a critical review of research into the influence of summative assessment on learning," Assessment Evaluation in Higher Education, vol. 35(3), pp. 335–345, 2010.

[19] S. Aderibigbe, J. Dias, and M. Abraham, "Understanding issues affecting students' commitment to online discussion forums in undergraduate courses.," International Journal of Interactive Mobile Technologies, vol. 15(1), pp. 4–23, 2021.

[20] Y. Lin, and H. Nguyen, "International students' perspectives on e- learning during covid-19 in higher education in Australia: a study of an Asian student.," Electronic Journal of e-Learning , vol. 19(4), pp. 241–251, 2021.

Technical papers

Engineering students' engagement and their perspective on compulsory classroom attendance

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***Abstract* — The link between class attendance, student engagement, and student success is controversial in Higher Education. Some universities monitor student attendance in the classroom. The difference between monitoring or recording attendance and enforcing a compulsory attendance policy should be clarified. This paper aims to explore engineering students' experience of applying attendance monitoring and enforcing a mandatory attendance policy. The relation between increasing the attendance rate and student engagement is also investigated. The primary research questions are: what are student perspectives on compulsory attendance monitoring? and why do senior engineering students attend classes? A pilot case study investigates senior undergraduate engineering student experience before and after the attendance monitoring system was performed. A survey was used to determine the view of students on how the compulsory attendance system influences their motivation and engagement in the classroom and what motivated them to attend before the compulsory policy became in effect. The findings can enrich higher education teaching and learning authorities with thoughts on future strategic policies and strategic research in the digital transformation era.**

Keywords — Attendance Monitoring System, compulsory attendance policy, student engagement, engineering education, student's motivational beliefs

I. INTRODUCTION

Many in the educational process would debate the importance of student attendance to their learning. Educators in higher education have different views about compulsory attendance. While one group agrees with imposing mandatory attendance [1], the other group insists that university attendance should be made non-compulsory [2]. Students' absences may or may not lead them to fail their degrees. If they progress without attendance, their institution's reputation must be questioned. If their absence leads to their failure, the program or the degree might be at risk of being nonattractive, eventually affecting the program or institution's sustainability [3]. The difference between monitoring or recording the attendance and enforcing a compulsory attendance policy should be clarified.

At the University of Nottingham Ningbo China, an electronic Attendance Monitoring System (AMS) has recently been implemented, and a compulsory attendance policy has become in effect. The policy was initially drafted to manage students' attendance of modules delivered by another school rather than the home school where the student belongs. The system helps students register their attendance, and the faculty and admin staff monitor the record. One advantage of having a plan for recording attendance is to help both academics and admin staff to collect data on students enrolled in a module or a program. This can be useful for making statistics to discover areas of improvement, visualizing the progress of a module or a program over time, or comparing different modules or programs. Another advantage is having a platform and an efficient mechanism that helps the educators and admin staff collect the attendance data. It would sometimes be challenging for the educator to collect the data manually, primarily as the number of students attending the module or program increases [4]. A third significant advantage is that a poor attendance rate may indicate students are at academic risk. Therefore, when monitoring their attendance, academic support and pastoral care could be offered in the early stages before it's too late for them to progress [5].

However, having an efficient system for collecting and recording attendance information doesn't necessarily mean enforcing a compulsory attendance policy equally for all programs and years of study, as attendance isn't the only factor indicating academic achievement [6]. Implementing a compulsory attendance policy certainly increases the attendance rate, but it doesn't justify academic achievement. Moreover, there's not much research investigating if compulsory attendance can improve student engagement in the classroom.

This paper presents a pilot study investigating why engineering students engage with a final year optional module. The study was motivated by the very high attendance rate and student engagement in the module before the compulsory attendance policy was applied. The study also presents students' views towards the attendance monitoring system and compulsory policy one semester later and its impact on their motivation and creative thinking. There are other reasons why students prefer to attend classes rather than compulsory attendance. The paper is structured as follows: Section II gives a brief review of the literature on attendance, performance, and student engagement in higher education. Section III overviews the attendance monitoring system at the University of Nottingham Ningbo China. Section IV presents the approach applied in the taught module used in this pilot study. Section V explains the methodology, Section VI presents the student survey and results, and section VII concludes.

II. LITERATURE REVIEW

Students' attendance and academic performance have been the subject of debate in higher education. Several studies have found some correlation between classroom attendance and academic achievement. Using quantitative analysis, a case study examined the tutorial program for first-year economics students at Stellenbosch University [7]. The study confirms that a tutorial program can improve the performance of first- year economics students, and peer teaching should therefore receive more attention as part of academic support initiatives for first-year students. The use and benefits of tutorials in a large enrolment first-year economics course were examined in [8]. The study revealed that many students attended the first tutorial of the semester. Most attended at least three tutorials, while fewer than half participated in all five. One tutorial did not improve performance on the final exam or the course as a whole, but multiple tutorials had a cumulative effect on the exam and course performance. Attending teaching sessions provides more than just a better grade. Within the context of employability, internationalization, and the move towards research-rich learning, session attendance is an integral component of a student's overall learning experience, with the development of skills and acquisition of knowledge that may not be directly assessed [9]. Without attendance, students may pass exams and coursework assignments, but their educational experience would be incomplete and calls for additional research on the broader advantages of attendance. In addition, students may miss out on peer support and require extra staff time [10].

Despite the widespread belief that there is a positive correlation between class attendance and academic performance, other studies have found this correlation is weak. The difference between the whole class and average attendance has led to a margin of one to three points in test scores. Therefore, compulsory attendance has a weak impact on performance [11, 12]. Similar findings resulted from studies made on engineering students [13-15]. A theoretically and practically relevant survey evaluated the relationship between teaching session attendance in higher education and students' classroom engagement using mediation analysis. As indicated by the results, cognitive and behavioral engagement fully mediated the relationship between attendance and performance [16]. The critical problems of student engagement are identified in a study that also conceptualized a framework to overcome those problems [17]. Another study investigated the definition of student engagement from engineering student and their faculty point of view. The study found that engagement is a process and outcome observed in class discussions and research projects with classmates and professors [18]. While [2] stated that a compulsory attendance policy would demotivate students instead of maintaining class attendance influenced by motivational beliefs and class context.

III. ATTENDANCE MONITORING SYSTEM

The University of Nottingham Ningbo China has decided to implement an AMS based on QR-code scanning in the classroom venue. A dynamic QR-code appears on the classroom display for the first 10 minutes of each teaching session, and all students attending the class can scan a dynamic QR-code using their smartphones. According to the announced attendance policy, students who arrive later than 10 minutes will be recorded absent. A pilot run of the AMS was done to record the attendance to the language module seminars over four teaching weeks at the end of the semester prior to the one in which the AMS was implemented widely for all modules and programs of study. Student's guide on how to sign in their attendance using their smart devices was shared with all students before the AMS launch. A soft launch was done in the first three teaching weeks period of the semester. This period covers the first two weeks of the semester, also known as the change of mind period, where attendance monitoring is not mandatory. During this soft launch, technical support and troubleshooting were offered to all students and lecturers to familiarize them with the monitoring system. Students were able to record their attendance in the classroom, but there was no penalty for their absence. The compulsory attendance policy was applied starting teaching week four until the end of the semester. Students who attended online due to approved learning disruption reasons, such as the pandemic, were exempted from scanning the code. During the entire semester, lecturers were able to monitor students' attendance to their classes on the cloud using their official university accounts.

The compulsory attendance policy was developed in accordance with the university regulations on engagement and attendance. The regulations require students to attend teaching activities to pursue their studies. The policy's objectives are to ensure students' satisfactory engagement by attending scheduled teaching activities that are needed to complete their studies and to provide consistent guidance across the university for identifying students who require additional support if their engagement is not deemed satisfactory. The policy states that students are required to attend at least 50% of their timetabled teaching activities; otherwise, their engagement is marked unsatisfactory. Students were still allowed to submit an absence form that their senior tutor should approve according to the rules. Where the accumulated unapproved absence reaches 30%, the student is called for an attendance meeting with their personal tutor to improve the student's attendance before any penalty is applied.

IV. ALTERNATIVE BLENDED LEARNING APPROACH

A mixed-mode teaching approach was applied to deliver the optional final-year engineering module utilized in this study [19]. This teaching delivery was made available to all students attending the module, whether they were still stranded off-campus or couldn't participate in one or more face-to-face teaching activities for any reason, allowing them to attend from anywhere. Several instructional tools were employed to make this approach as interactive as feasible. Moodle was used as the virtual learning environment for sharing learning materials, module information, and coursework submission. MS-Teams was introduced to promote immediate communication with students and office hours. MS-Teams was utilized to live-stream all classes, including lectures and seminars. A Microsoft Tablet with digital ink was used for online teaching, while the session was projected onto the classroom display for in-person teaching. Electronic whiteboards have replaced traditional whiteboards. The assurance was given to students that they may choose their preferred mode of attendance, whether in-class or online, and both will be manually recorded as present. To preserve the seriousness and interest of the online attendance, students were required to attend in a quiet environment and keep their microphones on for the entire teaching session. To promote classroom interaction, the classroom loudspeakers were used to broadcast the voice of online attendance at the classroom end.

