IC2EM'24
INTERNATIONAL CONFERENCE ON ENGINEERING EDUCATION AND MANAGEMENT

Proceedings of the International Conference on Engineering Education and Management (IC2EM'24)
Held on 23rd – 25th September 2024
In Palapye, Botswana

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International Conference on Engineering Education and Management (IC2EM'24)

Theme:

Enhancing Sustainable Quality Engineering Education for a Knowledge-Based Society

Organized by:

Botswana International University of Science and Technology (BIUST), Botswana

in collaboration with

Botswana Qualifications Authority (BQA), Botswana

and

Engineers Registration Board (ERB), Botswana

Venue:

Majestic Five Hotel, Palapye, Botswana

Dates:

23rd – 25th September 2024

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CONFERENCE PREFACE

International Conference on Engineering Education and Management (IC2EM '24)

THE CONFERENCE OBJECTIVES

The objective of the conference is to bring together professionals, academics, regulators, researchers, educators, managers, industrial collaborators, and policy makers engaged in the provision and management of quality engineering education to share their experiences and research outcomes on all aspects of Engineering Education. The theme of the conference will facilitate discussion and exchange of ideas on the status, accreditation matters, programme delivery, resource management, learner dynamics and provision of engineering education in a knowledge-based society. Comprehensive scholarly presentations and other events will be delivered during the conference. With its expected high quality, the conference will provide an interdisciplinary platform for professional bodies, education regulators, researchers, practitioners, and educators to present and discuss recent innovations, trends, and concerns as well as practical challenges encountered, and solutions proffered in the fields of Engineering Education.

THE CONFERENCE THEMES

Quality is a primary consideration in the provision of engineering education and should be given prominence during resource allocation, curriculum design and delivery of programmes to develop and promote a knowledge-based society. The interplay of accreditation, curriculum assessment, programme relevance and sustainability are usually challenging, and the situation now provides practitioners, academics, and policy makers with unique opportunities for collaboration to enhance internationalization of engineering programmes. The conference theme, enhancing sustainable quality engineering education for a knowledge-based society was conceived to facilitate lively discussions and sharing of practical experiences on the suggested topics.

THE CONFERENCE TOPICS

The topics to be covered during the conference are presented below. Articles, contributions or workshops on any topic or related issues will be considered by the organizers.

1. **Engineering Curriculum development, Implementation, and Evaluation**
    - Curriculum Design and Instructional Practices for Experiential Learning
    - Developing, Monitoring, and Assessing Engineering Graduate Skills / Profiles
    - Development, Design, and Innovative delivery of Engineering Curriculum

- Distance Learning, Continuing Education Methods, Technologies, and Assessment
- Endorsement Criteria of Curriculum and Registration of Engineers by Professional bodies

2. Quality assurance and management in Engineering Education

- Accreditation, quality assurance, evaluation, and standards
- Assessment and Testing in Engineering Education

3. Engineering Education Advances and Globalization

- Advances, Innovations, and New Technologies in Engineering Education
- Collaboration, Partnerships, and Internationalization of Engineering Education
- Engineering Education in Times of Uncertainty- Experiences and what have been learned.
- Engineering Education to promote Knowledge-based Economy
- Final Year Project Assessment and Evaluation
- Technology-enhanced Learning and Advanced Classroom Technologies
- Women in Engineering Education
- Laboratory and Engineering Design Experiences- on-site, online; at home and mobile labs
- Learner and Instructor Orientation and Dynamics
- Learning Resources to enhance Engineering Education
- Outcome Based Education- Assessment of programme and course outcomes.
- Problem and Project-based Learning
- Personalized learning
- Student Instructor exchange

4. Advances in Engineering Disciplines and Interdisciplinary Education

- Chemical Engineering Education
- Civil Engineering Education
- Computer Engineering and Computer use in Engineering Education
- Electrical Engineering Education
- Mechanical, Materials and Manufacturing Engineering Education
- Mining and Geological Engineering Education
- Energy Engineering, Power, and Green Technology Education
- Language and Communication in Engineering Education
- Nexus between Industry, Public sector, and Engineering Institutions to promote Learning and Entrepreneurship
- Future Trends, Changes, and Challenges in Engineering Education

- Simulation, Mathematical Applications, Modelling and Optimization for Teaching and Learning
- Design and Project Management in Engineering Education
- Risks and Uncertainties for Engineering Education and Engineering Enterprises

5. Advances in Research and Development and Industry-focused Education

- Research and Development in Engineering Education
- Smart Grid Education and Research
- Financing Models and Infrastructure development for Engineering Education

6. Education drive towards the 4th Industrial Revolution

- Digital Transformation and Changing Pedagogy
- IoT, AI in Engineering Education
- Virtual Reality and Augmented Reality as essential technologies for the transition of engineering education to Industry 4.0/ or 5.0
- Innovative Learning and Application of social media Technologies in Engineering Education
- Building resilience for drinking water safety in arsenic prone rural communities in the global south

LOCAL ORGANIZING COMMITTEE

MAIN COMMITTEE

- Professor M Tunde Oladiran (Chairman)
- Dr Vivekanandhan Chinnasamy (Secretary)
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- Ms Barbara Nabifo
- Ms Chizubelu Chinenye
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- Ms Kefilwe Mbizo
- Ms Dadiso Chikati

SUB COMMITTEES

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- Dr Badziili Nthubu
- Mr Kabo Ramotsheo

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- Dr B Obadele
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- Ms Barbara Nabifo
- Ms Chizubelu Chinenye
- Ms Belete Meseret
- Ms Angel Mutukwa
- Mr Ryen Metswi
- Ms Kefilwe Mbizo
- Ms Dadiso Chikati

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- Professor Cheddi Kiravu – New Era College, Botswana
- Professor Venkata P. Kommula – University of Botswana, Botswana
- Professor Maria Cecília Loschiavo dos Santos - Universidade de São Paulo, Brazil
- Professor Richie Moalosi – University of Botswana, Botswana
- Professor Mirian Gizejowski - Warsaw University of Technology, Poland
- Professor Giuditta Pezzotta - University of Bergamo, Italy
- Professor LJ Grobler - University of the Northwest, South Africa
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- ProfessorL. van Niekerk - University of Stellenbosch, Stellenbosch, South Africa
- Professor Joseph Mutale - Senior Partner & Energy Lead, Switzerland
- Professor Nelson Ijumba - University of KwaZulu Natal, South Africa
- Professor Prosun Bhattacharya - KTH Royal Institute of Technology, Stockholm, Sweden
- Professor Leon Cruickshank - Lancaster University, Lancaster, UK

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Botswana International University of Science and Technology, Botswana

Botswana Qualifications Authority, Botswana

Engineers Registration Board (ERB), Botswana

Botswana Ash (Pty) Ltd (Botash), Botswana

Botswana Power Corporation (BPC), Botswana

Botswana Institution of Engineers, Botswana

Botswana Digital and Innovation Hub, Botswana

Oracle Academy, Kenya

Human Resource Development Council (HRDC), Botswana

PROGRAM SCHEDULE

International Conference (Hybrid Mode) on Engineering Education and Management (IC2EM'24) taking place from 23rd - 25th September 2024

VENUE: MAJESTIC FIVE HOTEL, PALAPYE, BOTSWANA

Day 1: September 23, 2024

Time	Event
08:00–08:30	**Conference and Workshop Registration**
Day 1 - Morning Session Zoom Meeting Link **https://biust-ac-bw.zoom.us/j/81803352760?pwd=WUbcBcgMzoVR6cOCP40OonjCseGjd8.1** Meeting ID: 818 0335 2760 Passcode: aByHD4U4 Time : 8.30 HRS - 12.45 HRS	
08:30–09:00	Opening Ceremony **(Master of Ceremonies) Dr Mtengi & Dr Tjiparuro**
	National Anthem led by **Mabogo School Choir**
	Opening Prayer by **Pastor Letlhogonolo Keakantse**, Winners Chapel, Palapye
	Introduction of Guests
09:00–09:10	Welcome Address by Conference Chair-**Prof. M.T. Oladiran** (Chairperson, LOC) (Introduction to IC2EM'24)
09:10–09:20	Welcome Remarks by **Prof Elisha Shemang** (DVC T&L, BIUST)
09:20–09:30	Official Opening by **Prof. Otlogetswe Totolo** (Vice Chancellor, BIUST)
09:30 09:40	Cultural Entertainment by Mampo Cultural Group
09:40–09:50	Goodwill message by **Prof. Funso Falade**, President, African Engineering Education Association (AEEA)
09:50–10:00	Goodwill message by **Engr Donald Kandima**, President Botswana Institution of Engineers (BIE)
10:00–10:10	Goodwill message by **Dr Fernando Siamisang**, Director of Human Resource Development Planning, Human Resource Development Council (HRDC)
10:10–10:55	**Guest Speaker** (**Keynote Speaker 1**): **Prof. Botsalano Mosimakoko** CEO, Botswana Qualifications Authority (BQA). *"Enhancing Sustainable Quality Engineering Education for a Knowledge-based Society."*
10:55–11:05	Vote of Thanks by **Mr. Davies Tele, COO**, BIUST)
11:05–11:25	**TEA BREAK**

Time	Event
11:25–12:05	**Keynote Speaker 2 - Prof Oludayo Olugbara**, Durban University of Technology, Durban. *"Engineering Practice of Innovation Project Paradigm for Quality Education."*
12:05–12:45	**Keynote Speaker 3 -Prof Chithirai Pon Selvan**, Curtin University, Dubai - "*Engineering Education for Sustainable Development."*
12.45–13.30	**LUNCH**
Day 1 - Afternoon Session Zoom Meeting Link **https://biust-ac-bw.zoom.us/j/81803352760?pwd=WUbcBcgMzoVR6cOCP40OonjCseGjd8.1** Meeting ID: 818 0335 2760 Passcode: aByHD4U4 Time : 13.30 HRS- 19.30 HRS	
Theme: Enhancing Sustainable Quality Engineering Education for Knowledge-Based Society	
13:30–15.00	**WORKSHOP 1 - BQA:** BUILDING A SEAMLESS EDUCATION AND TRAINING SYSTEM: The National Credit Qualifications Framework- Mr Ofentse Disang, Botswana Qualification Authority, Botswana.
15.00–15.15	**BREAK**
15.15–17.15	**WORKSHOP 2 - BQA:** BUILDING A SEAMLESS EDUCATION AND TRAINING SYSTEM: The Quality Assurance System in Botswana - Mr Ofentse Disang, Botswana Qualification Authority, Botswana.
17.30–19.30	**WELCOME RECEPTION -** Poolside, Majestic Five hosted by BDIH & ERB
	END OF DAY ONE

Day 2: September 24, 2024

<table>
<tr><th>Time</th><th colspan="3">Event</th></tr>
<tr><td colspan="4">Day 2 - Morning Session
Zoom Meeting Link
https://biust-ac-bw.zoom.us/j/81803352760?pwd=WUbcBcgMzoVR6cOCP40OonjCseGjd8.1
Meeting ID: 818 0335 2760
Passcode: aByHD4U4
Time : 8.30 HRS- 11.00 HRS</td></tr>
<tr><td>08:00–08.30</td><td colspan="3">Conference Committee Team Meeting and Networking</td></tr>
<tr><td>08:30–09.10</td><td colspan="3">Keynote Speaker 4 Prof. Gbolagade Adekanmbi, Botswana Open University, Botswana - “Pushing the Open and Distance
Learning Agenda in Engineering Education: A Preliminary Submission.”</td></tr>
<tr><td>09.10–11.00</td><td colspan="3">WORKSHOP 3 - ERB: "Integrating Standards and International Collaboration to Elevate Engineering Education Quality"</td></tr>
<tr><td>11.00–11.15</td><td colspan="3">TEA BREAK</td></tr>
<tr><td rowspan="2">11:15–12.15</td><td colspan="3">Paper Presentation Session 1 (12 Papers)</td></tr>
<tr><td>Session 1A (Conference Hall)
Day 2 - Morning Session
Zoom Meeting Link
https://biust-ac-bw.zoom.us/j/81944751247?pwd=POAf0FJRM9cmCrJhTzm0UQaaite3F2.1
Meeting ID: 819 4475 1247
Passcode: 41YM68dh</td><td>Session 1B Tshukudu
Day 2 - Morning Session
Zoom Meeting Link
https://biust-ac-bw.zoom.us/j/85983680569?pwd=WDD7Ka4mNjYf2USqe94iMaAkn05RFh.1
Meeting ID: 859 8368 0569
Passcode: LrMC4BaM</td><td>Session 1C Nare
Day 2 - Morning Session
Zoom Meeting Link
https://biust-ac-bw.zoom.us/j/89082903821?pwd=5VwUdqOkQU4YyVQRObQaazRavkakGm.1
Meeting ID: 890 8290 3821
Passcode: MGfv2V3J</td></tr>
<tr><td>12:30–13:30</td><td colspan="3">LUNCH</td></tr>
<tr><td>13:30–14.10</td><td colspan="3">Keynote Speaker 5 - Prof. Awelani V Mudau, Department of Science and Technology Education (DeSTE) College of Education, University of South Africa. “Contextualising the Context of Advancing Engineering Education.”
Zoom Meeting Link
https://biust-ac-bw.zoom.us/j/81803352760?pwd=WUbcBcgMzoVR6cOCP40OonjCseGjd8.1
Meeting ID: 818 0335 2760</td></tr>
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<tr><th>Time</th><th colspan="3">Event</th></tr>
<tr><td></td><td colspan="3">Passcode: aByHD4U4
Time : 8.30 HRS- 11.00 HRS</td></tr>
<tr><td rowspan="2">14:10–15.10</td><td colspan="3">Paper Presentation Session 2 (12 Papers)</td></tr>
<tr><td>Session 2A (Conference Hall)
Day 2 - Afternoon Session
Zoom Meeting Link
https://biust-ac-bw.zoom.us/j/81944751247?pwd=POAf0FJRM9cmCrJhTzm0UQaaite3F2.1
Meeting ID: 819 4475 1247
Passcode: 41YM68dh</td><td>Session 2B Tshukudu
Day 2 - Afternoon Session
Zoom Meeting Link
https://biust-ac-bw.zoom.us/j/85983680569?pwd=WDD7Ka4mNjYf2USqe94iMaAkn05RFh.1
Meeting ID: 859 8368 0569
Passcode: LrMC4BaM</td><td>Session 2C Nare
Day 2 - Afternoon Session
Zoom Meeting Link
https://biust-ac-bw.zoom.us/j/89082903821?pwd=5VwUdqOkQU4YyVQRObQaazRavkakGm.1
Meeting ID: 890 8290 3821
Passcode: MGfv2V3J</td></tr>
<tr><td>15.10–15.25</td><td colspan="3">BREAK</td></tr>
<tr><td rowspan="2">15.25–16.30</td><td colspan="3">Paper Presentation Session 3 (8 Papers)</td></tr>
<tr><td>FREE</td><td>Session 3B Tshukudu
Day 2 - Afternoon Session
Zoom Meeting Link
https://biust-ac-bw.zoom.us/j/85983680569?pwd=WDD7Ka4mNjYf2USqe94iMaAkn05RFh.1
Meeting ID: 859 8368 0569
Passcode: LrMC4BaM</td><td>Session 3C Nare
Day 2 - Afternoon Session
Zoom Meeting Link
https://biust-ac-bw.zoom.us/j/89082903821?pwd=5VwUdqOkQU4YyVQRObQaazRavkakGm.1
Meeting ID: 890 8290 3821
Passcode: MGfv2V3J</td></tr>
<tr><td>19:00–21:00</td><td colspan="3">CONFERENCE DINNER: HOSTED By Human Resource Development Council of Botswana (HRDC)</td></tr>
<tr><td></td><td colspan="3">END OF DAY TWO!</td></tr>
</table>