V. METHODOLOGY

A pilot study was conducted on engineering students attending one optional engineering module of the BEng Electrical and Electronic Engineering program. The module contributes ten credits out of 120 credits students must complete in their final year of study. In-class attendance was made non-compulsory in this module in the semester before the AMS, and compulsory attendance policy was applied across the campus. The alternative online teaching approach was used during the entire semester, and students were assured they could opt for the online mode of learning in any teaching session without justifying the reason for in-class absence. To guarantee the freedom for attendance, students were also assured that all teaching sessions, including lectures and seminars, would be recorded and published on MS-Teams immediately at the end of each session. All videos will remain available the whole semester. All students in this module lived on campus, and no learning disruptions were noticed during the entire semester. The attendance was recorded manually at the beginning of each class. Students who attended online were marked attend.

A. Participants

Students were diverse in terms of their academic rank. Participation in the student survey was voluntary, and students were asked to complete an informed online consent form before completing the survey. The study was conducted under the human subjects guidelines from the institutional research ethics committee and was approved by the faculty research ethics officers.

B. Procedures

Students completed online self-report surveys regarding their engagement in the optional module when the in-class attendance was made non-compulsory and their view of the AMS and compulsory attendance policy in the following semester. Participants were told by their instructor that the specific responses to the surveys were anonymous and not graded. There was no chance for any participant to be disadvantaged as the survey was shared with the students at the end of the following semester of their attendance to the optional module. As a general instruction, it was emphasized that there were no right or wrong answers and that honest answers were valued. MS-Forms was used as a platform for the online survey. The survey was shared with all 26 students who attended the optional module. Announcements to the survey were made on the module team on MS-Teams. More than 69% of them voluntarily completed the survey.

VI. STUDENT SURVEY AND RESULTS

For the optional module used in this study, the attendance was manually recorded during the entire semester; however, the first two weeks were not considered for the attendance as it is the change of mind period. Figure 1 shows the distribution of two modes of attendance over nine weeks, starting teaching week 3. Two teaching sessions, a lecture, and a seminar were taught every teaching week, and one revision session in the final week. Figure 2 shows the overall attendance distribution during the semester. The average percentage of student attendance was above 92%, while the maximum absence was in teaching weeks 8 and 10, where the attendance percentage was recorded as 81%. This percentage was still considered very high, knowing that the reasons for absence in those two weeks were due to several coursework submission deadlines. No online attendance was recorded in more than 35% of the semester, and the highest online attendance (~15%) was in the revision week, where there was no absence as all students were keen on attending either in-class or online, so they not to miss the final revision. More than 61% of the students said they attend unless they're sick, while 22% said attendance depends on their view of their lecturer's teaching quality. Other reasons for classroom attendance included the relevance to assessment tasks or social reasons.

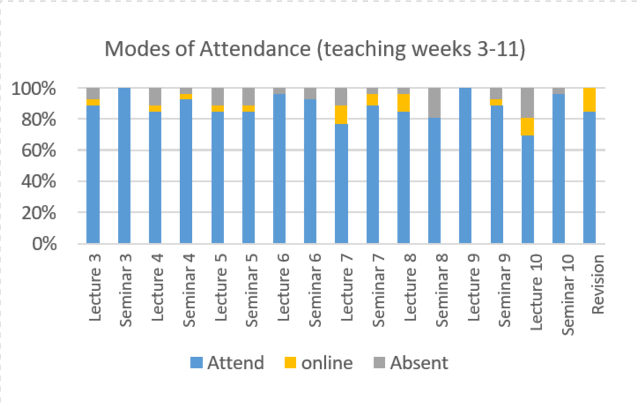

FIGURE 1: In-class and online attendance distribution

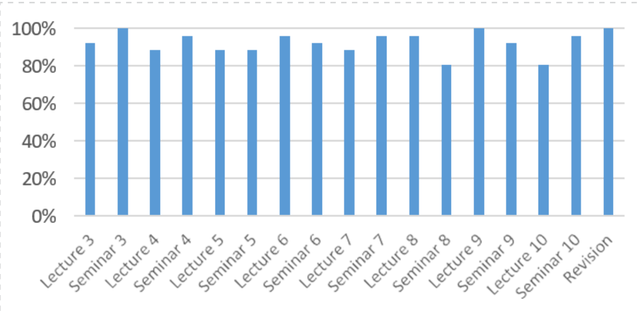

FIGURE 2: Overall attendance percentage

A. Classroom Context

In an intervention to investigate the effectiveness of the classroom context, students were asked about their experience of classroom interaction using the electronic whiteboard and lecturer annotation. 89% felt using the electronic whiteboard improved their learning experience, while all students thought the slide annotation was extremely useful, as shown in Figure 3.

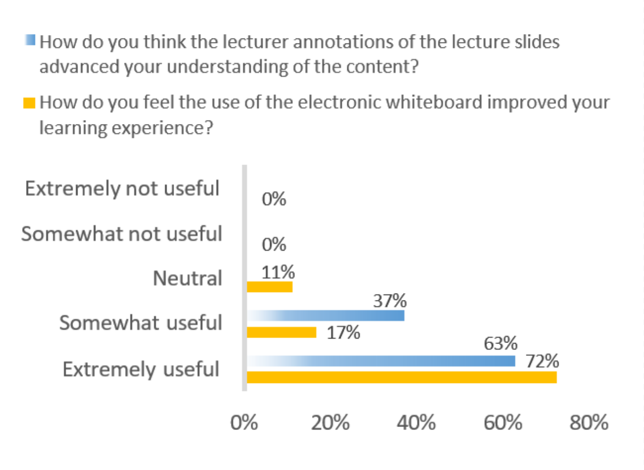

FIGURE 3: Student's view of the effectiveness of the classroom context

Figure 4 shows other reasons motivating students for in-class attendance. Besides having the learning material in advance, the lecturer seems to be a critical factor in attracting students for face-to-face attendance. 94% of the students said an effective and energetic lecturer makes their class enjoyable. Engineering students also feel motivated when their lecturer advises not necessarily on the topics but tips for gaining skills such as time management or future study or career.

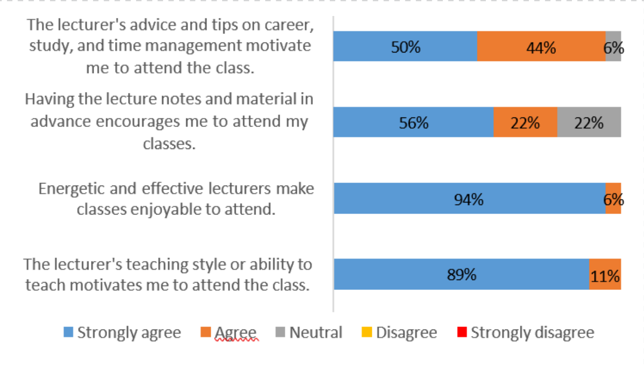

FIGURE 4: Students' motivation for in-class attendance

B. Compulsory Attendance and Academic Performance

Figure 5 shows the students' view of the AMS and the compulsory attendance policy deployed across campus. Most students agree that the technology used for the AMS system is efficient, and it's easy to scan the QR-code. It also seems that the students could accept that the system may help those at academic risk to be identified or get the chance to speak to their tutor; however, the majority couldn't make a clear opinion. Also, it isn't easy from the students' responses to determine if the attendance rate has increased after the AMS has become in effect. This's because the tendency of this group of students to attend their classes was already high before the compulsory attendance policy was made active, as indicated in Figure 1 and Figure 2. Even though, from Figure 5, it seems that students disagree that compulsory attendance improved their academic achievement.

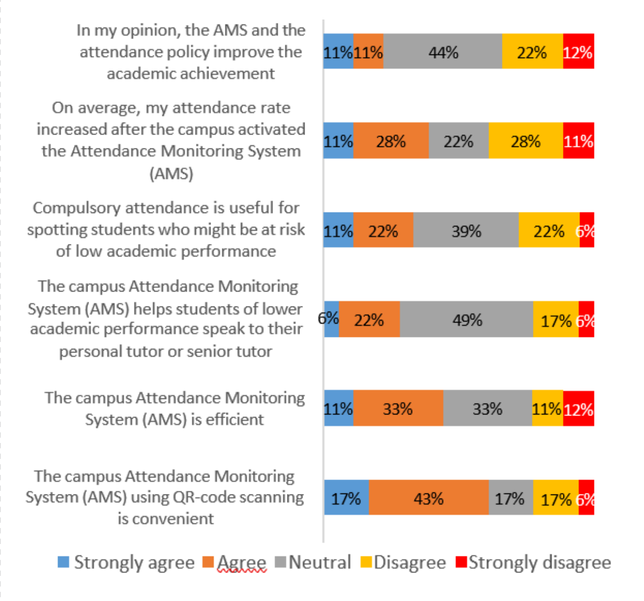

FIGURE 5: Students' view of the AMS and compulsory attendance

When the students were asked to comment on their responses, most students criticized the compulsory attendance policy:

"It's not an effective way to attract students to attend the lectures. The attendance, in my perspective, is solely based on interest towards the subject, lecturer, nothing more."