Day 3: September 25, 2024

Time	Event
	Day 3 - Morning Session Zoom Meeting Link **https://biust-ac-bw.zoom.us/j/81803352760?pwd=WUbcBcgMzoVR6cOCP40OonjCseGjd8.1** Meeting ID: 818 0335 2760 Passcode: aByHD4U4 Time : 8.30 HRS- 13.15 HRS
08:00–08.30	**Conference Committee Team Meeting and Networking**
08:30–09:10	**Keynote Speaker 6 - Prof. Ramodungoane Tabane**, University of South Africa. *"Support for Neurodiversity Students in STEM Fields."*
	WORKSHOP 4 - **Oracle Primavera for Engineering & Construction Project Educators by Oracle Academy**
09:10–09:15	Keynote welcome address: **Danny Gooris, Senior Regional Director, Oracle Academy, EMEA**
09:15–09:40	Oracle Academy Primavera P6 Professional Project Management Curriculum and Member Hub Demo: **William Mcrae – Principal Instructor, Oracle Academy, EMEA**
09:40–10:30	A Practical Approach to Construction Scheduling with Oracle Primavea P6 Professional (Presentation & Demo): **Eben Van Wyk, Principal Sales Consultant, Oracle.**
10:30–10:40	Q & A & Closing Remarks: **Lorna Juma, Oracle Academy Program Manager**
10.40–10.55	**TEA BREAK**
10.55–12.15	**Roundtable Discussion** - The Future of Engineering Education for Sustainable Development Facilitator - Prof. Rodrigo Jamisola
12:15–13:15	**Closing Ceremony - Dr B Nthubu**
	-Recap of Conference Highlights: Dr. B. Obadele
	-Announcement of Best Paper Awards: Prof. S. Ravi
	-Traditional Dance / Entertainment
	-Invitation to IC2EM'26: Prof MT Oladiran
	-Vote of Thanks: Prof J. Chuma Dean School of Electrical & Mechanical Engineering
	-Closing Remarks & Closing of the Conference by Prof. Abraham Ogwu, DVC (RDI), BIUST
	-Closing Prayer by Pastor J. D. Khumo, Pentecostal Holiness Church, Palapye
13.15–14.15	**LUNCH, NETWORKING AND DEPARTURE**

DETAILS OF PAPER PRESENTATIONS

SESSION	ROOMS & MEETING LINK	PAPER TITLE	PAPER TITLE	PAPER TITLE	PAPER TITLE
SESSION 1A - 11.15HRS - 12.15 HRS **Moderator** Dr.Oduetse Matsebe **Student Volunteer** Mr.Gbenga Samson Omogbehin	**Conference Hall** Zoom Meeting Link https://biust-ac-bw.zoom.us/j/81944751247?pwd=POAf0FJRM9cmCrJhTzm0UQaaite3F2.1 Meeting ID: 819 4475 1247 Passcode: 41YM68dh	**Paper ID 9 - Responsible Engineering Education Paradigm and Pedagogy through the Responsible Computing Window** Sunday O Ojo, Oludayo O. Olugbara, Ugeshni Moodley and Lana-Ann Brady	**Paper ID 7 - Problem and Project based learning: An advancement in Engineering Education in Africa Continent** Gbenga S. Omogbehin, Meseret Belete and Blessing I. Omogbehin	**Paper ID 30 - Embedding Entrepreneurship Training and Development in the Engineering Curriculum in three selected Universities in Botswana** Joseph Ssegawa and Keneilwe Ntshwene	**Paper ID 16 - Engineering Education and Entrepreneurship Education: Complementarities, Opportunities and Challenges** James Sharka Juana, Mapeto Bomani, Gladys Gamariel and Bonolo Montshiwa
SESSION 1B - 11.15HRS - 12.15 HRS Moderator Prof.Abid Yahya **Student Volunteer** Ms.Barbara Nabifo	**Tshukudu** Zoom Meeting Link https://biust-ac-bw.zoom.us/j/85983680569?pwd=WDD7Ka4mNjYf2USqe94iMaAkn05RFh.1 Meeting ID: 859 8368 0569 Passcode: LrMC4BaM	**Paper ID 29 - Responsible Human-AI Collaboration in Education** Boineelo Nthubu	**Paper ID 23 - Access is Not All you Need: Adopting Large Language AI Models in Engineering Education Requires Pedagogical and Cultural Adaptation** Adekemi Ayodele, Kayode Ayodele, Olusoji Ilori and Abiodun Ogunseye	**Paper ID 25 - Space X Starlink: Transforming Botswana's Internet Landscape** Dimane Mpoeleng	**Paper ID 38 - Innovative Learning and Application of social media Technologies in Engineering Education** Mohamed Toufiq Asifbeg Mirza and Katso Laron Golekanye

SESSION	ROOMS & MEETING LINK	PAPER TITLE	PAPER TITLE	PAPER TITLE	PAPER TITLE
SESSION 1C - 11.15HRS - 12.15 HRS **Moderator** Prof.Subash Rao **Student Volunteer** Ms.Chizubelu Chinenye	**Nare** Zoom Meeting Link https://biust-ac-bw.zoom.us/j/89082903821?pwd=5VwUdqOkQU4YyVQRObQaazRavkakGm.1 Meeting ID: 890 8290 3821 Passcode: MGfv2V3J	**Paper ID 1 -Integrating Building Information Modeling (BIM) into Civil Engineering Education: A Framework for Sustainable Quality in a Knowledge-Based Society** Keoagile Kerileng	**Paper ID 2 - Issues to consider in incorporating artificial intelligence learning for geomatics education in Botswana** Kealeboga Moreri, Mooketsi Segobye and Lopang Maphale	**Paper ID 24 - Challenges and Opportunities in Integrating Artificial Intelligence Education at the University of Botswana: Addressing Infrastructure and Educational Priorities for a Knowledge-Based Society.** Kobamelo Mashaba, Robert Monageng, Monageng Kgwadi, Ronald Chikati, Pulafela Akofhang Majoo	
SESSION 2A 14.10 HRS- 15.10 HRS **Moderator** Dr.Ezekiel Kholoma **Student Volunteer** Ms.Belete Meseret	**Conference Hall** Zoom Meeting Link https://biust-ac-bw.zoom.us/j/81944751247?pwd=POAf0FJRM9cmCrJhTzm0UQaaite3F2.1 Meeting ID: 819 4475 1247 Passcode: 41YM68dh	**Paper ID 34 - Preparing engineers for Industry 5.0: a study of the impact of AI and ML onEngineering Education** Oyarekhua Atemoagbo and Chinenye Chizubelu	**Paper ID 15 - Opportunities and Challenges of Using the Engineering Education Degree Show to Enhance Problem-Based Learning** Badziili Nthubu, Mosalagae Mosalagae, Keletso Orapeleng,	**Paper ID 19 - Promotion and sustainability of quality assurance in engineering education through academic and professional accreditation** Jacek Uziak, M. Tunde Oladiran, Giuditta	

SESSION	ROOMS & MEETING LINK	PAPER TITLE	PAPER TITLE	PAPER TITLE	PAPER TITLE
			Vivekanandhan Chinnasamy, Tunde Oladiran, Oduetse Matsebe	Pezzotta and Edmund Lorencowicz	
SESSION 2B 14.10 HRS- 15.10 HRS **Moderator** Dr.James Juana **Student Volunteer** Ms.Chizubelu Chinenye	**Tshukudu** Zoom Meeting Link https://biust-ac-bw.zoom.us/j/85983680569?pwd=WDD7Ka4mNjYf2USqe94iMaAkn05RFh.1 Meeting ID: 859 8368 0569 Passcode: LrMC4BaM	**Paper ID 21 - The effectiveness of MATLAB sSoftware–supported mathematics Lessons in Botswana senior secondary schools- The case of Naledi Senior Secondary School** Oteng Keganneng	**Paper ID 31 - Comparative analysis of Prototypes for Humanity against those of University of Botswana's Department of Industrial Design and Technology** Polokano Sekonopo, Ritchie Moalosi, Paulson Letsholo		
SESSION 2C 14.10 HRS- 15.10 HRS **Moderator** Prof. Enoch Ogunmuyiwa **Student Volunteer**	**Nare** Zoom Meeting Link https://biust-ac-bw.zoom.us/j/89082903821?pwd=5VwUdqOkQU4YyVQRObQaazRavkakGm.1 Meeting ID: 890 8290 3821	**Paper ID 37 - Engineering Pedagogy and Productivity Leveraging AI** Cheddi Kiravu and Masodzi Mushininga	**Paper ID 8 - Sustainable management model for process quality effectiveness measure** Buliaminu Kareem, Anakobe-Jimoh Yakubu, Basil O. Akinnuli	**Paper ID 3 - Priming Library and Information Service Delivery in Aid of Open and Distance Learners in the Digital Era** Olugbade Oladokun and Peter Mazebe Ii Mothataesi Sebina	**Paper ID 33 - Enhancing Sustainable Technology Transfer (T2) Centre Operations for Quality Transportation Engineering Education**

SESSION	ROOMS & MEETING LINK	PAPER TITLE	PAPER TITLE	PAPER TITLE	PAPER TITLE
Mr.Gbenga Samson Omogbehin	Passcode: MGfv2V3J				Adewole Simon Oladele
SESSION 3B 15.25 HRS - 16.30 HRS **Moderator** Dr.Babatunde Obadele **Student Volunteer** Ms.Belete Meseret	**Tshukudu** Zoom Meeting Link https://biust-ac-bw.zoom.us/j/85983680569?pwd=WDD7Ka4mNjYf2USqe94iMaAkn05RFh.1 Meeting ID: 859 8368 0569 Passcode: LrMC4BaM\	**Paper ID 22 - Adoption and Utilization of Emerging Digital Technologies in Engineering Education: A Systematic Literature Review with a Focus on Botswana Tertiary Institutions** Glory Ifiegbu and Godfrey Mlambo	**Paper ID 28 - Boothroyd and Dewhurst Method as a Creative Tool to Support Design for Manufacturing and Assembly (DFMA) Students Engineering Design Teams** Badziili Nthubu and Boineelo Reabetswe Nthubu		
SESSION 3C 15.25 HRS - 16.30 HRS **Moderator** Dr.Vive. Chinnasamy **Student Volunteer** Ms.Barbara Nabifo	**Nare** Zoom Meeting Link https://biust-ac-bw.zoom.us/j/89082903821?pwd=5VwUdqOkQU4YyVQRObQaazRavkakGm.1 Meeting ID: 890 8290 3821 Passcode: MGfv2V3J	**Paper ID 27 - A Material Mechanical Properties Simulator for Engineering and Material Science Education and Research** Theddeus Akano and Harrison Onovo	**Paper ID 26 - A User Interactive Procedural Application to Solve Numerical Methods for Engineering and Science Students** Theddeus Akano, Opadotun Iyanuoluwa and Oboetswe Motsamai	**Paper ID 18 - Exploring Virtual Reality Application in Conceptual Design: A Pilot Experiment with Engineering Students** Juliet Chiramba, Badziili Nthubu and Mosalagae Mosalagae	

KEYNOTE SPEAKERS

Goodwill message by Dr Fernando Siamisang, Director of Human Resource Development Planning, Human Resource Development Council (HRDC)

Guest Speaker (Keynote Speaker 1): Prof. Botsalano Mosimakoko CEO, Botswana Qualifications Authority (BQA). "Enhancing Sustainable Quality Engineering Education for a Knowledge-based Society."

Keynote Speaker 2: Prof Oludayo Olugbara, Durban University of Technology, Durban. "Engineering Practice of Innovation Project Paradigm for Quality Education."

Keynote Speaker 3: Prof Chithirai Pon Selvan, Curtin University, Dubai - "Engineering Education for Sustainable Development."

Keynote Speaker 4: Prof. Gbolagade Adekanmbi, Botswana Open University, Botswana - "Pushing the Open and Distance
Learning Agenda in Engineering Education: A Preliminary Submission."

Keynote Speaker 5: Prof. Awelani V Mudau, Department of Science and Technology Education (DeSTE) College of Education, University of South Africa. "Contextualising the Context of Advancing Engineering Education."

Keynote Speaker 6: Prof. Ramodungoane Tabane, University of South Africa. "Support for Neurodiversity Students in STEM Fields."

LIST OF WORKSHOPS

WORKSHOP 1: BQA: BUILDING A SEAMLESS EDUCATION AND TRAINING SYSTEM: The National Credit Qualifications Framework- Mr Ofentse Disang, Botswana Qualification Authority, Botswana.

WORKSHOP 2: BQA: BUILDING A SEAMLESS EDUCATION AND TRAINING SYSTEM: The Quality Assurance System in Botswana - Mr Ofentse Disang, Botswana Qualification Authority, Botswana.

WORKSHOP 3: ERB: "Integrating Standards and International Collaboration to Elevate Engineering Education Quality"

WORKSHOP 4: Oracle Academy: "Oracle Primavera for Engineering & Construction Project Educators"

ADDRESSES AND REMARKS

Welcome Address by Professor M.Tunde Oladiran (Chairperson, Local Organising Committee)

Good morning,

It is my privilege and honour to make these introductory remarks and also welcome everyone to the grand opening ceremony of the International Conference on Engineering Education and Management tagged as IC2EM'24. This gathering is diverse in calling and professional practice (engineers, academics, educationists, regulators etc.), but we are surely committed to advancing the field of engineering education, training and management for the benefit of our communities.

Our world faces several complex global challenges. Some of them are climate change, environmental degradation, insufficient infrastructure development, technological disruption leading to job displacement and unemployment, cybersecurity, issues of energy and water provision, resource scarcity, food security, and management of innovation. There are many more challenges in health and general human development.

Engineering plays a crucial role in addressing these global challenges. As the demand for competent engineers grows, so does the need for effective and quality engineering education that imparts technical knowledge and also infuses critical thinking, creativity, and ethical considerations in our learners. Therefore, robust engineers produced through engineering education process have a unique role of reducing the issues that threaten our world. By enhancing quality engineering education and training with a focus on sustainability and inclusiveness, we can obtain solutions to our world problems, foster collaboration, and promote mobility of professionals across borders.

Directors of Ceremony, ladies and gentlemen, Engineering Education has been changing significantly in the recent past and this is driven principally by technological advances, industry needs, and societal challenges. The responsibilities of engineering educators include designing programmes, creating content, delivering materials, promoting learning activities, assessing performance, certifying learners and monitoring post institutional engagement and experiences of completers or graduates.

During this conference, we will have the opportunity to engage in stimulating discussions, attend enlightening presentations, and participate in interactive workshops. These will undoubtedly broaden our horizon, and promote changes in our respective handling of matters related to engineering education. This gathering must generate ideas, diffuse misinformation and forge new collaborations leading to advances and paradigm shifts in many areas of engineering education and management. In this regard, I am looking forward to the workshops to be delivered by BQA, ERB and Oracle Academy based in Kenya. The Local Organising Committee (LOC) is grateful to these establishments for availing their staff to handle the workshops.

The round-table discussion will also be stimulating as participants gaze into the future to predict pathways that could influence the overall landscape of engineering teaching, learning and training. Thoughts about the future of engineering education could be mind bogging. Therefore we should be ready for what will be unfolding in years to come. Design, delivery and management of engineering programmes would change. Also new directions will be formed with rapid progress in technology. Online learning platforms and Massive Open Online Courses (MOOC) will be expanded to create access to engineering education, allowing learners from diverse backgrounds to participate. Using various pedagogical approaches, integrating technology, and emphasizing interdisciplinary collaboration will enhance the preparation of engineering graduates for the complexities of the modern world. The COVID '19 pandemic has taught us that modes of delivery of engineering curricula can be flexible. Are there other surprises in the horizon for training engineers?

Directors of Ceremony, this conference is jointly delivered by Botswana International University of Science and Technology (BIUST) in collaboration with Botswana Qualifications Authority (BQA) and Engineers Registration Board (ERB). In this circumstance, BIUST seems to represent other Engineering Education Training Providers (EETP) whether in the public or private sectors of the economy such as University of Botswana and New Era College of Arts, Science and Technology respectively. One major lesson from this conference is that if quality of engineering education is to be assured, then it is important for the tripartite relationship of BQA, ERB and EETPs to work cooperatively to make the mission of each member easy and fulfilling in producing engineering graduates with the needed skill sets for industry and society. Additionally, Human Resource Development Council (HRDC) that body which determines the skills gaps in the engineering sector (and other sectors) of the economy in the country is also positively involved in this conference. Actually HRDC is hosting the conference dinner to show its commitment to the alliance and working together of all bodies in the engineering education sector. Though the Permanent Secretary (PS) of the Ministry of Education and Skills Development (MESD) was not able to be with us this morning due to other urgent matters, her original plan to be present among us shows the intent of the government to achieve quality engineering education in the country. It is envisioned that future engineering education conferences will be driven and funded by your ministry. We at BIUST will avail ourselves to organise and deliver such events satisfactorily. Engineering education must be financed wholesomely and delivered pragmatically to mitigate the challenges of sustainable development.

The conference has been generously funded by various organizations listed in the programme. The LOC appreciates the management of these organizations. Their timely financial support has enabled us to deliver this conference. I would like to particularly appreciate BQA and ERB for their commitment to accreditation of sustainable quality engineering education in our country.

It is also pertinent to appreciate the Executive Management Team of BIUST for growing a tertiary institution that is becoming a classic heritage of the community and the nation. The Leadership of BIUST supported the planing of this conference and I hereby thank the Vice Chancellor and his team.

Director of ceremonies ladies and gentlemen, I would like to recognize members of the LOC for the current conference. Their names appear in the programme. The LOC members who are in the auditorium may please stand up for recognition.

In closing, I extend my gratitude to all and sundry for your commitment to excellence in Engineering Education. May this conference be a catalyst for transformational change, and a landmark of our resolve to advance the frontiers of engineering knowledge in shaping a better tomorrow for our people through delivery of quality engineering education.
I welcome you to the International Conference on Engineering Education and Management 2024.

Thank you.

PULA!

Welcome Remarks by Prof Elisha Shemang, DVC Teaching & Learning, BIUST

Good morning.

I take this opportunity to welcome all of you to this International Conference on Engineering Education and Management hosted by Botswana International University of Science and Technology (BIUST) in collaboration with Botswana Qualification Authority (BQA) and Engineers Registration Board (ERB). I particularly welcome our international visitors, on-line participants and professionals from Botswana who have shown interest in the conference and the accompanying workshops.

As the Deputy Vice Chancellor of this esteemed institution, I am proud and excited to receive the diverse gathering to discuss and exchange ideas on engineering education and management for sustainable development in a knowledge - based society. The discussion is not only timely but essential to foster and build quality engineering human capital that can respond to the myriads of challenges of today and those of tomorrow not only in Botswana but globally.

The theme of the conference which is "Enhancing Sustainable Quality Engineering Education for a Knowledge-Based Society" calls for a platform where all who are engaged in the provision and management of quality engineering education could share their experiences on all aspects of Engineering Education. The theme is apt in the present era of the 4th Industrial Revolution in which knowledge produces innovation, supports job creation, drives economies and enhances overall national development. The rapid growth in ICT such as application of Machine Learning and Artificial Intelligence makes this conference more necessary and compelling.

The participants have a chance to reflect on possible ways to improve design, management and delivery of engineering education programmes. The engineering graduate with the right skills will then be able to contribute to the growth of the economy and help transform Botswana into knowledge-based economy as envisioned by the administration of our President, His Excellency Dr. Mokgweetsi Eric Keabetswe Masisi.

For the benefit of visitors to Palapye, both from within and outside the country, it is pertinent for me to give a panoramic view of BIUST. The institution has a strong commitment to its strategic vision of 'Driving Change' by emphasising quality, equity, equality and access to its programmes and services. The first cohorts of students were enrolled in 2012, all of who were undergraduate learners. Since then, significant leaps in growth have been achieved in student numbers, available facilities and the international cream of academics.

For example, just two days ago, we conducted our 9th graduation ceremony where in particular 21 PhD degrees were awarded to young deserving researchers from various streams of Science and Engineering. This is indeed monumental and demonstrates that BIUST is living up to its dream of contributing to the provision of high human capital for economic development and diversification.

I am proud that BIUST recently coordinated the Science Technology Engineering and Mathematics (STEM) programme whose activities were integrated into the National Science week during the month of August. The primary objective was to popularize Research Science, Technology and Innovation (RSTI) across the society. The university has also developed collaboration and linkages with various institutions in the SADC, the rest of Africa and internationally. This continues to strengthen the impact of our research on teaching and learning.
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Directors of Ceremony, it is envisioned that before the end of the year, the construction of a modern, state of the art Student Center will be completed to serve the student activities. It will offer a variety of unique amenities and facilities focusing on student support, welfare and academic services. It will enhance service delivery to our learners and other stakeholders and also promote teaching and learning in a conducive world-class environment.

From the foregoing, I hope you will agree with me that this conference comes at the right time as it stands to draw from a good pool of lived experiences.

BIUST is co-hosting this conference with two other important partners and stakeholders in the education landscape in the country, namely, the Botswana Qualifications Authority (BQA) that is mandated to coordinate education, training and skills development and Engineers Registration Board (ERB) that is responsible for regulating the activities and conduct of engineering professionals in Botswana. In recognizing the role of these two institutions, the conference has been structured in such a manner that there shall be workshops where participants will be able to engage directly with BQA and ERB and resolve all frequently asked questions.

The conference also provides an opportunity for engagement with keynote speakers and presenters to share their experiences, and ways to improve delivery and teaching of Engineering and related courses.

Ladies and gentlemen, nowadays the world is driven by technology. One of the National Academy of Engineering Grand Challenges in the 21st Century is Advanced Personalized Learning where there is a growing appreciation to individual learning preferences which calls for development of teaching methods that optimize learning and promote knowledge creation. We have also seen the emergence of Artificial Intelligence and its simulation of the human intelligence using machines and computer systems. The challenge to institutions in Botswana and elsewhere would be to take advantage of such systems and enhance student learning experience.

Directors of Ceremony, Ladies and gentlemen, my task this morning is simple, to make you all most welcome to Botswana, Palapye, the University and this important Conference. Therefore, in conclusion, I hereby wish all participants a fruitful deliberation during the next two days.

I thank you and have a great conference.

PULA!

Official Opening by Prof. Otlogetswe Totolo, Vice Chancellor, BIUST

Greetings and a warm welcome to you all. It is a great pleasure for me to be here today at the opening of the International Conference on Engineering Education and Management 2024. It is a privilege to address such a distinguished gathering of professionals, academics, researchers, educators, and policy-makers. Indeed, the programme that we are about to start this morning is unique in several dimensions. Firstly, it is a collaborative effort and jointly organised by some parastatals and academia. It is funded by public departments, industry and academia. I am also informed of the diversity of events consisting of paper presentations, workshops and a Roundtable discussion. I am particularly delighted to know that HRDC, BQA, ERB, BIE, BDHI, BIUST and industry are positively involved in these events.

You are really poised for a rich academic and professional experience to be acquired in the next few days.

The theme "Enhancing Sustainable Quality Engineering Education: Building a Knowledge-Based Botswana" could not be more timely than now. As Botswana strives towards a knowledge-based economy, the role of engineers in shaping our future is paramount. Our nation is on a transformational journey toward a knowledge-based society, and engineering education stands at the heart of this vision. This conference presents a critical platform for collaboration, where the participants and resource persons can exchange ideas and experiences to ensure our engineering education system is both sustainable and of the highest quality. The discussions here will resonate deeply with our national goals and aspirations, aligning closely with several of the United Nations' Sustainable Development Goals (SDGs).

- SDG 4: Quality Education emphasizes inclusive and equitable quality education and promotes lifelong learning opportunities for all. By improving our engineering education, we ensure that our students receive high-quality instruction that prepares them for future service delivery and challenges in a borderless world.

- SDG 9: Industry, Innovation, and Infrastructure focuses on building resilient infrastructure, promoting sustainable industrialization, and fostering innovation. Engineering education is critical in training the professionals who will design, build, and maintain the infrastructure of tomorrow, driving innovation and sustainable development to new heights.

- SDG 7: Affordable and Clean Energy, SDG 11: Sustainable Cities and Communities, and SDG 13: Climate Action are directly impacted by the advances in engineering education. Engineers play a key role in developing sustainable energy solutions, creating smart cities, minimising environmental degradation and combating climate change through innovative technologies and practices.

Our country through is committed to fostering a vibrant ecosystem for science, technology, engineering, and mathematics (STEM) education. We recognize that a robust engineering workforce is essential for national development. Engineers are the builders, the innovators, and problem-solvers who translate scientific advances into tangible solutions for our communities. They design infrastructure, develop new and innovative technologies, and drive sustainable resource management.

However, the world we live in is constantly evolving. The demands on engineers are no longer limited to technical expertise. The 21st century engineer must be entrepreneurial and possess critical thinking skills, ability to adapt and innovate, and a strong foundation in communication and collaboration. They must be environmentally conscious and prepared to address the challenges of climate change. This conference, therefore, provides a valuable opportunity to explore how we can adapt our engineering education system to meet these new demands.

The government of Botswana has been steadfast in its efforts to improve our education system. In particular, we have implemented several initiatives and policies aimed at widening access, promote equity, resource training providers to enhance the quality of engineering education. Our recent achievements are a testament to our dedication, but we recognize that there is still much work to be done to have a critical mass of technologically minded human capacity.

We face several challenges, including provision of resource as funding is dwindling, technology (e.g. machine learning) is advancing at a fast rate and the adaptation of Artificial Intelligence is impending. However, these challenges present us with opportunities for growth and innovation. By leveraging the expertise and insights of the diverse group gathered here, we can develop practical solutions that will drive our education system forward, contributing to DG 8: Decent Work and Economic Growth and SDG 10: Reduced Inequalities.

Directors of ceremony, this gathering must address questions like:

- How can we ensure that our curricula are constantly evolving and relevant to reflect the latest advances in technology?
- How can we improve critical thinking, problem-solving, and communication skills in engineering education and training experiences?

- How can we create a more inclusive learning environment that fosters innovation and collaboration?
- How can we ensure that our programmes are aligned with the needs of industry and prepare graduates for successful careers?
- How can engineering education and training be less dependent on public funding by generating third-tier income through their professional practice and other services.

Ladies and gentlemen, this conference is not just about sharing best practices, but also about fostering collaboration. By bringing together stakeholders from across the spectrum of academics, policy-makers, and industry leaders, we can create a synergy that drives positive change in the socio-economic development of our country. Let us use this platform to build strong partnerships that will propel Botswana's engineering education system to new heights to enhance internationalization of engineering academy.

The knowledge shared here will not only benefit Botswana, but also contribute to the global discourse on engineering education. Let us strive towards a future where our engineers are not just technically proficient, but also responsible leaders, capable of building a sustainable and prosperous future for all.

I am particularly impressed that BIUST conceived the idea of this conference and has been relentless to successfully deliver it for the overall benefit of the Education and Training Providers in our country. I am hoping that moving forward there will be more collaboration and regular exchange of ideas and information between the providers and regulators. It is pertinent for me to also appreciate the committee that organised this conference. Without their hard work and commitment we will not be here today. The programme seems to be extensive and deep to leave no one in doubt that the committee has considered all the elements necessary for quality engineering education. I am intrigued by the topic of the Roundtable discussion, namely "The future of engineering education for sustainable development in a knowledge based society." We in government will anticipate the outcome of the discussion.

As we look to the future, I am filled with hope and optimism concerning engineering education in Botswana. Together, we can build a resilient, innovative, and inclusive engineering education system that meets the needs of our society and prepares our students for the challenges of tomorrow, aligning our efforts with the broader vision of sustainable development.

Distinguished guests, ladies and gentlemen, thank you for being here, and I wish you all a productive and inspiring conference and workshop sessions. Let us make the most of this opportunity to learn, collaborate, and inspire one another. The conclusion and recommendations of this conference should not be kept in your archives, shelves or computers but disseminated to me and other relevant officers in the public service and industry.

Distinguished guests, ladies and gentlemen, it is now my singular honour to declare this conference officially opened.

I thank you.

PULA!

Goodwill message by Prof. Funso Falade, President, African Engineering Education Association (AEEA)

Distinguished ladies and gentlemen, on behalf of the African Education Engineering Association (AEEA), I welcome you to the International Conference on Engineering Education and Management that is being organized by the Botswana International University of Science and Technology which is holding between 23rd and 25th September, 2024 in Palapye, Botswana.

I thank the Chairman, Organizing Committee, Professor Tunde Oladiran, and his team for inviting me to deliver a goodwill message during the Opening Ceremony of this Conference. I would have loved to attend this Conference in person but I am currently outside the shores of Africa for another engagement.

The theme of the Conference 'Enhancing Sustainable Quality Engineering Education for a Knowledge-based Society' and the sub-themes touched on the key areas in Engineering Education that are germane to the production of quality Engineers with relevant skills to function in the industry after graduation. The effectiveness of Engineering graduates in the industry depends on how grounded they are in engineering concepts and the knowledge they acquire during their training in the University, as well as their exposure to industrial practice via internships during their training.

Engineering Education focusses on the methodology of teaching and learning processes, assures the effectiveness of teaching techniques and programs designed for developing technologies. It evaluates the appropriateness of curricula of engineering programs, infrastructure and technologies necessary for the training of engineers, accreditation system as well as the relevance of industry inputs to the training of engineers. Engineering education concerns two principal facets of education: Teachers and the Students - the instructors and the future practitioners of engineering. It bothers on the development of programmes that will enhance the competences of teachers and improve their skills while students are better equipped with knowledge.

Even though engineering education is very important to the production of quality engineers, its thrust is poorly understood by engineering educators especially in developing countries in general and Africa in particular. Some faculty members believe that engineering education should be left to faculty of education and not faculty of engineering.

The 1st African Regional Conference on Engineering (ARCEE) was initiated at University of Lagos, Nigeria in 2002 to create necessary awareness among engineering educators about the importance of engineering education to the production of quality Engineers. The success of the conference necessitated the need to host the 2nd ARCEE in Lagos in 2004 with participants from different African sub-regions. The 3rd edition was held at the University of Pretoria, South Africain 2006. The major outcome of the conference was the establishment of the African Engineering Education Association (AEEA). The main objectives of AEEA are to promote quality engineering education in Africa and bridge the North-South divide as well as provide networking opportunities for engineering educators through attendance at regional conferences on engineering education, allowing teachers to collaborate and share innovative ideas, and improveteaching and learning in African educational institutions through workshops for engineering educators. Conferences and capacity building workshops have been organized in different sub- regions in Africa.

In 2013, AEEA championed the inauguration of the African Engineering Deans Council (AEDC) after the 5th edition of African Regional Conference on Engineering Education at the University. The council is to work in collaboration with the Global Engineering Deans Council to further promote quality engineering education in Africa and beyond and provide a platform for African Engineering Deans to interact and evolve strategies for engineering graduates to acquire relevantskills that meet industry needs.

In December 2022, a meeting was held in Cape Town, South Africa at end of the World engineering Forum (WEEF). The meeting was attended by the chairman , Global Engineering Dean's Council (CEDC), the Director of UNESCO ROSA; Secretary General and Executive Secretaryof GEDC, the President of AEEA; chairman WFEO Engineering Capacity Building Technical Standing Committee and the Chairman Federation of African Engineering Organization (FAEO),Engineering Education Standing Technical Committee, a declaration was made by the engineering education stakeholders in Africa that all the engineering education organizations would harmonize their operations and work together to build capacity in engineering education. The harmonization necessitated the establishment of the African Engineering Education Forum (AEEF) as an identity for the operation of the group.

University of Lagos hosted the first edition of the Forum in October, 2023. The second edition comes up in Marrakech in Morocco between 12th and 15th December 2024. The call for paper forthe Forum can be found at https://africaeef.org or www.aeeaonline.org. You are all welcome!

The greatest problem confronting engineering education in Africa apart from the general challenges facing education, is the poor awareness of the thrust of the engineering education bythe stakeholders particularly the members of Faculties of Engineering. I am yet to know of any University in Africa where publications in engineering education are considered for promotion ofacademic staff. Such publications are not taken as academic papers. This demoralizes faculty members who are interested in engineering education and limit their participation in the activities of AEEA. Around the world, typically in advanced countries, engineering education has evolved as a discipline with faculty members acquiring higher degrees M.Sc. and Ph.D. in engineering education.

The five (5) key areas of research in engineering education are:

i) Engineering Epistemology: Research on what constitutes engineering thinking and knowledge within social contexts now and in the future.
ii) Engineering Learning Mechanism: Research on learners' developing knowledge and competences in context
iii) Engineering Learning Systems: Research on the instructional culture, institutional infrastructure, and epistemology of engineering educators
iv) Engineering Diversity and Inclusiveness: Research on how diverse human talents contribute solutions to the social and global challenges and relevance of the engineering profession
v) Engineering Assessment: Research on, and the development of, assessment methods, instruments, and metrics to inform engineering education practice and learning.