"Students should have the right to decide whether to attend the classes based on their own views."

They also emphasized that compulsory attendance has a low impact on improving academic performance:

"weak for helping students of lower academic performance to improve in their academic performance."

Some students even disagreed that scanning a code is an efficient way to spot in-class attendance:

"Since you can scan a QR code anywhere, it's not an efficient way either for monitoring attendance."

C. Student Motivation and Academic Achievement

In an intervention to investigate the applicability of the compulsory attendance policy, students were asked to express their views about applying compulsory attendance in different programs or years of study. Figure 6 shows that 67% of the students either strongly agree or agree that compulsory attendance can be more effective for the early years of study, such as year one and year 2. These findings are consistent with the previous research denoting that class attendance mostly impacts the academic performance of the first and second years [6]. Students also expressed that compulsory attendance is more applicable to language study than engineering modules. To learn more about the impact of the compulsory attendance policy on the students' motivation, as shown in Figure 6, 61% of the students either strongly agree or agree that they feel more motivated if the attendance was recorded without making it compulsory, while 17% of them disagreed. 34% of the students disagreed that compulsory attendance improved their classroom engagement, while 28% agreed it did. On the other hand, as per their response in Figure 6, 67% of the students either strongly agree or agree that their motivation increases when they have the freedom to decide whether or not to attend a teaching session. This gives some insight that although the goal of the attendance policy is to improve students' engagement, there might be a risk of demotivating students whose attendance rate is very high, like the group that participated in this study.

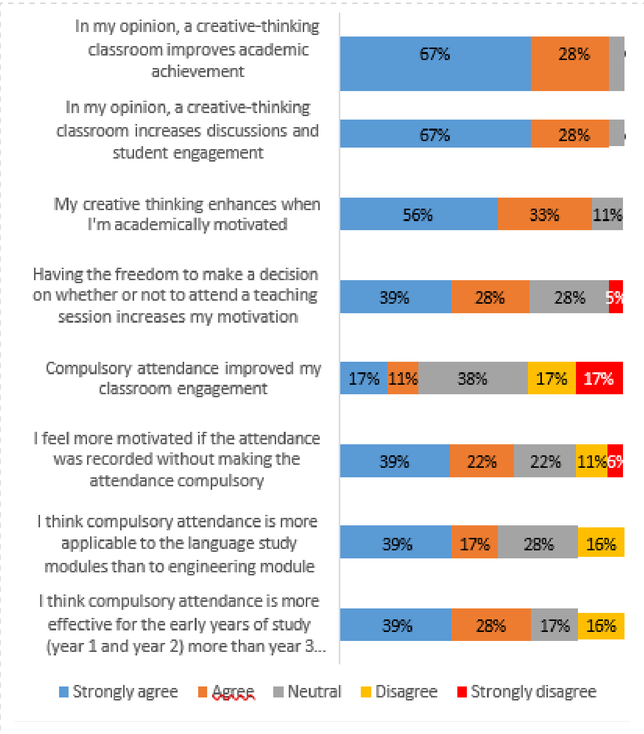

FIGURE 6: Student motivation and academic achievement

To further learn about students' motivation and how this influences their academic achievement, 89% of the students either strongly agree or agree that their creative thinking enhances when they're academically motivated. It also turns out from their response that the majority (95%) of them think that such a creative-thinking classroom environment increases their discussions and engagement, improving academic achievement. This is commensurate with previous research demonstrating how engineering students defined classroom engagement [18].

D. Student's Behaviour

To investigate the students' behavior towards classroom attendance, students were asked how they would spend their time if they decided not to attend. As per the response in Figure 7, 66% of the students either strongly agree or agree that they prefer to spend their time on more valuable tasks when they feel no value in attending a particular class. 28% of the students agree they think they're more likely to check non- class-related websites or use a text platform to chat with others during class time, while the same percentage also disagreed with the statement. 39% of the students agreed they attend to achieve high marks, against 11% disagreed, while 45% of them agreed they regularly attend to avoid feeling guilty or ashamed, against 16% disagreed.

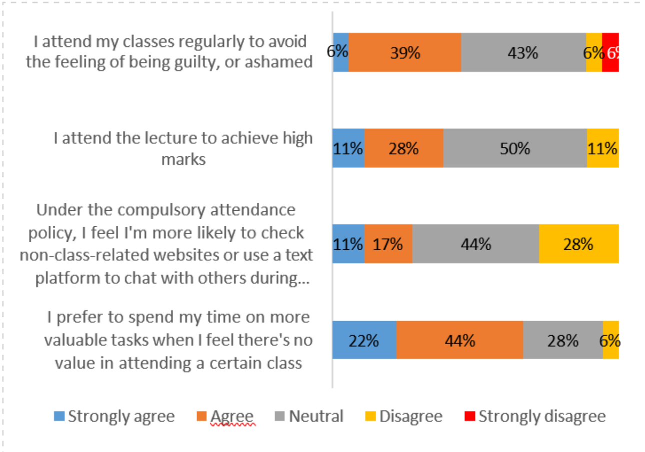

FIGURE 7: Students' behavior towards classroom attendance

VII. CONCLUSION

In this paper, a pilot study was made on a group of final-year engineering students. The study was motivated by the notable students' engagement in an optional engineering module before a compulsory attendance policy became effective. It turns out from the student survey that having an efficient and convenient system to record classroom attendance is beneficial for both students and their lecturers. On the other hand, there is a risk of demotivating students of high engagement if the compulsory attendance policy is applied equally among all programs and years of study. Instead, to improve academic achievement, a creative thinking classroom environment should be maintained to enhance discussions and student engagement. The study also found that engineering students become further motivated toward classroom attendance when some class time focuses on giving them tips and advice on their current and future study, time management, and skill development.

REFERENCES

[1] Newman-Ford L, Fitzgibbon K, Lloyd S, Thomas S., "A large-scale investigation into the relationship between attendance and attainment: a study using an innovative, electronic attendance monitoring system," Studies in Higher Education, vol. 33(6), pp. 699–717, December 2008.

[2] St Clair KL., "A case against compulsory class attendance policies in higher education," Innovative Higher Education, vol. 23(3), pp. 171– 80, March 1999.

[3] Fryer LK, Ginns P, Howarth M, Anderson C, Ozono S., "Individual differences and course attendance: why do students skip class?," Educational Psychology, vol. 38(4), pp. 470-86, April 2018.

[4] Shaban S, Magzoub ME, Elzubeir M, Shaban OH, Alsuwaidi AR, Al- Houqani M, Basheer A, Mohammed ZN, El-Jaily W, Mohamed AF., "Developing a student attendance app using QR codes: educational and practical considerations," International Journal of Technology Enhanced Learning, vol. 13(1), pp. 92–10.

[5] Macfarlane B., "The surveillance of learning: A critical analysis of university attendance policies," Higher Education Quarterly, vol. 67(4), pp. 358–73, October 2013.

[6] Méndez Suárez M, Crespo Tejero N., "Impact of absenteeism on academic performance under compulsory attendance policies in first to fifth year university students," Revista complutense de educación, vol. 32(4), pp. 627–637, May 2021.

[7] Horn PM, Jansen AI., "An investigation into the impact of tutorials on the performance of economics students," South African Journal of Economics, vol. 77(1), pp. 179–89, March 2009.

[8] Menard K, O'Shaughnessy B, Payne A, Kotlyachkov O, Minaker B., "The Effectiveness of Tutorials in Large Classes: Do They Matter?," Higher Education Quality Council of Ontario. 2015.

[9] Sloan D, Manns H, Mellor A, Jeffries M., "Factors influencing student non-attendance at formal teaching sessions," Studies in Higher Education, vol. 45(11), pp. 2203–16, November 2020.

[10] Paisey C, Paisey NJ., "Student attendance in an accounting module– reasons for non-attendance and the effect on academic performance at a Scottish University," Accounting education, vol. 13, pp. 39–53, December 2004.

[11] Stanca L., "The effects of attendance on academic performance: Panel data evidence for introductory microeconomics," The Journal of Economic Education, vol. 37(3), pp. 251–66, July 2006.

[12] Marburger DR., "Absenteeism and undergraduate exam performance," The Journal of Economic Education, vol. 32(2), pp. 99–109, January 2001.