There is a synergy between engineering and engineering education:

Engineering equips prospective engineers with skills to be resourceful, creative, innovative, knowledgeable and be able to solve societal problems in sustainable ways and ensures the delivery of the 17 Sustainable Development Goals (SDG) while engineering education provides training tools for the acquisition of relevant skills by prospective engineers for national/regional development. For the core engineering disciplines to yield the expected outcomes, there is a need for the practice of effective engineering education. This international conference on Engineering Education and Management cannot come at any time better than now when engineering education is being reshaped globally to incorporate innovative pedagogy that put students at the centre of learning, cultivate adaptable minds, capable of leveraging AI technologies along with creativity and ethical reasoning essential for sustainable innovation and development, adapt to prepare the next generation of engineers for a landscape dominated by intelligent systems. The curriculum for engineering programs must be redesigned to prepare students to thrive in an AI-driven world and enable graduates to contribute positively to solving societal challenges in sustainable ways.

I hope the keynote speakers and the other presenters will do justice to the topics to all the topics. The communique arising from this conference should not be left on the shelf of Chairman, Organizing Committee but should be made available to the relevant government agencies for implementation.

The membership of AEEA is opened to all engineering educators in Africa. The registration details can be found at the Association's website: www.aeeaonline.org
I thank you for your attention.

Goodwill message by Engr. Donald Kandima, President Botswana Institution of Engineers (BIE)

Thank you BIUST, on behalf of Botswana Institution Of Engineers, for the opportunity and privilege to deliver a goodwill message for the undertaking of this conference.

It is imperative that we must push ahead with transforming the growth model of engineering, making structural adjustments, improving quality and enhancing performance of our engineers.

“We just have to build this plane while we are flying it”- So to speak

May I touch on a topic that I am passionate about:- “Advancement of the Engineering profession”.

The 3 fundamental actions to advance the engineering profession:

- Re-appropriate our knowledge base,
- Be hands-on with the education of engineers,
- Re orientate to the next-stage client.

Engineering laid the foundation of Botswana’s post 1966 development.

It is the first profession to join the deep cultures of farming and deliberative politics at the core of Botswana’s strength.

Engineers have the highest turnover among professions, are indispensable to the widest range of public spending and co-ordinate the longest value chains with the greatest outsource and in-source capability. They are thus the catalyst of Botswana’s national growth.

As a commercial sector with a key body of knowledge, engineering remains mortgaged to the national state as a Client and National Universities for its reproduction and recruitment. To grow to its full scope engineering must build capacity to capture new kinds of client and manage its own knowledge base to re-orientate its value proposition and monetise what it knows.

The engineering profession must convene three capacity growth areas to secure its grip on a wider client base and its own know-how.

- Engineers need a simply implemented business-model design capability to enable them to refine their value proposition internally
- Engineers knowledge requires systematic management to enable its monetization by partnerships with higher learning organizations, create a turnkey capability and a proactive positioning in opportunities
- Engineers need a sector wide strategic capacity to redesign value chains to deliver their competitive advantage to more lucrative, reliable, and diverse clients.

We need to be making a case for value analysis and value engineering. Therefore conferences like this go a long way in achieving that goal.

I wish BIUST, BQA, ERB, there valuable sponsors and all participants a successful conference .

Thank You

WORKSHOPS

ORACLE WORKSHOP

The International Conference on Engineering Education and Management (IC2EM'24), organized by the Botswana International University of Science & Technology (BIUST), took place from September 23-25, 2024, with a wide range of workshops and sessions aimed at advancing engineering education and management. Among the key workshops was Oracle Primavera for Engineering & Construction Project Educators, presented by Oracle Academy. The workshop took place on September 25, 2024, in a hybrid format, with both virtual participation and an in-person session with participants at the Majestic Five Hotel, Palapye, Botswana.

The Oracle Academy workshop focused on introducing educators to Oracle Academy's Primavera P6 project management curriculum and resources, designed to enhance the teaching of project management to engineering and construction students. The workshop aimed to equip educators with practical tools and teaching materials to integrate Oracle Primavera P6, the industry gold standard for project management, into their curriculum. Oracle Primavera P6 is widely recognized for its use in large-scale engineering and construction projects. Free access through Oracle Academy provides students with real-world experience and the opportunity to gain skills that are highly valued in industry.

Through this workshop, Oracle Academy provided educators with critical insights into how Oracle Primavera project management curriculum supports the development of student expertise in project planning, scheduling, execution, and management. Attendees learned how Oracle Academy members gain access to a wealth of teaching materials and practical resources that help them prepare students in managing engineering and construction projects effectively, using industry-standard tools.

For educators teaching higher education construction or civil engineering project management, Oracle Academy offers Oracle Primavera P6 Professional Project Management curriculum.

International Conference on Engineering Education and Management (IC2EM'24), September 23-25th, 2024, BIUST, Botswana

INTEGRATING BUILDING INFORMATION MODELING (BIM) IN CIVIL ENGINEERING CURRICULA: SUSTAINABLE QUALITY FRAMEWORK IN A KNOWLEDGE-BASED SOCIETY

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Abstract: As the construction industry increasingly adopts digital technologies, integrating Building Information Modeling (BIM) into engineering education becomes crucial for preparing students to contribute effectively in a knowledge-based society. This paper outlines a strategic initiative by the Botswana International University of Science and Technology (BIUST) to incorporate BIM into its undergraduate civil engineering curriculum. The initiative aims to align academic outcomes with industry demands by introducing students to essential BIM tools and practices from the outset of their education. This phased approach ensures progressive learning, from foundational concepts to advanced applications, enhancing the quality and sustainability of engineering education. By fostering a deep understanding of BIM, the curriculum is expected to improve students' professional readiness, promote interdisciplinary collaboration, and encourage innovation in sustainable design and construction practices. The initiative underscores the role of BIM in advancing a resilient and adaptive educational framework that meets the challenges of contemporary and future construction environments. This paper details the curriculum integration process, pedagogical strategies, and preliminary feedback, setting the stage for a broader discussion on transforming engineering education through technology.

Keywords: Building Information Modeling (BIM), Civil Engineering Education, Sustainable Quality, Curriculum Innovation, Digital Transformation, Knowledge-Based Society.

1. INTRODUCTION

The construction industry is undergoing a significant transformation driven by the adoption of digital technologies. Building Information Modeling (BIM) is a key part of this change, offering a comprehensive approach that enables the creation, management, and sharing of detailed digital models throughout a structure's lifecycle from design to maintenance. The models encompass all aspects of the project, which includes the geometry, spatial relationships, geographic information, and the properties of building components. This facilitates a collaborative environment where stakeholders in a project ranging from architects to civil engineers and contractors can work on a shared digital model, which streamlines communication and reduce design conflicts, optimize construction schedules, and helps to reduce errors, delays, and costs. Globally, governments and industry bodies are recognizing the value of BIM and have begun mandating its use in public projects, such as in the United Kingdom and the United States (NBS, 2019). Despite these advancements, the adoption of BIM in many developing countries like Botswana and South Africa has been slower, often due to high implementation costs, limited infrastructure, lack of expertise, and resistance to change from traditional methods (Sawhney et al., 2018). Table 1 summarizes the barriers to BIM adoption in developing countries, which includes lack of financial resources, lack of technological infrastructure and regulatory support, lack of BIM educational training, low industry awareness and lack of skilled workforce, and lack of standards to guide designers. However, as global construction practices evolve, there is increasing pressure on industries in these regions to adopt BIM to remain competitive.

Table 1: Barriers to BIM adoption in developing countries.

Barrier	Developed Countries	Developing Countries
Financial	Financially capable of investing in BIM software and infrastructure	High initial costs of BIM software, hardware, and training limit adoption
Technological	Established digital infrastructure supports seamless BIM integration.	Limited digital infrastructure, poor internet connectivity in rural areas
Regulatory	Strong government mandates and policies promote BIM adoption (e.g., UK, Singapore).	Lack of government mandates and incentives hinders widespread adoption.
Educational	Widespread availability of BIM training and university programs. .	Insufficient access to BIM training and skilled professionals
Industry Awareness	High level of industry awareness and collaboration among stakeholders.	Low awareness of BIM benefits, limited collaboration between stakeholders.
Skilled Workforce	A well-established workforce proficient in BIM technologies.	Shortage of skilled professionals trained in BIM methodologies
Standardization	Strong standardization efforts (e.g., ISO 19650) ensure interoperability.	Lack of standardized BIM processes across the industry.

2. SELECTED LITERATURE REVIEW

The benefits of BIM in construction are well-documented across numerous studies. According to Azhar et al. (2011), BIM was able to detect clashes and optimize designs before the beginning of construction, which reduced errors, omissions, and rework during the construction phase. In addition, the use of BIM has been found to improve collaboration across different disciplines. By providing a shared platform for architects, engineers, contractors, and facility managers, BIM fosters better communication and coordination, reducing the likelihood of miscommunication and design conflicts (Azhar et al., 2011). BIM enables the integration of energy analysis and life cycle assessment tools, allowing project teams to optimize designs for energy efficiency and environmental impact (Ghaffarianhoseini et al. (2017)). As sustainability becomes a key concern in construction, especially in the context of global climate change, BIM is increasingly seen as a critical tool for designing greener buildings.

BIM adoption in developed countries has accelerated significantly since the early 2010s, driven largely by government mandates and industry pressure to improve productivity and sustainability. The United Kingdom has been at the forefront of BIM adoption, particularly through the implementation of BIM Level 2 in 2016. A study by NBS (2019) reported that over 73% of UK construction professionals are using BIM, and the percentage continues to rise annually as more companies recognize its benefits. Studies have shown that this mandate has led to significant cost savings, improved project delivery times, and fewer project errors and reworks. A 2019 study by the UK's National Audit Office estimated that the use of BIM saved up to £2.2 billion on public sector projects from 2016 - 2018 due to more efficient design and construction processes. Public sector projects experienced a 15-20% reduction in costs due to improved project coordination and fewer errors, while projects saw a 30-40% decrease in completion times, demonstrating the power of BIM to streamline operations. This example shows the potential for developing countries to replicate similar outcomes by incorporating BIM in public and private sector projects. Similarly, in the United States, BIM adoption has been encouraged by both government and private sectors, particularly in large-scale infrastructure projects. The General Services Administration (GSA) requires the use of BIM in major public buildings since 2007. A study by McGraw-Hill Construction (2014) found that BIM users in North America reported a 30% reduction in project durations, a 13% cost reduction, and a significant decrease in the number of project errors and omissions. Projects have been completed 20-25% faster through improved coordination and clash detection. In Europe, Germany and France have implemented BIM mandates for public sector projects, with the European Union actively promoting BIM adoption through initiatives like the EU BIM Task Group. The EU's focus on standardization and interoperability has played a crucial role in promoting cross-border collaboration within the AEC industry across Europe (ISO 19650). Figure 1 shows global BIM adoption rates in leading countries [4]

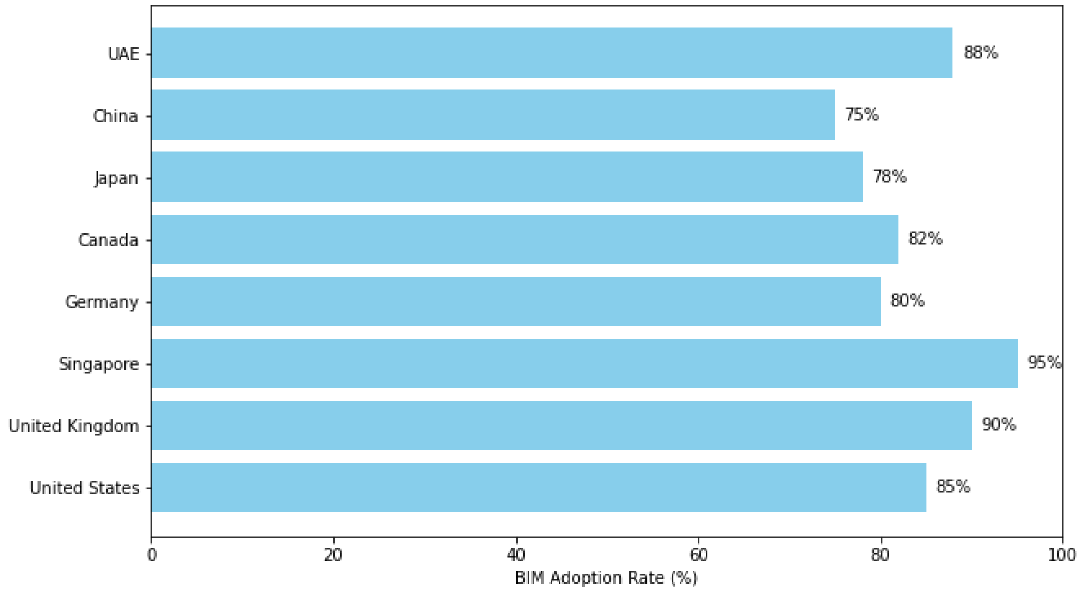

Figure 1. Global BIM adoption rates in leading countries in 2024 [4].

Australia has leveraged BIM for its large-scale infrastructure projects, particularly in transportation, where productivity increased by 30% due to real-time updates and streamlined collaboration. Cost savings of 25% were achieved by integrating BIM from the planning stage to the construction phase. The Netherlands has utilized BIM to drive sustainability in construction, focusing on energy-efficient buildings. For instance BIM was employed to reduce energy consumption by 25% during construction and operations, helping the country meet stringent EU sustainability standards. Thus, BIM is not only a tool for improving construction efficiency but also a pathway to achieving long-term sustainability goals.

The adoption of BIM in developing countries, however, has been slower due to several barriers. According to Sawhney et al. (2018), the primary challenges are the high implementation costs, lack of infrastructure, and insufficient expertise in BIM technologies. In many African countries, including South Africa and Nigeria, BIM implementation has been limited to large construction firms, leaving smaller firms struggling to adopt these technologies due to financial and technological constraints. In South Africa, BIM adoption has been primarily driven by multinational construction firms working on large infrastructure projects. However, smaller firms face significant challenges, which includes the lack of government mandates and limited access to BIM training and education (SACPCMP, 2020). A survey conducted by the South African Council for the Project and

Construction Management Professions (SACPCMP) in 2020 found that while 40% of large firms were using BIM, only 12% of small-to-medium-sized enterprises (SMEs) had adopted the technology. In Botswana, BIM adoption is still in its infancy. A 2021 survey by the Botswana Institute of Engineers (BIE) revealed that less than 10% of construction firms had fully implemented BIM in their projects, primarily due to the high cost of software, lack of skilled professionals, and limited government support. A study by Kerileng et al. (2022) highlighted the need for BIM-specific education programs at universities to bridge the skills gap and prepare future civil engineers for a digital construction environment.

Despite these clear benefits, BIM adoption remains limited because of several key challenges, particularly in developing countries. As noted earlier, the high cost of BIM software and hardware remains a significant barrier. According to Olatunji et al. (2016), the upfront costs associated with BIM can be prohibitive, especially for small and medium-sized enterprises (SMEs) in developing economies. Another critical challenge is the lack of skilled personnel trained in BIM technologies. A report by the Royal Institute of Chartered Surveyors (RICS, 2017) highlighted the need for more extensive BIM education and training programs, particularly in developing countries, where the lack of skilled professionals has stunted BIM growth. Similarly, the South African Institute of Civil Engineering (SAICE) has called for greater government investment in BIM education and infrastructure to promote adoption among smaller firms. Finally, the lack of standardized processes for BIM adoption remains a challenge, particularly in countries where governments have yet to mandate BIM use. Without standardized regulations, BIM adoption often remains fragmented, with firms implementing their own systems and standards, leading to issues with interoperability and collaboration.

3. THE ROLE OF EDUCATION IN PROMOTING BIM ADOPTION

Education plays a vital role in overcoming BIM challenges, particularly in developing countries. In developed countries, the integration of Building Information Modeling (BIM) into civil engineering and architecture curricula has become a standard practice. In developing countries, universities and technical institutions are beginning to recognize the importance of BIM in preparing students for the modern construction industry. According to Wong et al. (2011), early exposure to BIM tools and methodologies in educational programmes significantly improves students' competencies in digital construction practices, making them more employable and better prepared to work in collaborative environments. Table 2 shows how leading universities have embedded BIM courses into their programmes. In the United Kingdom, universities such as University College London (UCL) and the University of Salford have embedded BIM into their undergraduate and postgraduate programs, with students gaining hands-on experience through courses like BIM in Practice and interdisciplinary collaboration in BIM-driven projects. In the United States, prestigious institutions like Stanford University and Georgia Tech have pioneered BIM education, offering specialized courses in BIM and Virtual Design and Construction (VDC) to prepare students to implement BIM in large-scale infrastructure projects. Similarly, Australian universities such as the University of Sydney and RMIT University have incorporated BIM into their curricula, providing advanced training in digital tools like Revit and Civil 3D for complex infrastructure projects.