[13] McCool R, Kelly S, Maguire M, Clarke D, Loughran D., "Factors which influence the academic performance of level 7 engineering students," All Ireland Journal of Higher Educationvol, vol. 7(2), June 2015.

[14] Obeidat S, Bashir A, Abu Jadayil W., "The importance of class attendance and cumulative gpa for academic success in industrial engineering classes," World Academy of Science, Engineering and Technology, pp. 1192–1195, 2012.

[15] Moldabayev D, Menicucci JA, Al-Zubaidy S, Abdulaziz N., "Attendance, performance and culture experience of the school of engineering, Nazarbayev University-an update," In2013 IEEE Global Engineering Education Conference (EDUCON), pp. 5–10, March 2013. IEEE.

[16] Büchele S., "Evaluating the link between attendance and performance in higher education: the role of classroom engagement dimensions," Assessment & Evaluation in Higher Education, vol. 46(1), pp. 132–50, January 2021.

[17] Kahu ER., "Framing student engagement in higher education," Studies in higher education, vol. 38(5), pp. 58–73, June 2013.

[18] Heller RS, Beil C, Dam K, Haerum B., "Student and faculty perceptions of engagement in engineering," Journal of Engineering Education, vol. 99(3), pp. 253–61, July 2010.

[19] Welsen S., "Impact of Blended Learning on Engineering Student Attendance Post COVID-19," In2021 World Engineering Education Forum/Global Engineering Deans Council (WEEF/ GEDC), pp. 88–94, November 2021. IEEE.

Technical papers

A methodology for integration of project based learning into core engineering courses

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***Abstract* — In this paper, we propose a paradigmatic shift in conventional engineering education curricula, transforming out of the currently widespread and common conventional chalkand-talk lecture based pedagogical approaches, which are also accompanied by attendant and limited assessment methods of traditional problem sets and exams. We suggest that engineering programs and curricula need to implement a number of substantive changes to update and upgrade their curricular and programmatic approach to ensure that the programmes will indeed be able to create transformative thinkers and creative problem solvers who will address the critical challenges facing humankind including catastrophic climate change, nuclear disaster, and the unsustainable degradation and devastation of the human, social, and natural environments. These faculty and curricula will embrace service learning, incorporate and integrate project based learning (PBL), engaging students in open ended design projects and thinking. In this paper, we demonstrate a rigorous pedagogical approach and sequential method through which PBL can be integrated into core engineering courses. The paper demonstrates the engagement of students through the provision of substantive feedback on well-defined and well-spaced Initial, Preliminary and Interim Progress reports. The paper shows that this pedagogical approach leads to the successful development and submission of Final Project Reports and Final Group Oral Presentations that address overall learning outcomes and prepare students to be transformative problem solvers**

Keywords — Engineering pedagogy, service learning, project-based learning, engineering curricula, Engineering Education

I. INTRODUCTION, BACKGROUND AND MOTIVATION

Engineering educators have an ethical responsibility to nurture and develop the coming generations of critical and innovative thinkers who will be the problem solvers capable of not only taking on the grand engineering challenges facing humankind but also of developing the innovative technologies, products and processes that will address the critical sustainable development goals that humankind need to address and achieve in order to meet the holy grail of social justice.

The state of pedagogy and pedagogical approaches in engineering education appears, for the most part, to be stuck in old models that no longer address current needs [7]. There are exceptions, such as the Olin School of Engineering, but for the most part, engineering curricula (and faculty) emphasize theory over practice, rely on a lecture and problem/set exam approach, and are embedded in the pipeline model with sequences of courses in math and science that students must take resulting in many students being precluded, not just excluded, from getting an engineering degree, and the implications this has for equity. The need for transformative change in engineering curricula has been recognized and discussed before [1], including curriculum redesign, course redesign, including ability to omit irrelevant material from course syllabi with feeling neither that we have short changed students nor that we let student's get off easy [13].

Project Based Learning (PBL) is a teaching method in which students learn by actively engaging in real-world and personally meaningful projects. PBL is a teaching method in which students gain knowledge and skills by working for an extended period to investigate and respond to an authentic, engaging, and complex question, problem, or challenge. Students work on a project over an extended period – from a week up to a semester or longer – that engages them in solving a real-world problem or answering a complex real question. Students then demonstrate their knowledge and skills by creating a public product for presentation to a real professional audience of their peers. Benefits to students are broad and deep and have been highlighted before [13].

Service Learning (SL) is an academic and/or curricular activity that is both course based and credit-bearing, and that includes two major components: engagement of students in a self-selected, driven and planned, but professionally and academically supervised and mentored, service activity, and an opportunity and requirement to engage in scholarly reflection and writing on the service activity in an academic context [2,3]. Service learning has been deemed of great value to a diverse set of stakeholders, delivering benefits of academic and experiential nature to students, faculty, community partners, and society in general. It has been shown over the past several decades that SL experiences promote independent and critical thinking skills and greatly improve educational outcomes [4,5]. Earlier work has demonstrated use of SL [8] through extension of Engineers Without Borders project activities into academic service-learning experiences [9] including implementation of a renewable energy project through service learning tied to a broader research project [10].

II. AIM AND RESEARCH QUESTION

In this paper, we propose a paradigmatic shift in conventional engineering education curricula, transforming out of the currently widespread and common conventional chalk-and-talk lecture based pedagogical approaches, which are also accompanied by attendant and limited assessment methods aside from traditional problem sets and exams. We suggest that engineering programs and curricula need to implement a number of substantive changes to update and upgrade their curricular and programmatic approach to ensure that the programmes will indeed be able to create transformative thinkers and creative problem solvers who will address the critical challenges facing humankind including catastrophic climate change, nuclear disaster, and the unsustainable degradation and devastation of the human, social, and natural environments.

The paradigmatic shift will involve the integration of Project Based Learning (PBL) into all engineering courses, specifically shifting the teaching and learnig model from one of students regurgitating theories that were delivered to them in lecture, while redoing problem sets assigned out of textbooks, either in an assignment or in a test, to a teaching and learning model where the focus is a project that the students have to identify, research and define, and then develop potential solutions for the same.

III. METHODOLOGY

In the core Introduction to Chemical Engineering Design course, as part of the requirements for the course, students formed design teams comprised of a maximum of four (4) students. This Design Teams were tasked with taking on a project that identified a community-based problem and were charged with researching and studying the situation to develop a clear understanding of the problem as a "Primitive" problem, then devolve the primitive problem into the component specific problems, and develop a comprehensive and broad based solution to this problem. Students were told that the community-based problem the team identified should be real – it could be local, regional, national, or international and remote – but the community and the problem needed to be comprehensively and rigorously documented through field orlibrary research. Students were told their project could forexample, investigate a particular chemical industry, chemical process, or other significant chemical incident and the attendant consequent community-based problem(s) that ensue from the operation of the chemical industry or the consequence of the chemical incident.

The student teams work on these projects throughout the semester. The Initial Report itself involves the students engaging with their classmates as they form their self-selected project teams. The Initial Report is required three weeks into the semester, when the students have already had a minidesign project that they were assigned to groups to develop and execute, and so by the third week they have sufficient familiarity with specific classmates to form their group.

The group now has three weeks to develop and submitt a Preliminary Report as they identify a community-based problem; feedback to the groups include assessment of the suitablity of the community problem and suggested approaches to solution. The format and content for the Initial and Preliminary Project Reports are shown in Table 1. Tables 1 – 3 will be presented as a model method for PBL implementation.

Following receipt of feedback from the Preliminary Report, each student team has a month to work to develop the Interim Progress Report (IPR). The Interim Progress Report are developed after the student teams conduct extensive research to understand the background and contextualize the problem in the community and work to develop several potential approaches to solve the problem they have identified. Through this whole process, they are receiving rigorous review and feedback from the professor at each stage. The rigorous review and feedback is provided to each student team/group in breakout group meetings during class time, providing ample time for discussion, questions and clarifications for each entire team in a group setting.

TABLE 1: *Initial and preliminary report content and format*

1. **Initial Report (IR):** Students choose teams, research possible community problems and make an initial problem/project selection. Submission includes identification of team members including their signatures acknowledging joining the team and tentative community problem selection.
2. **Preliminary Report (PR):** Following selection of the community problem and submission of the Initial Report, student teams work to prepare preliminary report:

Preliminary Report Format

Maximum length 3 - 4 pages tds

The report text and content should be typed, double spaced and the content structure and format should be as follows:

A. Page 1: Cover Sheet: Course, Instructor, Date, Deliverable Title, Team Name; Team Members: All team members should be listed with name, and ID No. Below each Name, there should be a personal statement (maximum 2-3 sentences) describing and outlining your contribution to the project. This statement must be esigned by that team member
B. Page 2: Tentative Title of Project: This may be modified prior to the final submission.
C. Page 2 – 3: Summary description of the community-based problem your group has identified, researched and documented, and a brief summary and tentative outline of your proposed solution or solutions.
D. Page 4: Expanded List of References/ Documentation of field research your team consulted or conducted.

The Interim Progress Report format and content is shown in Table 2 and will be presented as part of the model PBL implementation method.

TABLE 2.: *Interim progress report content and format*

3. **Interim Progress Report (IPR):** Following submission of the PR, the student teams are provided detailed feedback and then continue independent and group research and project work to develop the IPR.

   Interim Report Format - Maximum length 3-5 pages
   For your project report, all student teams are required to submit an Interim Progress Report:

   A. Cover Sheet including Course Name and Number, Professor, Interim Project Report, Title of Project, Group ID and Team Name, Team Member Names and ID's, Team Member Accountability and Responsibility Statement (2-3 sentences) with signature.
   B. Tentative Title of Project: This may be modified prior to the final submission, as long as it is in keeping with your design projects' initial overall goals and objectives, or after consultation with the Prof.
   C. Expanded Outline of Report (2 page maximum): The outline should include a brief (1 to 2 sentence) description of each component of the report, presented in clear rigorous Outline Format.
   D. An expanded summary of your research and team accomplishments to date (1 page max) The purpose of the summary is to update yourselves and me on your progress and provide material for which you can get feedback and comments.
   E. An Expanded Reference List. This must include references other than the one you may have initially consulted.

The feedback to their Interim Progress Report includes the charge to now develop their team's written Final Project Report and their Final Project Oral Presentation, to be submitted and made, respectively, at the end of the semester.

The Final Project Report and presentation are now the final product that the student teams will develop and produce and then finally present through submission of the Final Report as well as a group presentation of the project. Table 3 outlines content and format for the Final Report and will be presented for discussion.

TABLE 3: *final project report content and format*

4. **Final Project Report and Presentation (FPR&P):**

   FINAL PROJECT REPORT: SUBMISSION GUIDELINES TOTAL PAGE LIMIT: Maximum Twenty (20) Pages, tds SUGGESTED OUTLINE: The following is only a suggested outline; Include a Table of Contents in your final report.

   I. **INTRODUCTION, PROBLEM STATEMENT AND CONTEXTUALIZATION (2-3 Pages):**
   A description of the situation and a statement of the environmental problem, including a discussion of the technical problems and the socio-political and economic issues that need to be considered, as well as your informed consideration of same.
   II. **PROBLEM REVIEW AND CONTEXTUALIZATION (3-4 Pgs):**
   A thorough review of the problem, the environmental research conducted into the problem and contextualization of the problem in terms of the community, the location etc.
   III. **PROPOSED SOLUTION AND POSSIBLE MODEL (6-8 Pgs)**
   A description of your technological approach to the problem, a brief background of the technology that you will utilize, a description of the form that the technology will take and how it will be implemented. A diagram of the proposed solution will be useful. A description of the model you are using to assess your proposed technology, and the calculations that indicate that the model of your proposed solution will actually achieve the environmental objective that is required. These could be actual or from research.
   IV. **DISCUSSION AND CONCLUSION (4-6 Pgs)**
   A discussion of your solution and of the social, economic, and political implications the solution has for the communities that are affected by your proposed solution.
   V. **APPENDICES AND OTHER INFORMATION (Not in Page Limit)**
   Bibliography and References for your report: Note all references in your bibliography must be cited in the body-text of your report.

IV. DISCUSSION AND FINDINGS:

Integration of PBL into the core engineering course has been successful, as demonstrated by student learning outcomes over the past two decades, that have been documented in successful ABET accreditation process site visits to the program. The integration of PBL has been through a sequential set of submissions from student teams, where each submission is followed by rigorous feedback and comment from the professor. This method of execution of a PBL project, by staging student team work through initial, preliminary, interim progress and final reports enables the student team to leverage this continuous review and feedback to develop outstanding written final project reports as well as make excellent oral group presentations. The latter have been conducted smoothly virtually and on line through Zoom®.

This pedagogical approach and methodology demonstrates a straightforward and rational but rigorous integration of PBL into a core engineering course. The implicit and evident success of this PBL integration method needs to be rigorously researched through comparative evaluations of different students cohorts and in different course types, Student outcomes evaluations suggest this pedagogical approach could be employed across the program.

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REFERENCES

[1] Apte, Poornima,(2021) "Solving for Equity," Prism, ASEE, January 2021.

[2] Bringle, RG and JA Hatcher,(2007) "Civic Engagement and Service Learning: Implications for Higher Education in America and South Africa", Education as Change, 11 (3) Dec 2007, Special Issue: CSL

[3] Bringle, R. G., Phillips, M. A., & Hudson, M. (2004). The measure of service learning: Research scales to assess student experiences. Washington, DC: American Psychological Association.

[4] Eyler, J., & Giles, D. E. (1999). Where's the learning in servicelearning? San Francisco: Jossey-Bass.

[5] Eyler, J., & Giles, D. E. (2001). At a glance: What we know about the effects of service-learning on college students, faculty, institutions, and communities, 1993-2000. Retrieved from Campus Compact Web site: http://www.compact.org/resources/downloads/aag.pdf

[6] George, S., R. Menon, P. Thevanoor and J. Tharakan, "Service Learning in Engineering Education: A Study of Student-Participatory Survey for Urban Canal Rejuvenation in Kochi, India," Procedia Comp. Sci. 172 (2020) 263-269.

[7] Sorby, S., N. Fontenberry and G. Bertoline, "Stuck in 1955, Engineering Education Needs a Revolution," Issues in Science and Technology, National Academy of Sciences, September, 2021.

[8] Tharakan, J., "Institutionalizing a Student-Centered Community-Based Service Learning Engineering Education Experience," Proc. Int'l Engineering and Technology Education Conference, IETEC 2011, Kuala Lumpur, Malaysia, January 2011.

[9] Tharakan, J, "Potential for Implementing Renewable Energy Projects through Service Learning Engineering Education Experiences," in Momoh, J. (ed) Proc. Intl. Conf. Power Systems Operation and Planning – Sustainable Energy Development, pp.178-183, Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya, January 2012.

[10] Tharakan, J, M Mitchell, J Moore and G Jenkins, "Design of a Combined Solar Energy System for a Remote Flux Tower and a Rural Community," in Tharakan, J. and J. Trimble (eds) Proc. 3rd Int'l. Conference on Appropriate Technology, Kigali, Rwanda, November 2008(ISBN 978-1-60725-559-8), pp. 51- 58.

[11] Tharakan, J, "Using Educational Technology to Enhance Creative and Critical Thinking Skills through Open Ended Design Projects," J. Engineering Education Transformation, Vol 33, Jan 2020

[12] Tharakan J., S. George, R. Menon and P. Thevannoor, "Service Learning in a Graduate Environmental Engineering Program – Community Engagement, Knowledge and Technology Transfer for Capacity Building and Sustainable Development", Extended Abstract published in: Proc. 7th Int'l Conf. on Appropriate Technology, Victoria Falls, Zimbabwe, November 2016.

[13] Tharakan, J., "Re-Engineering Engineering Education for Sustainaable Development," Proc. 10th Int'l Conf. Appropriate Technology, November 24-27, 2022, Khartoum, Sudan

Technical papers

Engaging engineering mathematics students online: Tutoring using MS Teams

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***Abstract* — Uncommon in the South African higher education landscape, online learning came to the fore during the global pandemic. We present an account of the use of Microsoft Teams for hybrid mathematics tutorials in a one-semester Vector Calculus course at a South African university in 2022. Interviews with the lecturer, analysed through a Community of Inquiry lens, showed the lecturer's perspective of the design and experience for tutors and students. Our aim is to improve the design of future hybrid tutorials to ensure engineering students' capacity in mathematics is well developed, their communication skills are improved, and that they experience working in a team. Future research will evaluate students' and tutors' accounts of their experiences. Our findings raise awareness of the possibilities and potential difficulties when using Microsoft Teams for communication, teaching and learning mathematics.**

Keywords — Microsoft Teams, tutorials, hybrid learning, blended learning, community of inquiry, calculus, flexibility.

I. INTRODUCTION

If you were a fly on the wall in a university classroom, what would indicate that you had landed in a mathematics tutorial? Probably you would find students working in groups or a single group or individually. Explanations and questions would come from tutors and peers. Students would be engaged in assigned mathematics problems designed to help them form and assess their understanding of concepts previously covered in the course. Less commonly, you may find some students or tutors attending online.

Tutoring is a vital strategy for academic success [1], but it is an inherited concept passed down over generations. We may be at risk of somewhat complacently accepting the tutorial status quo without questioning its pedagogical appropriateness for facilitating student engagement in our context. When the Covid-19 pandemic-imposed isolation, limited venue capacity and reduced in-person contact at universities, lecturers were forced to rethink these taken-for- granted learning spaces.