In Asia, Singapore leads BIM education, with institutions like the National University of Singapore (NUS) and the Singapore University of Technology and Design (SUTD) offering BIM-focused programmes as per the government mandate. China, driven by rapid urbanization, has integrated BIM into the core curricula of top institutions like Tsinghua and Tongji Universities, where students engage in real-world applications of BIM in smart city planning and megaprojects. India's leading universities, which includes IIT Delhi and CEPT University, have adopted BIM to improve project management and sustainability in urban infrastructure, while Malaysian institutions such as the University of Malaya and Universiti Teknologi Malaysia focus BIM in large-scale infrastructure projects.

In the Middle East, universities in the UAE and Saudi Arabia, such as the American University of Sharjah and King Fahd University of Petroleum and Minerals, have integrated BIM into their programs to support ambitious urban development and smart city projects. In Africa, Egypt has also made strides in BIM education, with Cairo University embedding BIM into its civil engineering and architecture programmes. Similarly, South African universities, such as the University of Pretoria and Stellenbosch University, are increasingly incorporating BIM into their curricula to enhance project coordination, sustainability, and infrastructure development. These examples demonstrate that BIM education is not only crucial for developed nations but is also gaining traction in developing countries, particularly those with growing infrastructure needs. For Botswana, integrating BIM into the civil engineering curriculum at BIUST is essential to modernizing the country's construction industry and equipping graduates with the digital skills necessary to meet the demands of Botswana's infrastructure development and Vision 2036 goals (Kerileng et al., 2022). By following the footsteps of these global institutions, BIUST can bridge the skills gap in the construction industry and prepare students to lead Botswana's transition to a knowledge-based, digitally enabled economy.

Table 2. BIM courses in leading universities.

Country	University	Programs with BIM Integration	Focus of BIM Curriculum
United Kingdom	University College London (UCL)	MSc in Construction Economics and Management	Hands-on BIM practice with tools like Autodesk Revit, Navisworks, and Bentley Systems
United States	Stanford University	Civil Engineering, Construction Management	Focus on Virtual Design and Construction (VDC), large-scale project implementation using BIM.
Australia	University of Sydney	Master of Architecture, Master of Construction Management	Advanced training in BIM tools like Revit and ArchiCAD, with emphasis on interdisciplinary collaboration.
	RMIT University	Undergraduate & Postgraduate Engineering Programs	Digital management of complex infrastructure projects using Autodesk Civil 3D and InfraWorks
Singapore	National University of Singapore (NUS)	Master's in Project Management	BIM integration for digital construction management, sustainability initiatives, and project collaboration
China	Tsinghua University	Master of Architecture, Master of Civil Engineering	Real-world applications of BIM in megaprojects, urban planning, and infrastructure development.
	Tongji University	Civil Engineering, Architecture Programs	Smart city planning and large-scale infrastructure projects using BIM tools like Revit and Rhino.
India	IIT Delhi	Construction Project Management, Civil Engineering Programs	Digital construction management, clash detection, and sustainability analysis using BIM tools.
Malaysia	University of Malaya (UM)	Master of Project Management	Large-scale infrastructure projects, BIM for transportation and high-rise buildings
United Arab Emirates	American University of Sharjah (AUS)	Civil Engineering, Architecture Programs	BIM for urban development, smart cities, and large-scale infrastructure like airports and metro systems.

Saudi Arabia	King Fahd University of Petroleum and Minerals (KFUPM)	Construction Engineering and Management	Digital construction techniques, advanced project management using BIM tools to support Vision 2030.
Egypt	Cairo University	Civil Engineering, Architecture Programs	BIM for enhancing project coordination and efficiency in large-scale developments like Egypt's New Capital.
South Africa	University of Pretoria	Master of Construction Project Management	BIM for digital construction, sustainability, and interdisciplinary collaboration.
	Stellenbosch University	Civil Engineering Program	BIM for project management, infrastructure development, and smart city planning.

While many civil engineering programmes still emphasize traditional design and construction methodologies, the modern construction industry increasingly demands graduates who are proficient in digital tools, particularly BIM. In developing countries like Botswana, this issue is particularly acute, since the construction industry cannot keep pace with global technological advances. The skills gap is especially concerning within the context of Botswana's Vision 2036, a national development plan that envisions the country transitioning into a knowledge-based economy. To achieve this goal, it is essential to equip civil engineering students with the digital competencies necessary to contribute effectively to Botswana's infrastructure development and broader economic objectives. BIM education is a crucial component of this transformation, as it fosters innovation, efficiency, and sustainability key pillars of modern construction. This study outlines and discusses the strategic initiative undertaken by the Botswana International University of Science and Technology (BIUST) to integrate BIM into its undergraduate civil engineering curriculum. The adoption of BIM into engineering education is expected to bridge the existing skills gap by providing students with the expertise necessary to thrive in a digital construction environment. This is expected to enhance the quality of civil engineering education, and to contribute to the development of a workforce that can meet the demands of the modern construction industry. It is anticipated that the curriculum design, and the anticipated outcomes of this initiative would provide a framework that can serve as a model for other institutions in developing countries seeking to modernize their engineering programmes.

4. METHODOLOGY

This methodology is designed to ensure that students are proficient in BIM by the time they graduate, enabling them to contribute effectively to the construction industry in Botswana and beyond.

4.1. Phase 1 - Proposed Curriculum Design and Development

The integration of BIM into the curriculum follows a phased approach, where BIM concepts are gradually introduced throughout the civil engineering programme, as in Table 3. In the first phase, students are introduced to the foundational concepts of Building Information Modeling (BIM). This includes an overview of BIM tools like Autodesk Revit, Civil 3D, and Navisworks and Rhino, which are used for digital modeling and design. The focus is on familiarizing students with the basics of digital construction, including how BIM fits into the broader context of the architecture, engineering, and construction (AEC) industries. These tools are integrated into existing courses such as design, construction management, and structural analysis.

Table 3. Phase 1 - Proposed curriculum.

Year	Key Components	Learning Outcomes	Expected Outputs	Technological Tools
1	Introduction to Digital Design. Visualization and Design Communication.	- Basic competency in digital modeling and design visualization.	- Students gain foundational skills in digital design and communication.	- Autodesk Revit - Rhino
2	Fundamentals of BIM (Autodesk Revit, Rhino). Digital Construction Management.	- Basic BIM proficiency using industry-standard tools. - Understanding the role of BIM in construction processes.	- Students are able to create digital models and understand BIM basics in a construction context.	- Autodesk Revit - Rhino
3	Advanced BIM Applications (Navisworks, Civil 3D). - Interdisciplinary Coordination.	- Intermediate BIM skills, including project coordination and clash detection. - Collaboration with other disciplines.	- Students proficient in using BIM for project coordination and resolving interdisciplinary conflicts.	- Navisworks - Civil 3D

4	Capstone Project in Collaboration with Industry. BIM for Sustainability and Infrastructure.	- Advanced BIM skills applied to real-world projects - Ability to integrate sustainability into BIM workflows.	- Students can apply BIM to industry-sponsored projects, focusing on sustainability and infrastructure.	- BIM 360 - Autodesk Revit - Civil 3D - Rhino - Navisworks
5	Advanced Infrastructure Modeling- BIM for Urban Planning and Smart Cities.	- Mastery of BIM tools for complex infrastructure and urban projects. - Advanced project lifecycle management skills.	- Students complete comprehensive BIM projects, contributing to smart cities and complex infrastructure.	- BIM 360 - InfraWorks - Civil 3D - Navisworks - Autodesk Revit

4.2. Phase 2 - Faculty Training and Development

The second phase moves beyond the basics to explore advanced BIM applications such as project coordination and clash detection (Table 3). Students collaborate with peers from other disciplines, like architecture and mechanical engineering, using tools like Navisworks and Civil 3D to manage more complex projects. The emphasis here is on real-time collaboration and resolving conflicts through digital coordination.

Table 4. Phase 2 - Faculty Training and Development.

Component	Key Actions	Learning Outcomes	Expected Outputs	Technological Tools
Initial Training Workshops	- Hands-on training for faculty in Autodesk Revit, Navisworks, Civil 3D, Rhino, and BIM 360.	- Faculty proficiency in core BIM software and advanced modeling techniques.	- Certified faculty capable of teaching BIM concepts. - Increased faculty competence in BIM.	- Autodesk Revit - Civil 3D - Navisworks - BIM 360
Professional Certifications	- Faculty encouraged to pursue certifications in BIM technologies.	- Faculty gain formal certification and expertise in BIM.	- Certified and knowledgeable faculty to deliver BIM education.	- Professional certification programs (Autodesk, Bentley, etc.)
Continuous Professional	- Ongoing development through	- Faculty stay updated on emerging	- Continuously improving faculty	- Online courses - Industry

Development (CPD)	conferences, webinars, and industry collaboration.	trends, technologies, and practices in BIM.	proficiency and curriculum quality.	conferences - Webinars

4.3. Phase 3 - Interdisciplinary Collaboration and Project-Based Learning

In Phase 3 (Table 5), students engage in project-based learning through simulations and case studies that mimic real-world construction scenarios. This experiential learning approach allows students to apply their BIM skills to infrastructure projects and sustainability analysis. Software such as InfraWorks and BIM 360 are introduced to manage entire project lifecycles, from design to operation.

Table 5. Phase 3 - Interdisciplinary Collaboration and Project-Based Learning.

Component	Key Actions	Learning Outcomes	Expected Outputs	Technological Tools
Year 3: Interdisciplinary Projects	- Collaboration between civil engineering, architecture, and mechanical engineering students.	- Students learn interdisciplinary project coordination, clash detection, and teamwork.	- Successful interdisciplinary BIM projects with collaborative problem-solving.	- Navisworks - Civil 3D - Autodesk Revit
Year 4: Real-World Capstone Projects	- Industry-sponsored projects with guidance from professionals. - Focus on sustainability and infrastructure.	- Advanced BIM proficiency applied to real-world, industry-standard infrastructure projects. - Sustainability integration.	- Industry-ready capstone projects demonstrating real-world application of BIM.	- BIM 360 - InfraWorks - Civil 3D - Autodesk Revit - Navisworks

4.4. Phase 4 - Capstone Projects and Industry Collaboration

When the students reach the final year, they engage in capstone projects that involve real-world projects (Table 6). In this phase, students engage in project-based learning through simulations and case studies that mimic real-world construction scenarios. This experiential learning approach allows students to apply their BIM skills to infrastructure projects and sustainability analysis. These projects could be done in collaboration with industry partners, allowing students to apply BIM to the design and construction of sustainable infrastructure. Software such as InfraWorks and BIM 360 are introduced to manage entire project lifecycles, from design to operation.The curriculum design will ensure that students are proficient in using BIM software and understand its role in modern construction processes. This phase bridges the gap between academic learning and professional practice.

Table 6. Phase 4 – Capstone Projects and Industry Collaboration.

Component	Key Actions	Learning Outcomes	Expected Outputs	Technological Tools
Industry-Sponsored Capstone Projects	- Students complete capstone projects in collaboration with industry partners. - Focus on solving real-world challenges.	- Application of advanced BIM skills to practical challenges, with emphasis on sustainability and lifecycle management.	- Completed capstone projects meeting industry standards. - Real-world infrastructure designs using BIM.	- BIM 360 - Civil 3D - InfraWorks - Autodesk Revit - Navisworks
Internships and Mentorship	- Industry internships providing hands-on experience. - Mentorship from professionals in construction firms.	- Students gain practical industry experience applying BIM in construction projects.	- Industry-ready graduates with practical BIM knowledge and professional mentorship experience.	- Industry-specific BIM software and tools as per the project requirements.

4.5. Phase 5 - Evaluation and Continuous Improvement

The final phase involves assessing the outcomes of the BIM curriculum through student performance, feedback from faculty, and input from industry partners (Table 7). The goal is to continuously refine the curriculum based on these evaluations, ensuring that it remains aligned with both academic objectives and industry needs. Quantitative and qualitative metrics will be used to measure success, including exams, project evaluations, and feedback from stakeholders.

Table 7. Phase 5 - Evaluation and Continuous Improvement.

Component	Key Actions	Learning Outcomes	Expected Outputs	Technological Tools
Student Performance Evaluation	Evaluate students through exams, project evaluations, and technical assignments. - Assess accuracy, sustainability, and BIM skills.	- Students demonstrate proficiency in BIM software, project coordination, and sustainability integration.	- Consistent measurement of students' capabilities and readiness for the workforce.	- Grading systems - Survey tools for student feedback
Student and Faculty Feedback	Collect qualitative feedback from students and faculty through surveys and interviews. - Regularly review teaching methodologies and course content.	- Identify areas for curriculum improvement. - Continuous alignment with industry demands.	- Enhanced teaching approaches and content based on direct feedback.	- Survey and feedback collection tools
Industry Partner Feedback	Gather feedback from industry partners on student preparedness during internships and capstone projects.	- Ensure curriculum aligns with industry needs and provides job-ready graduates.	- Curriculum updates based on industry trends and the applicability of BIM skills.	- Industry feedback collection tools
Curriculum Review and Updates	Annual curriculum review incorporating feedback from students, faculty, and industry partners.	- Continuous curriculum improvement to keep pace with technological advances and industry demands.	- Regular updates to keep curriculum relevant and effective for modern industry practices.	- Curriculum review processes and documentation

5. POST-IMPLEMENTATION PHASES: SUSTAINING GROWTH AND INNOVATION

After the successful implementation of BIM in the civil engineering curriculum at BIUST, the focus will shift to ensuring continuous improvement, growth, and long-term impact. These phases outline the strategic steps needed to enhance the curriculum, foster industry collaboration, and position BIUST as a leader in digital construction education.

- **Annual Curriculum Review and Innovation -** To ensure that the BIM curriculum remains relevant and aligned with industry standards, an annual review process will be established to evaluate the curriculum, update the technology and introduce innovate teaching methods. The course content, learning outcomes, and teaching methodologies will be regularly evaluated to assess their effectiveness. Feedback will be gathered from students, faculty, and industry partners to identify areas for improvement and adaptation. To ensure that the students are trained on the latest tools and practices, the BIM software and hardware will be regularly updated to reflect industry advancements. New BIM technologies such as Artificial Intelligence (AI) for predictive modelling, Virtual Reality (VR) for immersive design experiences, and advanced sustainability analysis tools will be explored. To enhance student engagement and learning flexibility, new pedagogical approaches such as flipped classrooms, online learning modules, and blended learning will be incorporated into the curriculum.

- **Faculty Development and Certification -** A robust faculty development plan will be developed to ensure that instructors remain proficient in BIM technologies and are equipped to teach effectively by conducting continuous training and professional development (CPD) and engage in BIM-related research**.** Hands-on training workshops will be provided to build faculty proficiency in Autodesk Revit, Navisworks, Civil 3D, Rhino, and BIM 360. Faculty members will be encouraged to pursue certifications in BIM technologies from industry-leading providers such as Autodesk and Bentley. To ensure that faculty members become experts in BIM, support will be provided so that they can participate in industry conferences, webinars, and research collaborations to stay updated on the latest BIM trends and technologies. Further, to contribute to global BIM knowledge and strengthen BIUST's academic reputation they will be **e**ncouraged to engage in BIM-related research, publish findings in academic journals, and present at international conferences

- **Expansion of Industry Partnerships** - Industry collaboration is critical for ensuring that the BIM curriculum meets real-world demands and enhances students' employability. Key initiatives will include the establishment of the industry advisory board, international collaborations, BIM consultancy services. An industry advisory board, composed of industry leaders, will be established to provide input on curriculum relevance, emerging trends, and job market needs. Further, the advisory board will identify internship opportunities, research collaborations, and job placements for graduates. Mechanism will also be put in place to develop partnerships with global institutions in BIM-leading countries such as the UK, US, Australia, and Singapore to foster student exchanges, joint research projects, and faculty collaboration. ABIM consultancy division will be established at BIUST, with students and faculty working on real-life BIM projects for local industry. This initiative will provide valuable hands-on experience while contributing to the digitalization of Botswana's construction sector.

- **Research and Development -** BIUST will invest in BIM research to foster innovation and explore new applications of BIM in construction. A dedicated research hub, which focuses on BIM innovation, smart cities, sustainability, and infrastructure development will be established at BIUST. Grants and funding for BIM-related research projects will be secured, particularly in the areas of smart infrastructure and digital construction. Faculty members and students will be encouraged to participate in research projects and publish their findings in reputable academic journals and conferences. BIUST will host an annual BIM symposium to bring together industry professionals, academics, and students to discuss the latest developments in BIM and share research findings.

- **Monitoring Long-Term Impact -** To assess the long-term success of BIM integration at BIUST, a system to track the career progression of graduates will be implemented, focusing on their placement in BIM-related roles and their contribution to digital construction projects. The employers will provide regularly feedback on the performance and preparedness of BIUST graduates to ensure the curriculum remains aligned with industry needs. Ultimately, BIM-trained graduates will be evaluated, based on their contribution to sustainability and digitalization of Botswana's infrastructure. This includes assessing their ability to reduce project costs, enhance building performance, and improve project timelines.

- **Sustainability and Scale-Up -** To ensure the long-term sustainability and scalability of the BIM curriculum at BIUST, it is important to integrate sustainability into all BIM-related courses and projects, emphasizing green building practices, energy efficiency, and life cycle management. In addition, the BIM curriculum can be expanded to other engineering disciplines such as mechanical, electrical, and environmental engineering to broaden the impact of BIM education. Finally, professional BIM certification programmes can be established for practicing engineers, architects, and construction managers in Botswana and the region. This initiative will provide continuing education opportunities and help further BIM knowledge and implementation across the industry.

6. EXPECTED RESULTS AND DISCUSSION

The integration of BIM into the civil engineering curriculum at BIUST is expected to yield significant positive outcomes for students, faculty, and the construction industry in Botswana. This section discusses the anticipated results of the BIM curriculum implementation and the potential broader impacts on education, industry, and the national economy.

6.1 Expected Results

At the completion of the BIM curriculum, students are expected to have developed advanced digital modeling skills and BIM proficiency, allowing them to operate effectively in modern, technology-driven construction environments. Students will be adept at working in interdisciplinary teams, collaborating with peers from other engineering and architecture fields to solve real-world design and construction challenges using BIM tools. With hands-on projects and industry-sponsored capstone experiences, students will gain valuable problem-solving skills, particularly in areas like clash detection, project coordination, and sustainability integration. Graduates will be job-ready, equipped with practical BIM skills that make them competitive candidates for roles in digital construction management, infrastructure planning, and smart city development.

Through continuous professional development and certifications, BIUST faculty will become proficient in cutting-edge BIM tools and methodologies. This expertise will elevate the overall quality of instruction and allow for innovative teaching methods. Faculty members will be better positioned to engage in BIM-related research, leading to an increase in publications, conference presentations, and research grants. BIUST is expected to emerge as a research leader in BIM education and digital construction innovation in Africa. The collaboration between BIUST and industry partners will ensure that graduates are well-prepared for the workforce. Through internships and capstone projects, students will gain practical experience, making them valuable contributors to ongoing and future infrastructure projects in Botswana and beyond. The introduction of BIM-trained professionals into the workforce will encourage wider adoption of BIM in

Botswana's construction industry. Over time, this could lead to improvements in project efficiency, cost savings, and sustainability in construction practices.

By producing graduates skilled in digital construction, the BIM curriculum will contribute to Botswana's Vision 2036 goal of transitioning to a knowledge-based economy. The increased use of digital tools like BIM in national infrastructure projects will drive economic growth and innovation. BIM's integration into the construction sector will promote more sustainable practices, resulting in better-designed, energy-efficient buildings and infrastructure that contribute to Botswana's long-term development goals.

6.2 Discussion of the results

The implementation of a BIM-focused curriculum at BIUST is a significant step towards modernizing civil engineering education in Botswana. The results are expected to not only benefit students but also have far-reaching effects on the construction industry and national development. One of the primary motivations behind integrating BIM into the curriculum is to address the existing skills gap in Botswana's construction industry. With the rapid pace of urbanization and infrastructure development, there is a growing demand for professionals who are proficient in digital construction tools like BIM. By equipping students with these skills, BIUST is directly contributing to the development of a future-ready workforce. BIM's ability to improve design accuracy, project coordination, and sustainability is well-documented. By embedding BIM into the curriculum, BIUST is promoting innovation in construction practices. Graduates will be capable of applying BIM not only to improve project efficiency but also to integrate sustainability features into their designs, contributing to greener, more sustainable infrastructure. Despite the anticipated benefits, several challenges may arise during the implementation of BIM in the curriculum. These challenges include ensuring that faculty are adequately trained, securing sufficient industry partnerships, and keeping the curriculum updated with the latest technology. BIUST's phased approach, coupled with continuous faculty development and strong industry collaboration, is designed to mitigate these challenges and ensure the program's success.

The implementation of BIM at BIUST also positions the institution within the global context of BIM education. By following the examples of leading universities in the UK, US, China, and Singapore, BIUST ensures that its curriculum is globally relevant and competitive. The adaptability of the curriculum to emerging technologies and industry trends will further enhance its effectiveness in preparing students for international job markets. The long-term sustainability of the BIM program will depend on several factors, including ongoing faculty training, continuous curriculum updates, and maintaining strong industry partnerships. Regular feedback loops, graduate tracking, and industry consultations will play a vital role in ensuring that the curriculum evolves to meet future demands. As the curriculum matures, its impact is expected to extend beyond BIUST and Botswana. Graduates will bring their skills to the wider Southern African region, contributing to the digital transformation of the construction industry in neighbouring countries. This regional influence could lead to increased collaboration across borders, knowledge exchange, and the promotion of BIM standards throughout the continent.

7. CONCLUSION

The integration of Building Information Modeling (BIM) into the civil engineering curriculum at the Botswana International University of Science and Technology (BIUST) represents a transformative step toward modernizing education and aligning it with the evolving demands of the construction industry. As countries around the world embrace digital technologies to enhance project efficiency, sustainability, and collaboration, BIUST's commitment to BIM education positions the university as a leader in digital construction education within Botswana and the wider African region. The phased approach to BIM integration ensures that students develop both foundational and advanced skills, culminating in real-world applications through capstone projects and industry collaborations. By embedding BIM into the curriculum, BIUST not only addresses the existing skills gap in the local construction industry but also prepares graduates to be future leaders in digital construction, capable of contributing to national and regional development initiatives.

The benefits of BIM are clear improved project coordination, reduced errors, better cost estimation, and enhanced sustainability in design and construction. The successful implementation of BIM at BIUST is expected to produce graduates who are highly skilled in these areas, ready to meet the demands of modern infrastructure projects and contribute to Botswana's Vision 2036 goals of transitioning to a knowledge-based economy. Furthermore, the strong focus on industry collaboration and faculty development ensures that the curriculum remains relevant and responsive to technological advancements and industry needs. By fostering partnerships with local and international construction firms, government agencies, and global universities, BIUST creates a dynamic educational environment that continuously evolves to prepare students for the future.

In conclusion, the integration of BIM into BIUST's civil engineering program is not just an academic initiative but a vital contribution to the development of Botswana's construction industry. It promises to drive innovation, promote sustainability, and equip the next generation of engineers with the digital skills required for the challenges of the 21st century. Through this initiative, BIUST is laying the foundation for a more digitally literate, competent, and competitive workforce that will play a crucial role in the country's infrastructure development and its broader aspirations for economic growth and sustainability.

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PROMOTION AND SUSTAINABILITY OF QUALITY ASSURANCE IN ENGINEERING EDUCATION THROUGH ACADEMIC AND PROFESSIONAL ACCREDITATION

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Abstract: Engineering accreditation is a fiduciary requirement for academic institutions to meet certain educational standards during the duration of registration of such institutions. The status of accreditation should be continuously monitored to ensure that those standards are maintained. This paper opines that accreditation enhances quality and sustainability of engineering education. The totality of quality and sustainability of engineering education includes provision of adequate resources, supply of well qualified applicants from lower-level schools, availability of robust academics, design and delivery of excellent curricula, graduation of students who are registrable by professional bodies and employable by public and private sectors of the economy. Accreditation ensures that qualifications meet quality assurance standards and requirements, establishes a mechanism for verifying qualifications and learning outcomes and articulation strategies. All of these measures can create long term trust in qualifications and enhance movement of learners and graduates across national boundaries.

Keywords: accreditation, quality assurance, engineering education, outcome-based education

1. INTRODUCTION

Accreditation is considered as a powerful tool of quality assurance, especially higher education. However, accreditation in general covers a lot more ground, as it may include much broader spectrum including many types and levels of education. In consequence, accreditation may have different meaning to different people. For example, depending on the profession, any member of the so-called regulated profession (e.g. engineers, doctors, nurses) would consider accreditation as professional accreditation dealt with by a professional body. However, for a graduate of other professions, though still holding a degree, it is rather academic accreditation (being it either institutional or programme specific) that is prevalent.

2. TRADITIONAL VS OUTCOME BASED EDUCATION

Accreditation standards are derived from the philosophy, paradigm and principles of the Outcome Based Education (OBE) model. Those principles are used in professional accreditation, like in case of engineering accreditation [1, 2], where these standards are defined by the International Engineering Alliance's, and the Washington Accord for worldwide equivalency and quality assurance of engineering programmes at tertiary level [3]. The Washington Accord was formed in 1989 as an international agreement among professional bodies responsible for accrediting engineering degree programmes initially in some English-speaking countries. Over the years, the accord has been expanded and now includes professional bodies in several parts of the world including Russia, and China. Basically, the accord promotes the equivalency of accredited programmes and recommends that graduates of programmes accredited by any of the signatory bodies be mutually recognized and accepted by the other signatories as having met the academic requirements for entry to the practice of engineering in member countries. There are currently 25 members of the accord as presented in Table 1 [4]. The Washington accord's programme requirements are designed on the principles of OBE.

Also, for academic accreditation, the OBE model has become a standard used in all institutions like the European Association for Quality Assurance in Higher Education (ENQA), The Quality Assurance Agency for Higher Education (QAA), The British Accreditation Council (BAC), Tertiary Education Quality & Standards Agency (TEQSA) or Council for Higher Education Accreditation (CHEA), the Agency for Quality Assurance through Accreditation of Study Programs (AQAS) [5].

Outcome-Based Education (OBE) is a student-centred teaching and learning approach which attempts to replace the traditional education system that focuses on what is taught. It can be considered as the reformed concept of education which requires shifting curricula, staff, and students' approach and the support system for education.

3. ACCREDITATION

The word accreditation in an educational context refers to the fact that an institution or a course programme is officially recognized, accepted, or approved in terms of its status. Accreditation principally implies reaching certain predetermined requirements, criteria, or

Table 1: Current Membership of the Washington Accord [4].

No	Country	Signatory organization
1	Australia	Engineers Australia (EA)
2	Bangladesh	Institution of Engineers, Bangladesh
3	Canada	Engineers Canada (EC)
4	China	China Association for Science and Technology (CAST)
5	Costa Rica	Colegio Federado de Ingenieros y de Arquitectos de Costa Rica (CFIA)
6	Hong Kong, China	The Hong Kong Institution of Engineers (HKIE)
7	India	National Board of Accreditation (NBA)
8	Indonesia	Persatuan Insinyur Indonesia (PII)
9	Ireland	Engineers Ireland (EI)
10	Japan	Japan Accreditation Board for Engineering Education (JABEE)
11	Korea	Accreditation Board for Engineering Education of Korea (ABEEK)
12	Malaysia	Board of Engineers Malaysia (BEM)
13	Mexico	Consejo de Acreditación de la Enseñanza de la Ingeniería (CACEI)
14	New Zealand	Engineering New Zealand (EngNZ)
15	Pakistan	Pakistan Engineering Council (PEC)
16	Peru	Instituto de Calidad y Acreditacion de Programas de Computacion, Ingenieria y Tecnologia (ICACIT)
17	Philippines	Philippine Technological Council
18	Russia	Association for Engineering Education of Russia (AEER)
19	Singapore	Institution of Engineers Singapore (IES)
20	South Africa	Engineering Council South Africa (ECSA)
21	Sri Lanka	Institution of Engineers Sri Lanka (IESL)
22	Taiwan	Institute of Engineering Education Taiwan (IEET)
23	Turkey	Association for Evaluation and Accreditation of Engineering Programs (MÜDEK)
24	United Kingdom	Engineering Council United Kingdom (ECUK)
25	United States	Accreditation Board for Engineering and Technology (ABET)

standards of quality assurance. It confirms to the public that an educational institution has met and is maintaining a high level of standards set by an accrediting agency. Beyond ensuring quality standards, accreditation encourages institutions to identify and implement good practices that are functional for continuous improvement [6]. This process not only focuses on the outcomes but also emphasizes the importance of the process by which these outcomes are achieved, fostering a shift in the way academic institutions reflect on their practices. In this way, accreditation becomes a vehicle for quality enhancement, promoting systematic management and monitoring of educational processes to achieve excellence.

Accreditation is extremely important to an institution, its staff as well as current or potential students. It demonstrates a commitment of the institution to excellence, continuous improvement, and meeting national and international standards.

Despite criticism and discussions that there is little empirical proof that accredited universities and programmes are superior to non-accredited ones, accreditation is still considered as the system to assess, sustain, and enhance quality of higher education and its graduates. Yet, there are doubts as pertaining to accreditation's worth, sincerity, effect, and its value in improving quality [7, 8]. Not all academic staff have a good understanding of accreditation and the process of achieving it. [9].

Accreditation implies an enormous amount of work and pressure on the institution by for example asking higher education governance to change the way they plan, implement and measure their strategy and use of resources, and teaching staff to change the usual approach to teaching and learning and then adopting OBE; the paradigm actually needs a change in the culture as well. Also, increases in workload negatively affect time available for research, reduced time spent on actual teaching and attending to students' educational needs, and generally create some uncertainty about its effectiveness and possible conflicts within the institution or department. It carries additional costs, and prosaically, demands an incredible amount of paperwork, including time associated with its processing and preparation of supporting documents. With the general tendency at universities of ignoring educational achievements or simple tasks, the time spent on accreditation issues is usually underestimated and not adequately rewarded during staff assessment. This may delay (or even deny) staff promotion or tenure for deserving academics.

However, the discourse of whether accreditation is a valuable tool to improve programmes is immaterial as such discussions are not sustainable. Following the well-known mantra 'publish or perish' describing the pressure to publish academic work, the same may be applied to accreditation; 'be accredited or be irrelevant'.

Educational accreditation implies that an institution or a particular programme is reviewed by an external body to assess its standard, normally according to a certain predetermined set of norms. Typically, educational accreditation is processed and granted by a government organization. However, there is also another type of accreditation that is external to government, especially for professional degrees (registered professions). Such a system was originally developed in the late 19th and the early 20th century in the USA as a forerunner of, what now would be called articulation, which was 'used by a college or university to convince other institutions that its students and courses should be recognised by them, and vice versa' [10].

In the Southern African Development Community (SADC) there is a network of qualifications authorities across its member countries. These authorities are part of the SADC Qualifications Verification Network (SADCQVN), which works towards the recognition of qualifications across the region. Some of the members of the network are The Botswana Qualifications Authority (BQA), Eswatini Higher Education Council (EHEC), Namibia Qualifications Authority (NQA), South African Qualifications Authority (SAQA) and Zambia Qualifications Authority (ZQA).

There are two primary categories of accreditation in education, both important:

- academic (either institutional or for a particular programme of study in an institution),
- professional (or specialized).

4. ACADEMIC ACCREDITATION

Academic accreditation can take the form of either institutional or programmatic accreditation and is done by an accrediting body established by either government or any designated body, but the one which is representing educational rather than professional organization.