At our university, the usual in-person tutorials for mathematics students were replaced by tutorials on an online platform in March 2020. When in-person classes with reduced numbers were allowed on campus during 2021, a hybrid tutoring setup was introduced. The design of this interactive mathematics activity had to be carefully considered to ensure success of student engagement and student learning. We reflected on what was required to provide an authentic and effective learning experience for our students. Would students be open to this new way of doing?

Would they consider whether the effort to learn a new system would be beneficial to their learning? How would we entice them to see value in their participation? What challenges would they face and how would we mitigate those challenges?

If students were to work together under the guidance of a tutor where some students would be online, we needed to consider how to create a community of learning. The trigger to engage students in participating would be very important. The lens of the Community of Inquiry (COI) framework suited this study as it was designed to preserve the quality of education when moving an in-person course online [2]. The basic ideas of 'community' and 'inquiry' foreground the social nature of knowledge construction and the desire of individuals to construct meaning. The description of a COI as 'a cohesive and interactive community whose purpose it is to critically analyse, construct, and confirm knowledge' [3 p.9] positions this theory within the learning theory of constructivism [4]. The very nature of mathematics knowledge as developed through active participation in a community [5] gave us the idea that students would need to be inquirers to enter this community and to experience it as valuable.

Much has been written on COI in engineering education with hundreds of publications emerging, not surprisingly, in the past two years in line with the rapid shift to online learning. However, less common is research that focuses on the teaching and learning of mathematics in engineering education. Noteworthy research [6, 7] uses the COI framework for the design of activities in mathematics education.

Quinn and Aarão [8] experimented with a variety of online and in-person activities for engineering mathematics students, concluding that (1) in-person learning activities helped students self-regulate their mathematics learning, and (2) having a record of questions and answers with an online tutor provided a way for "key learning conversations" to be accessed by other students asynchronously [8 p.939]. Similarly, Johns and Mill [9] recommended both synchronous

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and asynchronous support as best practices for mathematics tutorials under the constraints imposed by the Covid-19 pandemic. The functionality of channels, folders and pages on Microsoft Teams (hereafter Teams) provided an easy and efficient way to store written interactions with tutors. Further factors that pulled us towards Teams as a platform were Ismail and Ismail's [10] finding that first-time users found Teams user-friendly, and that we had the added advantage of input from our university's technology support staff on training students to use Teams. We acknowledge that without institutional support in the form of an online learning management system, the integration of Teams may have resulted in less positive reactions to Teams, as found by a study from Egypt [11].

We were less sure of how to handle the challenge of facilitating student-student interaction and group work in an online space [12] within the restricted time of the weekly hybrid tutorial. We embarked on a pilot study of tutoring practices in a second-year Vector Calculus course for engineering students at a South African university. Students find the transition from first-year calculus to second-year multivariable calculus challenging, emphasising the need for consistent engagement with the content and interaction between students and their tutors. The engineering students we teach need to master multivariable calculus to be successful with their other engineering courses. In addition, the collaborative problem-solving environment created by the tutorials mimicked the world of work they would enter upon graduation and which they should build their capacity to negotiate. The aforementioned reasons foreground the aim of this study, its rationale and the relevance for engineering education.

II. THE TEAMS MATHEMATICS TUTORIAL EXPERIENCE

Tutors are a fundamental aspect of the tutorial experience whether it be face to face or online. Therefore, tutors with the relevant mathematics content knowledge were chosen and "trained" with respect to online interaction and the necessary pedagogical skills [13]. The tutors were given access to the university's Teams training meetings one week before the semester began. These meetings gave an overview of how Teams worked and how it could be used within a tutorial context.

The Vector Calculus course is usually taught over a 12- week period with mainly in-person activities including daily lectures, and weekly tutorials. In addition, an online platform facilitated online assessment and included access to online resources.

During the semester, weekly meetings between the course convenor and tutors were held to share tutors' experiences and brainstorm common problems they experienced when trying to engage students in online tutorial participation. These weekly meetings provided regular opportunities for tutor training to continue. A lesson page was set up in the class Team weekly with exercises. The format of the tutorials included an expectation that students would attempt these exercises in preparation of the synchronous Teams tutorials. Preparation by students was a crucial factor on which their active participation in the tutorial hinged. Failing to do the lesson page exercises would result in students being ill-prepared to attempt the tutorial questions presented at the synchronous tutorial. If a topic was not studied before the tutorial, the tutorial would not serve its purpose.

The Teams platform keeps track of all the activities of the students who attend tutorials online allowing the convenor to keep a register of active students in the course and to alert who the non-attendees are. In the Class Notebook, tutors created folders for each weekly tutorial with distinct pages for each tutorial question (Figure 1). These were live collaboration spaces for students to ask questions during the weekly one-hour tutorial sessions on Tuesdays, Wednesdays, and Thursdays.

Having a predefined Class Notebook space on Teams using tutorial and question numbers made for easy asynchronous engagement. Students could write or paste their questions and their contributions into the Class Notebook space. Tutors would provide hints for tutor problems based on their past experiences of tutoring in the course and these would be added to the Class Notebook space (Figure 2).

Tutorials were mandatory but could be attended online or in person. Students could later explore these spaces asynchronously if they had been unable to attend the tutorial, underprepared or unable to engage with the concepts under discussion during the tutorial, or when they were revising concepts.

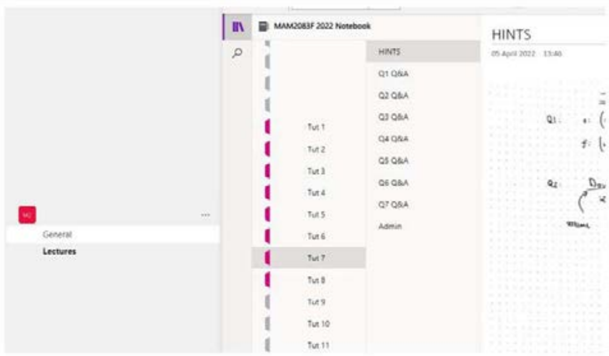
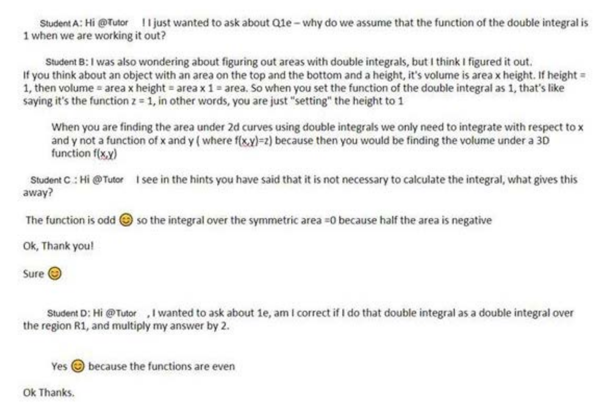


FIGURE 1: *Changes archived in structured threads on Teams*



Student A: Hi @Tutor ! I just wanted to ask about Q1e – why do we assume that the function of the double integral is 1 when we are working it out?

Student B: I was also wondering about figuring out areas with double integrals, but I think I figured it out.
If you think about an object with an area on the top and the bottom and a height, it's volume is area x height. If height = 1, then volume = area x height = area x 1 = area. So when you set the function of the double integral as 1, that's like saying it's the function z = 1, in other words, you are just "setting" the height to 1

When you are finding the area under 2d curves using double integrals we only need to integrate with respect to x and y not a function of x and y (where f(x,y)=z) because then you would be finding the volume under a 3D function f(x,y)

Student C : Hi @Tutor I see in the hints you have said that it is not necessary to calculate the integral, what gives this away?

The function is odd 😊 so the integral over the symmetric area =0 because half the area is negative

Ok, Thank you!

Sure 😊

Student D: Hi @Tutor , I wanted to ask about 1e, am I correct if I do that double integral as a double integral over the region R1, and multiply my answer by 2.

Yes 😊 because the functions are even

Ok Thanks.

FIGURE 2: *Interaction between learners and tutors*

Figure 3 and Figure 4 represent activities built into tutorial questions to get students to explore Teams. The tagging a tutor feature was an essential skill that allowed students to access tutors outside tutorial sessions remotely. Tutors could respond during their work hours or when convenient. Journaling and engaging with tools to visualise the concepts in one space were promising features of the Teams Class Notebook that students regrettably under-utilised.