Both, the USA, and Canada subject their tertiary institutions to the institutional accreditation, done in the USA by regional bodies whereas in Canada by the entities controlled by provincial governments. In Italy quality assurance in higher education is guaranteed through both internal and external evaluation defined by National law and is based on the ENQA framework. The external evaluation is under the responsibility of an autonomous national agency (ANVUR) supervised by the central government.
Institutional accreditation is a comprehensive evaluation of an entire educational institution, including its mission, academic programmes, assessment procedures, policies, resources, faculty, and student services. The terms refer to the accreditation of the whole

institution, including all its programmes (bachelor, master and PhDs), sites offering those programmes, and methods of delivery, without any implication as to the quality of the study programmes of the institution. It proves that an institution meets minimum standards for quality and integrity. Accreditation from those agencies ensures that such institutions meet certain criteria for federal, national, or local government funding.

However, more popular is the system where national bodies, being government departments or government-initiated agencies, such as South African Qualifications Authority (SAQA), New Zealand Qualifications and Credentials Framework (NZQCF), Tertiary Education Quality & Standards Agency (TEQSA) or Botswana Qualifications Authority (BQA), register an institution as higher education provider, whereas accreditation is done for a particular programme – programmatic accreditation.

Programmatic accreditation evaluates specific academic programmes within an institution. This type of accreditation is important for several reasons, but mainly because it ensures that a programme meets rigorous academic standards and prepares students for their chosen careers. Therefore, accreditation provides assurance to students, employers, and other stakeholders that graduates possess the necessary knowledge and skills for professional practice.

Institutional accreditation provides a broad evaluation of an institution's overall quality, while programmatic accreditation focuses on specific academic programmes. Both types of accreditations are crucial as they confirm that students receive a high-quality education that meets rigorous international academic standards.

5. ENGINEERING ACCREDITATION

Programme accreditation may have two implications; namely, it has a proper academic status, and it declares graduates competent to practice a profession. It is clearly the latter one which refers to accreditation of engineering programmes [11].

In general, professional accreditation (or sometimes termed specialized accreditation) is the process (or the outcome of the process) by which a programme of study is validated by a professional or regulatory body as a programme that instilled into graduates the competencies required for professional practice and registration in a regulated profession. It may be considered as a statement by an independent authority to students (also potential) of an educational programme validating educational processes and product quality.

Accreditation is the central instrument for quality assurance in engineering education but also for international recognition, benchmarking, sustainability of programmes and finally an instrument to attract students and funding. Therefore, it has a clear appeal to programme and university administrators as it may result in higher student intake and enrolment. Whether it has an appeal to the staff, as mentioned before, may be debatable and not too convincing.

There is also an additional element normally not mentioned which is the problem of 'ordinary' lecturers who have no clue about OBE, accreditation, regulators, accrediting agencies, and their requirements. Frankly, even staff quite familiar with the concept of accreditation can be lost in the plethora of institutions performing the process or just being an 'umbrella' above accrediting organization.

It has been a constant and reasonable question by engineering staff at some of the European universities why some European programmes are not accredited by an organization which is part of Washington Accord? Why do we have European Network for Engineering Accreditation (ENAEE), with its country members (again not very recognized organizations) with no relation to Washington Accord?

It may be the reason that in some countries not many engineering programmes are accredited. For example, out of the 1018 engineering programmes in Poland [10], only 73 (7.2%) are registered by Accreditation Commission of Universities of Technology (KAUT) – Polish accreditation agency, member of ENAEE [12]. Frankly, not many engineering lecturers ever heard about KAUT or ENAEE, although they certainly heard about Polish Accreditation Committee (PAK), an organization performing compulsory academic accreditation, required by the ministry of education.

As of today, Agenzia per la Certificazione di Qualità e l'Accreditamento EUR-ACE dei Corsi di Studio in Ingegneria (QUACING) has accredited more than 50 Italian study programmes out of over 800 engineering programmes. In Italy, not many engineering faculty members and experts in institutional accreditation have heard of QUACING, given the significant effort that engineering programmes must make to comply with the quality assurance requirements set by the ANVUR standard framework, which allows the programmes to issue legally recognized degrees.

It is worth mentioning, that among European members of ENAEE only Engineers Ireland, Engineering Council of the United Kingdom and Association for Engineering Education of Russia are also signatories of Washington Accord. However, it has been reported that both organizations started 'strategic discussion' in 2019, though there so far is no information on the results of that discussion.

In the African context, no engineering programme may be offered in a country if it has not been accredited by relevant institutional and programmatic regulator such as SAQA, BQA, NQA and other regulatory bodies. The Engineering Council of South Africa (ECSA) and the Engineers Registration Board (ERB) have the mandate to provide professional accreditation in South Africa and Botswana respectively.

6. SUSTAINABILITY OF ACCREDITATION

Sustainability can be defined as the ability to maintain or support a process over time. Traditionally, sustainability is broken into three core concepts: economic, environmental, and social. However, sustainability in the educational context should also be considered.

In order to achieve sustainability in educational practices, it is not only necessary to develop suitable curriculum and enhance programme structure but also to fundamentally adjust culture and organizational processes across institutions. Sustained quality practices help learners to comprehend and acquire knowledge and develop required skills. It can be argued that the primary condition to achieve the above rests in human development, especially in knowledge and abilities of teaching staff, as well as their motivation and continuous improvement. Active involvement of all staff of the institution, though especially teaching staff, helps to make the quality issues sustainable rather than a one-time effort.

The other important factors include effective planning, provision of financial resources, availability of continuous stream of well-qualified potential students, supply of physical infrastructure, support of administration and institution's authority, all elements important and inevitable for sustainable development of an educational institution. Factors normally not examined such as improvement in trustworthiness within the organization, reflection on the quality assurance efforts (not necessarily only accreditation) and general acceptance among staff towards quality (including accreditation) may also play an important role in the ability of institution to foster sustainable quality practices.

Global accrediting systems for engineering education may provide the necessary momentum towards achieving sustainable education, denoting the ability to maintain and support quality (and its improvement) of programmes and hence quality of graduates.

7. CONCLUSION

Engineering accreditation is almost a compulsory requirement for academic institutions to prove and show that they meet certain educational standards. And despite its shortcomings, accreditation may provide several benefits to the quality and sustainability of engineering programme, the essence of the process is to ensure quality by providing accountability and imbibing transparency. As the ultimate goal of an educational programme is to produce graduates who would be able to advance the profession, accreditation is generally expected by employers and subsequently adopted by the majority of all engineering programmes. It can be summarized that it gives the 'seal of approval' regarding the programme and moreover enhances a stronger internationalization of the programme. However, it also gives programme leaders and staff an opportunity to reflect on its educational goals, methods and achievements plus helps them to identify areas for enhancement and to continuously improve the quality. That in essence stipulates the sustainability of accreditation.

The status of accreditation should be continuously monitored to ensure that those standards are maintained. Accreditation ensures that qualifications meet quality assurance standards and requirements, establishes a mechanism for verifying qualifications and learning outcomes and articulation strategies. All of these measures can create long term trust in qualifications and enhance movement of learners and graduates across national boundaries.

Another issue raised in the paper concerned academic and professional accreditation. Both obviously use similar frameworks and processes, and from an educational perspective, both are important for ensuring that students receive a high-quality education. However, in terms of recognition, benchmarking, and graduates achieving engineering-oriented outcomes, professional accreditation should be more widely disseminated and reinforced to produce professionals capable of responding to contemporary challenges on an international scale.

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ISSUES TO CONSIDER IN INCORPORATING ARTIFICIAL INTELLIGENCE LEARNING FOR GEOMATICS EDUCATION IN BOTSWANA

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Abstract: In the last couple of years, Artificial intelligence (AI) applications in education have received a lot of attention from both the research and the general community at large. Several international reports describe AI in education as one of the emerging fields of interest in educational technology. Despite AI technology being around for almost 30 years, it is still unclear for geomatics educators how they can take pedagogical advantage of it on a broader scale and how it can impact meaningful teaching and learning in higher education. As a result, learners miss out on opportunities to study AI-propelled smart technologies and big data-driven approaches to solve societal problems. Moreover, they are deprived of developing skills to think in terms of AI use and AI-inspired innovations to improve current processes. It is necessary to investigate meaningful ways and approaches to incorporate AI literacy and AI thinking in the school curriculum to increase the knowledge gap among learners and encourage critical thinking. Therefore, this study investigates major issues to be considered in incorporating artificial intelligence concepts in geomatics education in Botswana particularly the opportunities, challenges, ethical considerations, and overall curriculum requirements for a successful integration. Furthermore, it has designed a conceptual framework that demonstrates how artificial intelligence and data science technologies can be incorporated into geomatics education in Botswana to produce well-rounded graduates.

Keywords: Artificial Intelligence, Machine Learning, Deep Learning, Geomatics Education, Geographic Information Systems, Geospatial Technologies

1. INTRODUCTION

The Geomatics profession is a multidisciplinary field that includes several disciplines such as geodesy, surveying, remote sensing, photogrammetry, mapping, and geographic information systems (GIS). According to Klinkenberg [1], the geospatial industry can be regarded as an information technology field of practice that collects, manages, interprets, integrates, displays, and analyses data on the geographic, temporal, and spatial contexts. It is an integrated academic field that has a diverse number of applications. These include urban planning, facilities management, land surveying and management, business geographics, precision farming, automated web mapping, real estate management, environmental management, land administration, telecommunication, and so on. Other location-based applications such as vehicle and object tracking, and radio frequency identification (RFID) tags can be regarded as part of geospatial technologies. Therefore, graduates of geospatial technologies have an opportunity to pursue varying, exciting yet challenging careers.

Geospatial technologies particularly GIS have a strong connection with other information and communication systems such as data acquisition, data sharing, database management, networking, computer graphics, and visualization. The surveying field of geomatics also can benefit greatly from the advanced technological infusion of artificial intelligence (AI). For example, advancements in instruments such as electronic distance measurement, data collectors, 3D laser scanners, total stations, and automatic levels have improved surveying applications in many ways.

The computation of geospatial data sometimes requires the integration of data from different sources. For example, it may be necessary to analyze satellite images with drone imagery and crop health data in real or near real-time, which is not an easy task when performed manually. Such issues can be addressed by applying AI methods. In recent times, AI technologies have made significant strides in several industries including education, engineering, and the business community [2]. Education providers in high schools and tertiary levels need to recognize the competitive advantage that AI technologies can have in improving teaching and learning. Unfortunately, such knowledge and recognition are lacking in developing countries like Botswana. Therefore, these countries fail to benefit from a 'smart university' concept powered by AI which provides seamless platforms for automation, advanced information discovery, and dissemination, through machine learning (ML) and natural language processing (NLP) technologies. Moreover, such institutions miss out on opportunities to automate duties which include administration, curriculum development, assessment, and the highly sensitive issuance of official transcripts and degrees.

Several research studies have been conducted in the past to demonstrate how geospatial technologies can be integrated with AI methods in data mining, machine learning, and high-performance computing to extract insights and knowledge from spatial big data [3-7]. However, most of these studies have concentrated in Western countries with well-defined and structured education systems, with little focus on developing nations. It is necessary to investigate how AI technologies can benefit the latter to enhance their spatial analysis and decision support systems in education, which eventually can lead to more accurate, effective, efficient, and sustainable delivery of curricula and the production of well-rounded graduates.

The objective of this study is to conduct a comprehensive study on how AI technologies can seamlessly be incorporated into geomatics education in developing countries taking Botswana as a case study. It aims to explore the potential benefits and limitations of incorporating AI in geomatics education in Botswana and outline possible mitigation strategies for addressing the identified challenges. The structure of this paper is as follows: Section 1 introduces the subject matter and highlights key areas where geomatics education can benefit from AI technologies. It further emphasizes challenges and missed opportunities that universities could be taking to improve current processes and service delivery within the campus. Section 2 is a review of the literature on AI and its associated technologies on how they handle the processing of complex geospatial data and further outlines key challenges associated with AI integration and their possible mitigation measures. Section 3 provides a review of the Data and Methods currently used in the industry to incorporate AI into tertiary education in particular geomatics education to provide insights on how a comprehensive framework can be developed for a seamless integration of AI technologies in Botswana. A data collection study was conducted in Section 4, to examine the extent of understanding and use of AI technologies at the University of Botswana. Section 5 develops the conceptual framework that demonstrates how key components identified in this study, crucial for AI integration in geomatics can be incorporated such that the objectives of this research are adequately achieved. Section 6 discusses the findings of this study and highlights some anticipated benefits of the framework components. Section 7 concludes the study by summarizing the achievements of the research and outlining future research prospects.

2. LITERATURE REVIEW

The education sector could benefit from assistive technologies in AI for their critical thinking, geographic research, learning, and overall curriculum development. Platforms like chatting robots commonly known as 'chatbots' enable users to interact directly via text-to-text, and image-to-text prompts to benefit from several technologies such as deep learning, unsupervised learning, and instruction fine-tuning to better deliver learning material to students. AI has many sub-fields and advanced technologies which include [8]: a) artificial neural network – simulates the working neurons of the brain, b) natural language processing – produces systems that can understand, translate, and disseminate information in human languages, c) theorem provers – facilitate the computation of mathematical problems and the discovery of new mathematical concepts, d) knowledge-based systems – encodes expert human knowledge so that computers can reason with it, and e) case-based reasoning – simulates how humans reason based on past experiences.

Complex systems such as geographic information systems (GIS) need advanced reasoning mechanisms to deal with spatial data contained in their database management systems. Nonetheless, their utilization is limited particularly in systems where the data is dynamic and of a large volume. Hence, the need for futuristic technologies such as AI. From the several AI sub-fields discussed, GIS mainly uses artificial neural networks (ANN), designed to model the human brain and its ability to learn tasks using mathematical models. Unlike other forms of computer intelligence systems, ANN is not rule-based, it is trained to recognize and generalize relationships between a set of inputs and outputs. Such a training mechanism which involves learning from data, helps ANN solve complex problems by 'learning' from prior applications. Neural networks have previously been applied by the GIS community for many years as alternative tools for image classification and feature extraction purposes [9], while others have been used to perform land suitability analysis [10] and to model travel forecasts for transportation planning in metropolitan areas [11], to mention but a few. Most projects that utilize AI tools for GIS applications are done to improve selection approaches in spatial patterns or to assess the predictive accuracy and appropriateness of a spatial modeling technique, and lastly to gain insights into crucial spatial functions and processes via rule extraction [8].

Remote Sensing (RS) is another geospatial application area where AI techniques are used for several purposes which include image analysis, automation, land use, and land cover detection using imagery data. RS involves the collection of geospatial data without direct contact with the subject, using sensors to measure various types of energy, such as electromagnetic radiation and acoustic signals emitted, reflected, or scattered by the object of interest. As technology advances, more sensors have been developed and the amount of data collected increased to provide more insights because of improved quality. Nonetheless, such data volume increases and quality improvements require computational platforms and effective tools to handle and extract valuable information from the collected datasets. Janga, et al. [12] stress that AI tools can be used to manage large volumes of observations, modeling, and analysis, and that they have proven effective in reducing noise in the data collected. Other capabilities that AI tools can manage with remote sensing data include object detection [13] and data fusion [14].

AI algorithms, especially deep neural networks (DNNs), are changing how real-world tasks are approached. Although still new in geosciences, DNNs show promise in tasks like classification, anomaly detection, regression analysis, and space or time-dependent state predictions [15]. DNNs are increasingly used in geomatics because they learn data abstractions well. Initially seen as "black boxes", these models now need to be interpretable and explainable [16]. Another tailored computational model of AI designed to deal with complex computational geospatial data is called Deep

Learning (DL). The model is essential for dealing with complex statistics, multiple outputs, noise, and high-dimensional spaces associated with geographic data. In most cases, DL models fit observations well when conducting predictions. However, their projections may sometimes be inconsistent due to extrapolation or biases [17].

2.1. Anticipated challenges and strategies to mitigate them

According to Wilby and Esson [18], AI is viewed as a 'weapon of mass deception' and facilitates criminal activities in the digital world. The fears are exacerbated by the sudden releases of platforms such as OpenAI, ChatGPT, and Gemini whose consequences are felt mostly in education and research [18]. Unfortunately, most AI platforms do not have access to real-time information which can make them obsolete or irrelevant when seeking current information. For example, the open version of ChatGPT was trained on data only up to September 2021. As for the quality of the answers produced by these platforms, Ray [19] argues that they are dependent on a user asking unambiguous questions or clarifying queries, else they produce unsatisfactory or irrelevant responses. As a result, they have challenges in handling ambiguity which could be resolved by enhancing their ability to handle ambiguous queries which subsequently would improve their utility and user experience. According to Yeo-Teh and Tang [20], conversational AI models often struggle to maintain the context of a conversation, especially when it spans multiple turns. Such challenges can be improved by training the models to better track and manage context to present more consistent and relevant responses [20].