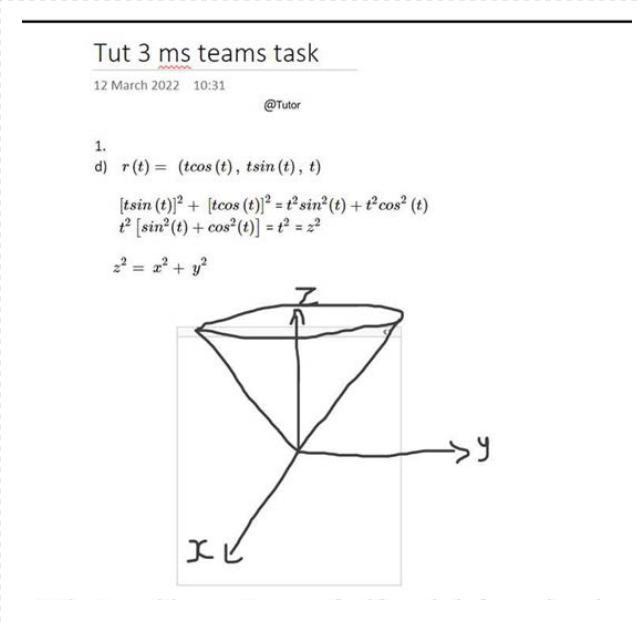


FIGURE 3: Private archive on Teams of self-made information sheets for possible 'currency exchange' in later inquiries

Teams provided a storage facility for screenshots of images drawn with tools such as GeoGebra 3D. These archives of 'mined currency' were available for later exchanges of inquiry with tutors or fellow students.

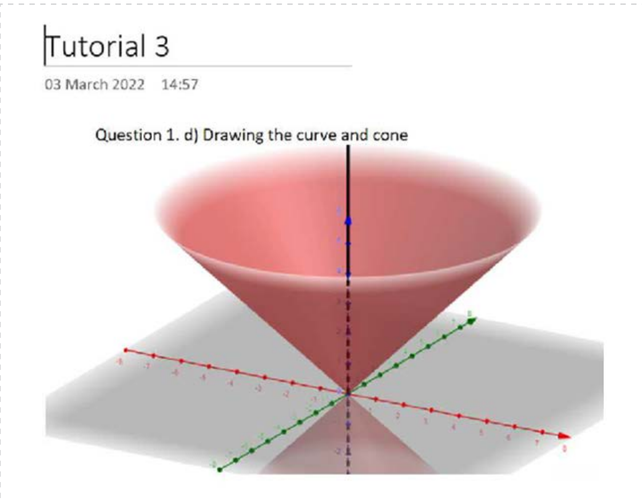


Fig. 4. GeoGebra images pasted in Teams, used in a student's private navigation of inquiry.

III. METHODOLOGY

To address the issue of adapting and enhancing the design of the mathematics tutoring experience for students and tutors, we posed the research question: From the perspective of the lecturer, how did hybrid tutorials for engineering mathematics on Teams develop cognitive presence, teaching presence and social presence?

The methodology of the entire project, of which this research is a part of, is design-based research, with iterative cycles of design, enactment, analysis, and redesign in an authentic setting [14], and the goal of producing design principles for hybrid mathematics tutorials. Data for this study was collected via semi-structured interviews with the convenor-lecturer (author 3) on their reflections of the implementation of Teams. The interview was conducted by author 1 whilst author 2 recorded the interview. Analysis of the transcribed "spoken language" followed the steps of thematic analysis [15], forming codes under the themes defined by the community of inquiry framework [2]. Ethical clearance for the project was obtained prior to data collection.

IV. FINDINGS AND DISCUSSION

The findings of the research revealed overall that tutorials using Teams encouraged student engagement with the concepts taught and supported students learning in mathematics. Interview data gave reasons from the perspective of the lecturer on why students felt encouraged to participate, how engagement could have been improved, and what students found difficulty with. Whilst the Teams platform was initially new to students, it appeared to have benefitted their understanding of mathematics through enhanced engagement due to comments and pictures of workings from students, tutors and lecturer being more available. Importantly it had a layer of accountability that was necessary to 'force' students to engage, requiring students to be present and participate.

This is an ongoing research project, and we present preliminary findings of the lecturer's perspective through the COI framework.

A. Inquiry - currency to enter the community

Students who had questions about the course content were motivated to attend and participate in the online tutorials. On the other hand, other students felt compelled to attend only to satisfy a course requirement and were passive participants. Some students were not up to date with lectures and did not attend at all. A student's willingness to be present in tutorials is central to learning in mathematics tutorials. In some cases, their 'presence' would have required them to be willing to be vulnerable in the spotlight of the Teams tutorial space by asking questions without fear of judgement from peers and tutors. Another aspect equally important for online learning is that students must prepare for the tutorial. The tutorial threads on Teams reveal that valuable engagement took place for students who brought 'currency' to exchange, in the form of questions, suggestions and resources such as diagrams. If students do not have a question or a struggle to grapple with, the benefit from explanations from their peers or tutors will be reduced [16]. It seems that for engineering students particularly, the tutorial design needed to trigger their participation and sustain their involvement. The level of difficulty of the tutorial questions was pitched higher than the pre tutorial exercises and this made it unlikely that many students would complete all questions if they only started them in the tutorial. In this context, it is important for students to be given the tutorial problems days before the event for them to attempt and reflect on their learning in preparation for tutorials sessions. Future iterations of such tutorials will need to consider this to improve student engagement and participation and contribute to effective learning in the course.

B. Community - organically develops out of a well-created Teams space

In addition to inquiry, community is foregrounded in the COI framework. In the context of online tutorials, a community is formed of students with common mathematics 'struggles' and of tutors who facilitate their engagement to address such 'struggles'. Students need to feel that this is a safe space and that they will not be judged for the questions they ask in tutorial sessions. A greater sense of collaboration and stronger community are advantages in a synchronous mode. In an asynchronous tutorial, students rarely feel part of the community, and their participation - recorded, as in the Teams Class Notebook - are a one-way consumption of knowledge. These students can be part of the community when they are ready if it is not too late in the progress of the semester course. Although any participation in the tutorials is better than none, it is questionable to what extent an asynchronous participant singly engages with the concepts and what depth of understanding they reach.

Students find each other in the Teams Class Notebook spaces for specific mathematics problems from tutorials, depending on the inquiry or problem they have encountered. The question-level pages were environments where students could collaborate with each other and tag the tutor when needed. The lecturer planned for students to create their own pages. However, students did not show a willingness to do this and as an afterthought this may have resulted in too many places on Teams to navigate to.

Synchronous tutorial sessions were recorded as videos which have a 30-day storage limit on Teams, so students need to engage with the recordings within the restricted time frame. A demand for student presence is central to the creation and success of a tutorial community. The time limitation keeps students on task, by imposing a time allowed for catching up as the course is a semester course.

C. Social presence

Social presence appears more prevalent in cases where students have met previously in person. This worked positively for those students who attend the weekly initial in- person tutorial. At subsequent online tutorials students could see each other via video and the familiarity appeared to make them more engaged in their learning. Teams allows the lecturer to connect with students audibly using the chat function to solve administrative problems or difficulties with the course content. Sometimes students needed pep talks and this chat feature allowed for one-to-one communication between lecturer and student.

Synchronous participation promoted collaboration and community building within the cohort and the camaraderie was evidenced by students helping each other. Students who chose asynchronous participation, or private interaction with tutors by tagging them, seemed not to have experienced the full extent of this learning community. Since asynchronous engagement does not necessarily show who posed or answered questions, this anonymity meant that the discussion could not continue further either online or in an in-person setting. However, a benefit of having the two modes of delivery was that in-person students could choose not to be anonymous to ask their questions on Teams and in this way could indirectly connect with asynchronous students who accessed the recordings later.

Social presence was affected by timing of course events. Before tests are to be written and when students have a higher cognitive demand there is a preference for in person tutorials rather than online tutorials.

D. Cognitive presence

The cognitive presence was reflected in both the synchronous and asynchronous modes of the tutorial and suited a diversity of learning styles and learning pace. The synchronous mode enabled students to ask questions in real time and have their responses in real time. Students could learn at their own pace and the tutorial dialogues were stored for them to revisit concepts asynchronously. Some students proactively created their own collaboration pages and, in some cases, private pages on Teams to do their work. However, when students do not engage while attending online, it is not easy to gauge their cognitive engagement. The lecturer seeks to explore questions in weekly tutorial tests to encourage metacognitive reflection by students in future iterations of the hybrid tutorials.

Posting queries on Teams required students to formulate a question out of their mathematics workings and doing so reinforced their engagement with concepts. In addition, recognising or being alerted to other students' misunderstandings added to their learning in this course. Students found Teams helpful to their progress with tutorial questions as tutors could be tagged whenever aid was needed. It was easy to send pictures of their work to the relevant question page on Teams for tutors and other students to respond to and collaborate on. The turnaround time for responses from tutors in synchronous tutorials was short, and this served as an important factor for online synchronous participation in tutorials. In addition, the lecturer added photographs of the work queried by students in the in-person tutorials to chats in Teams for other students to access and engage with. This allowed for possible follow ups and ideas that might arise after the event, making learning continuous and not a one-time event. Eventually this would be added as a resource in the Class Notebook feature of Teams if the discussion added depth and insight.

Learning to navigate Teams added to the cognitive load of the course for those students for whom it was 'alien'. We highlight an important finding of students choosing to attend online tutorial sessions with tutors whose home language matched theirs and we speculate that this not only increased their comfort in participation but also facilitated their understanding in mathematics. This interesting finding will need to be probed in future research.

E. Teaching presence

It appeared to the lecturer that students needed to understand the rationale for doing the pre tutorial exercises. The lecturer made an introduction video to explain how doing the exercises before tutorials would lead them to gain the confidence to engage with subsequent tutorial questions better. On reflection, smaller, more frequently posted videos might help students to understand the design of the tutorials. The challenge is to find an optimum number of videos for reinforcing the purpose and best practice for tutorial participation.

Simply providing tutorial solutions removes the struggle, and therefore removes the valuable inquiry or 'currency' contribution from students that is so important for effective tutorial engagement and participation. The strategy was to release tutorial solutions on Fridays, after the Tuesday to Thursday tutorials. The two-way interaction between student and tutor, which is prevalent in an in-person tutorial, needs to be replicated online. During in-person support, tutors can pick up on non-verbal cues regardless of what students might say. In weekly meetings, tutors reported on their realisation of how much they relied on their own gestures and facial expressions when explaining in-person, and that they had to bear that in mind when explaining via audio, writing on screen or recording a video. The teaching presence extended to tutors learning from each other on Teams by attending each other's hybrid Teams sessions to see how certain questions were facilitated. Additionally, tutors used WhatsApp to communicate with each other. Creating a private channel on Teams or on WhatsApp for tutors to chat about their tutoring journeys is an important feature of tutor development which will be explored in future iterations.

V. CONCLUSION

The overarching theme that prevailed after analysis of the lecturer's reflections was the need for and demonstration of flexibility. This is not surprising if students are viewed as individuals who learn differently. The theme of flexibility also confirms our belief that a one size fits all model of teaching and learning is far from ideal. The flexibility from using hybrid tutorials on Teams extended to catering for students' different learning styles (visual, auditory); tutor facilitation (online, in-person, different languages); the tutorials format (online, in-person), time (synchronous, asynchronous) and students' emotional and cognitive readiness to participate in tutorials. This research allowed us to interrogate our practice in mathematics tutorials prior to the Covid-19 pandemic and to reconsider how to integrate this new online tutorial implementation to best suit the learning needs of our students. This ongoing research holds potential for an improved provision of tutorials to not only ensure engineering students' capacity in mathematics is well developed, but their communication skills are improved, and that encourages working in a team.

The limited social dimension and additional cognitive demand on students and tutors initially of how to navigate Teams may discourage its optimal use. However, this can be mitigated and engagement can be made easier by the introduction of Teams in first-year courses for students to gain familiarity with the tool. Although Teams is not a strong substitute for in-person tutorials in mathematics, it does have value in its asynchronous mode, and is a viable platform for hybrid mathematics tutorials.

As we move into a post-pandemic world, we will have to rethink the value of tools such as Microsoft Teams. This is not to suggest that such tools replace in-person tutorials but rather that the best of both modes be optimally blended for the best possible experience for all our students' learning and success. Our initial research shows that Teams holds potential to deliver such an experience. Further research is necessary to formulate best practice for tutorial engagement in mathematics. The next stage of this research will be to incorporate tutor and student perspectives and investigate an efficient blending of in-person tutorials and Teams tutorials to engage students in learning mathematics for success.

REFERENCES

[1] B. D. Faroa, "Considering the role of tutoring in student engagement: Reflections from a South African University," J. Stud. Aff. Africa, vol. 5, no. 2, pp. 1–15, 2017.

[2] D. R. Garrison, T. Anderson, and W. Archer, "Critical inquiry in a text- based environment: Computer conferencing in higher education," Internet High. Educ., vol. 2, no. 2-3, pp. 87-105, 1999.

[3] D. R. Garrison, and N. D. Vaughan, Blended learning in higher education: Framework, principles, and guidelines, John Wiley and Sons, 2008.

[4] M. Ndlovu, "Revisiting the efficacy of constructivism in mathematics education," Phil. Math. Educ. J., vol. 27(April), 2013.

[5] J. Lave, and E. Wenger, Situated learning: Legitimate peripheral participation, Cambridge University Press, 1991.

[6] B. Jaworski, S. Treffert-Thomas and D. Hewitt, "Student Partners in Task Design in a computer medium to promote Foundation students' learning of mathematics," Int. Net. D. Res. Univ. Math. 2018, Apr 2018.

[7] M. Moradi, L. Liu, C. Luchies, M. M. Patterson, and B. Darban, "Enhancing teaching-learning effectiveness by creating online interactive instructional modules for fundamental concepts of physics and mathematics," Educ. Sci., 2018.

[8] D. Quinn, and J. Aarão, "Blended learning in first year engineering mathematics," ZDM., vol. 52, no. 5, pp. 927–941, 2021.

[9] C. Johns, and M. Mills, "Online mathematics tutoring during the COVID-19 pandemic: Recommendations for best practices," PRIMUS, vol. 3, no. 11, pp. 99–117, 2021.

[10] S. Ismail, and S. Ismail, "Teaching Approach using Microsoft Teams: Case Study on Satisfaction versus Barriers in Online Learning Environment," J. Phys. Conf. Series., vol. 1874, no. 1, pp. 012020, 2021, May.

[11] A. E. E. Sobaih, A. E. Salem, A. M. Hasanein, and A. E. A. Elnasr, "Responses to Covid-19 in higher education: Students' learning experience using Microsoft Teams versus social network sites," Sustainability, vol. 13, no. 18, pp. 10036, 2021.

[12] K. Jones, "'We had a good laugh together': using Teams for collaborative learning," J. Learn. Dev. High. Educ., vol. 28, no. 21, 2021.

[13] R. Walsh, "A case study of pedagogy of mathematics support tutors without a background in mathematics education," Int. J. Math. Educ. Sci. Tech., vol. 48, no. 1, pp. 67-82, 2017.

[14] F. Wang, and M. J. Hannafin, "Design-based research and technology- enhanced learning environments," Educ. Tech. Res. Dev., vol. 53, no. 4, pp. 5–23, 2005.

[15] V. Braun, V. Clarke, and N. Hayfield, "'A starting point for your journey, not a map': Nikki Hayfield in conversation with Virginia Braun and Victoria Clarke about thematic analysis," Qual. Res. Psyc,. vol. 19 no. 2, pp. 424-445, 2022.

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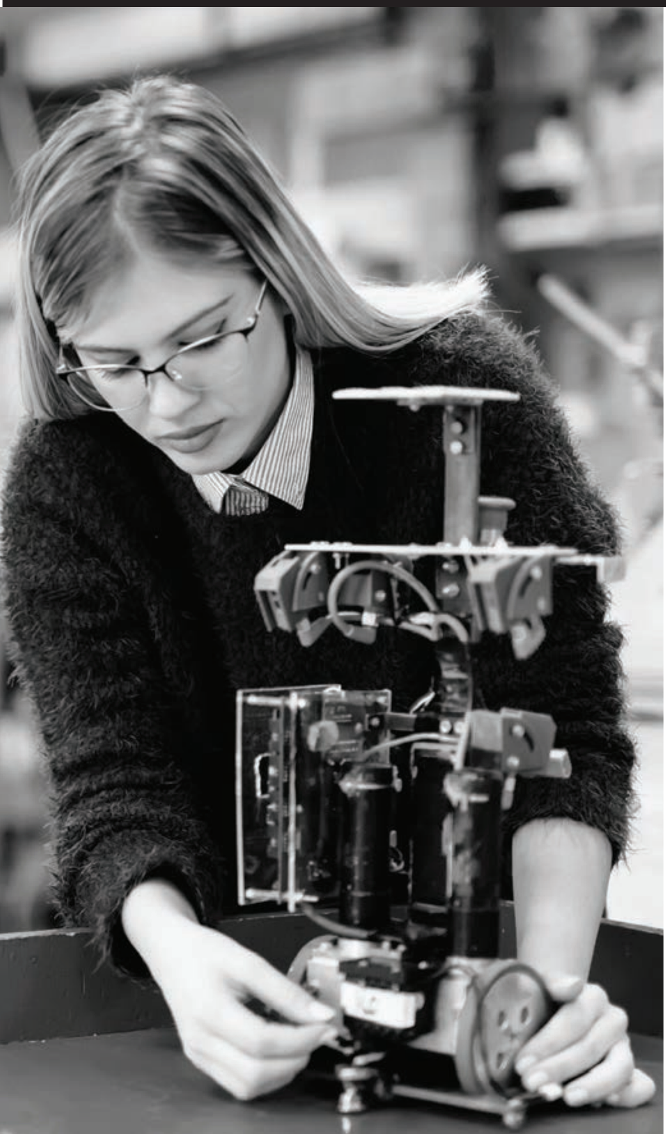

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