AI models like ChatGPT cannot provide personalized experiences for users as they fail to adapt responses based on users' preferences, interests, and conversational styles [21]. As a result, they are unable to provide enhanced user experiences to clients which needs further scrutiny and development. The emergence of AI technologies also presents threats to academic integrity through cheating and plagiarism [22]. Such concerns can be addressed by redefining university statutes and codes of conduct about the utilization of AI, and by explicitly outlining acceptable uses in teaching and assessment [18]. As lamented by George and Wooden [23], organizations venturing into this new educational paradigm need to thoroughly explore potential pitfalls which include the potential for job losses, educational quality, risks of bias, safety concerns, and privacy breaches. A study of AI models by [24], observed that they often lack common sense understanding or the ability to reason logically through a problem. Improving their reasoning capabilities through continuous work on its training data would lead to more accurate and insightful responses. Conversational AI models can be vulnerable to attacks and malicious inputs, so it is necessary to enhance their robustness when dealing with security and privacy issues to ensure their reliability [25].

Issues of the legal and regulatory framework are a concern for integrating AI with geomatics, particularly those related to liability, intellectual property, and accountability [26]. Robust legal and regulatory frameworks that focus on ethics and legal implications of AI in geomatics are imperative for a responsible deployment. To harness the full potential of geomatics with AI, interdisciplinary collaborations between policymakers, data scientists, geospatial scientists, and community leaders are important to navigate challenges.

The successful integration of AI with geomatics is reliant on a skilled workforce capable of adequately utilizing these technologies. An observation by Lang, et al. [27] is that there is a desperate need for experts well versed in both geospatial sciences and AI methodologies. Such a challenge can be mitigated by conducting interdisciplinary training programs essential to harness the full potential of the integration.

Despite the outlined challenges, this study believes that future advances in AI platforms and other language models such as ChatGPT can address these shortcomings. They have transformative potential in geomatics education and knowledge production which can sufficiently support critical thinking, synthesizing abilities, and potential for data extrapolation if used properly. By enhancing their AI literacy, geographers and educators can provide an environment for the responsible and effective use of these assistive technologies in academic practice.

3. METHODOLOGY

The evolution of AI models from their predecessors to the current state has made it an invaluable resource for advancing geomatics research and education with impacts felt across various applications including data analysis and processing, hypothesis generation, and interoperability. The geomatics community needs to give extraordinary attention to the research and development of AI models. This section explores and elaborates on the methodology of incorporating AI models into geomatics education and investigates key application areas to the different fields of the profession. Furthermore, it highlights issues to be considered and how they could be addressed in the geomatics field for a successful integration.

Practitioners particularly in academia must familiarise themselves with emerging technologies such as AI to establish means in which the existing curriculum of geomatics can be revised adequately to meet current demands. Nowadays, the geomatics profession has grown due to technological advancements from engineering and cadastral surveys and has expanded to newer areas of geospatial information systems engineering. For example, the current status of a land surveyor is the most vulnerable profession in this digital technology era. Other than the material resources required to conduct the surveys and a human being to perform the work, its procedures are the same, despite the project scope. In the past, human beings would be required to perform repetitive tasks of surveying, often marred with errors, resource costs, and time constraints. Computers have become the best tools to perform routine and computationally intensive tasks of a surveyor's activities with precision and within a short period. Thus, it is evident that these technological advancements in surveying are inevitable.

Equipment manufacturers have fully embraced innovation and advances in technology to boost their sales by integrating mathematical and scientific aspects of surveying into their products. Such strategies enable untrained people to conduct surveys of an acceptable standard without necessarily understanding the underlying science involved. Indeed, this is a threat to the industry that key players particularly in academia, known to be innovators should lead, embrace, and establish effective ways of addressing these challenges. To modernize the geomatics curriculum to meet market needs, it is necessary to examine the legal implications, educational requirements, and professional strategies required for a successful implementation.

Currently, the curricula for traditional surveying practiced in Botswana are designed for graduates to precisely locate positions on the earth's surface. Such a profession requires physical fitness, inquisitiveness, high mental capacity, above-average skills in mathematical calculations, and an ability to work in harsh conditions where necessary. However, technological advancements have rendered most of these requirements outdated and no longer pre-conditions. Recently, several tools and techniques have been developed to acquire survey data with high precision, flexibility, and reduced cost. For example, ground surveys nowadays are performed using electronic total stations and Total Scan systems which provide direct measurements to establish spatial locations of physical objects. AI algorithms are characterized by the ability to emulate human-like intellect. As a result, they have become indispensable in geomatics because of their ability to process large amounts of geospatial datasets swiftly and accurately. This capability is crucial in geomatics applications particularly surveying which at times can be large in volume, often overwhelming traditional methods. Thus, the integration of AI into surveying facilitates the expedited processing and analysis of large datasets, which subsequently increases speed and enhances the accuracy of the surveying process [28].

For urban planning projects, it has been identified by Smith, et al. [29] that AI combined with geomatics facilitates the creation of intelligent models that are data-driven for sustainable urban development.

4. DATA COLLECTION AND SIMULATION

To examine the extent of understanding and use of AI technologies at the University of Botswana, approximately 122 engineering students were engaged at the Faculty of Engineering, in an online questionnaire via SurveyMonkey platform. They were engaged for three months, April, May, and June 2024. The findings indicate student's familiarity with the use of AI models, particularly ChatGPT, and their positive perceptions towards the use of AI tools in learning. Almost all respondents 104 (85%) reported that they were familiar with ChatGPT and more than half of them, 68 (56%) used it regularly. Regarding their feeling towards the use of AI language tools and other chatbots in education, a large proportion of students, 94% expressed their delight towards these platforms.

Even though about 73% of the respondents articulated their desire for AI tools to be integrated into the geomatics curriculum, they were unsure if the university had regulations and guidelines regarding the responsible use of AI. Questions on ethics and plagiarism concerns, received mixed feelings amongst the students, as some 47% felt the use of AI would be unethical as it might encourage laziness and negatively affect their critical thinking skills. Nonetheless, other respondents, 53% expressed their desire to have AI tools regulated such that they become integral to their academic study routines to enhance their everyday learning.

Approximately three-quarters, 73% of the respondents reported making positive use of ChatGPT as a personal tutor and a tool that enabled them to derive insights about topics, which they later expanded using relevant literature. However, an in-depth analysis of the results obtained from the study revealed negative uses of ChatGPT, about 40% of students used it to complete their assignments. Most students, 96% reported awareness of regulations on academic dishonesty principles of cheating, copying, and plagiarism and the consequences of such. A follow-up question that asked if students desired AI tools to be fully incorporated into their curricula with proper guidance from the university received a similar outcome as the previous question. In terms of privacy, accuracy, and security issues, about 65% of respondents reported that they trust AI tools and the accuracy of the information they produce.

The data collection activity described here demonstrates the need for a balanced approach that harnesses the potential of AI tools while mitigating their risks. Nonetheless, there is a bigger challenge for the academic community on how such new technologies and tools can be leveraged to improve learning and to provide a conducive safe, and secure online environment for students. Some studies in the past [30-32] have shown that applications such as ChatGPT can broaden knowledge and learning processes on diverse subjects, promote personalized learning experiences

[33], facilitate the writing process [34], and give learners the autonomy to increase their sense of control over their learning processes and further strengthen their sense of ability [35]. It is anticipated that all these benefits can improve the learning experiences of students even in developing countries like Botswana. AI tools if properly used with honesty, can increase the involvement of students in the learning process and increase their ability to critically analyze information and ask pertinent questions, thus increasing their problem-solving skills.

5. FRAMEWORK DEVELOPMENT OF AI INCORPORATION INTO GEOMATICS EDUCATION

This study has designed a conceptual framework that demonstrates how key components identified in this study (from the review of literature and the data collection study), crucial for AI integration in geomatics education can be incorporated such that the objectives of this research are adequately achieved. Geomatics education can effectively be integrated with AI technologies to equip learners with skills and knowledge necessary to excel in a data-driven geospatial environment. The consideration of the framework components does not only enhance academic learning, but also fosters innovation and adaptability in the field of geomatics.

The impact of AI on geomatics is still in its early stages, but it has the potential to be transformative. AI is already used in a variety of geomatics applications, and its use can increase in the future. There is a need for clear policies, guidelines, and frameworks to responsibly integrate AI in geomatics education. Empirical research to understand user experiences and perceptions is also necessary. The findings of this study represented in the conceptual framework outline the main issues to be addressed, anticipated benefits, and key curriculum development aspects to focus on, for a successful integration.

The framework components further provide insights that can guide future research efforts in understanding the implications of incorporating AI systems in geomatics education. By addressing the outlined challenges in the framework, AI integration in geomatics learning can be a powerful tool for advancing education, although a comprehensive collaborative effort from governments, educational institutions, and the technology industry is required to effectively address these challenges.

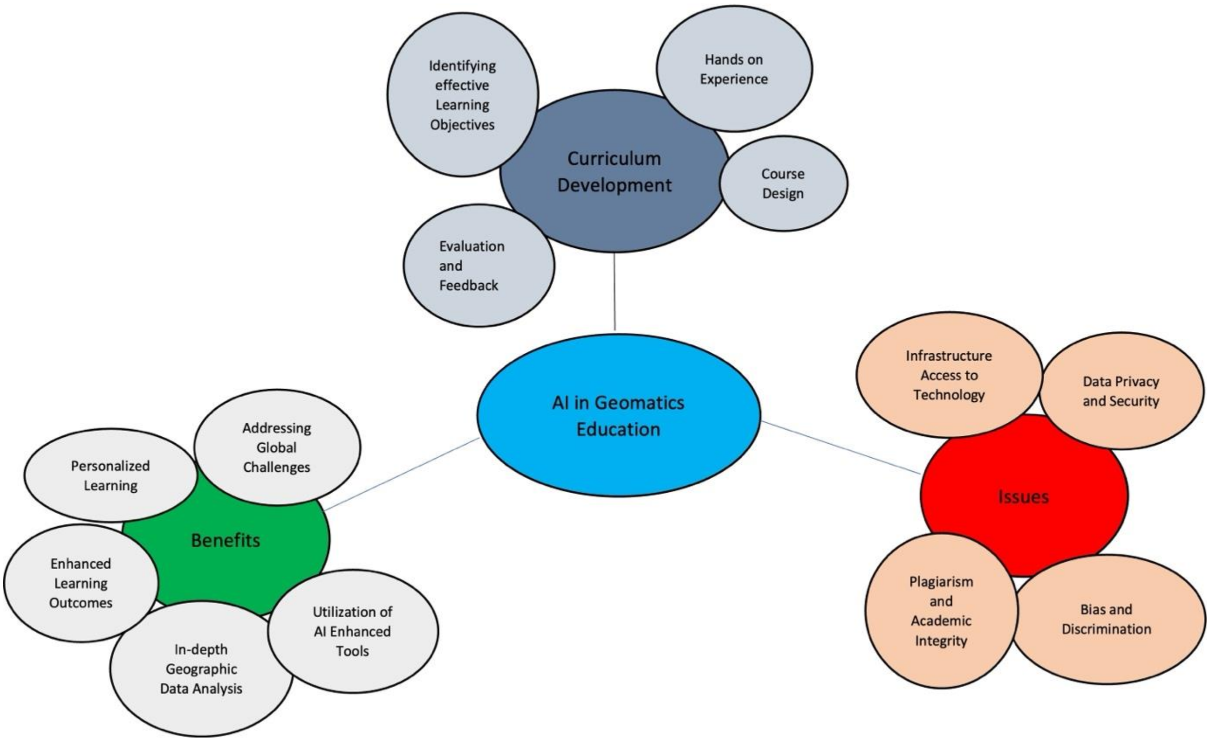

Figure 1. Conceptual framework for incorporating AI techniques into geomatics education.

6. RESULTS AND DISCUSSION

For the incorporation of AI into geomatics education to be effective, educational institutions need to confront immediate implications for academic integrity and design new policies, ethical standards, and sufficient training for staff and students. Faculties need to investigate effective ways of integrating AI ethics into curricula. Moreover, it is necessary to develop tools to detect text written by AI platforms. The automation of geospatial data analysis, propelled by machine learning algorithms, expedites the identification of intricate patterns and the extraction of meaningful geographic features [36].

As AI empowers geomatics with predictive modeling capabilities, researchers in academia should explore how professionals can simulate and analyze different scenarios, to aid in strategic decision-making. For example, the capacity of AI to handle intricate spatial relationships makes it a cut above the rest in geomatics. AI algorithms can manipulate complex patterns and relationships in geospatial data which naturally may elude traditional systems. Such capabilities further extend to the identification of trends over a period providing insights important for informed decision-making in diverse applications, such as infrastructure development and urban planning [37].

The growth of AI into geomatics holds immense potential for applications like predictive modeling, scenario analysis, and decision support systems. Predictive modeling utilizes historical data to anticipate future trends in the spatial domain, which can provide valuable foresight for professionals. Scenario analysis allows users to model and simulate various conditions to provide a strategic advantage in decision-making avenues [38]. The integration of both predictive modeling and scenario analysis by AI models empowers professionals to simulate and evaluate the potential impacts of various situations on the areas of study. In a nutshell, the integration of AI into geomatics education can usher in a transformative era in the profession. In addition, the precision, speed, and learning capabilities of AI technologies have elevated geospatial data analysis to high levels of accuracy and efficiency, hence the need for their consideration and inclusion in the curricula of geomatics education.

This study recommends strategies for integrating AI into geomatics education to create positive outcomes which include: raise awareness about disruptive change, train faculty, change teaching and assessment practices, partner with students, impart AI learning literacies, bridge the digital divide, and conduct applied research.

7. CONCLUSION

Overall, it is believed that universities incorporating AI with geomatics education can lead to the achievement of personalized learning trajectories, and enhanced accessibility to learning materials. The incorporation of AI into geomatics education facilitates complex data analysis, which enables the recognition of sophisticated spatial patterns and the extraction of meaningful objects. Therefore, more accurate results are obtained that support informed decision-making processes, which subsequently contribute to sustainable development. The dynamic nature of AI and geomatics education requires continual research and development efforts. There is a need for in-depth explorations to keep pace with evolving technologies to ensure that geomatics applications benefit from the latest improvements. These include research on novel AI algorithms and tools, improved geospatial data collection and analysis methods, and enhanced integration techniques. Therefore, future work acknowledges that current AI platforms are lacking in terms of recency as they work on latent training data. They may not be sufficient to geomatics education as up-to-date data and processing capabilities are required to produce tangible results. Therefore, future research will focus on investigating innovative ways of establishing AI techniques that can train data on a regular basis such that the profession can offer unprecedented opportunities for graduates, professionals, and the local community for sustainable and informed development practices.

DATA AVAILABILITY STATEMENT:

Data is available on request.

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DECLARATION OF INTEREST:

The authors declare no conflict of interest.

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PRIMING LIBRARY AND INFORMATION SERVICE DELIVERY IN AID OF OPEN AND DISTANCE LEARNERS IN THE DIGITAL ERA

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Abstract: Given the understanding that the word 'distance' portends 'standing apart', 'separation' or 'remoteness', the term distance education could connote the form of study where there is the element of separation between the learner and the teacher. This signifies that teaching and learning between the teacher and learner are conducted at a distance and indeed, remoteness is a common feature of this form of education. Consequent upon the fact that the students who enrolled for this type of education are hardly seen on the campus of their institution to enjoy any form of face-to-face interaction with their lecturers and librarians, they are sometimes referred to as remote learners. But then, irrespective of their scattered locations, a library of an institution that floats open and distance learning programmes owes it a binding duty and responsibility to ensure that students are reached and accorded the right service equitable to what is given to the on-campus face-to-face students. This paper examines the concept of distance learning in-depth and indicates the major distinction between this mode of education delivery and the conventional face-to-face teaching and learning process. The paper underscores the general characteristics of distance learners, culminating in the strategies that could be adopted by the library of an institution that promotes distance education either as a single- or dual- mode system to meet the information needs of these learners. The methodological approach adopted for this paper revolves around an in-depth desk-top literature review and the author's viewpoints based on the prevailing digital environment of distance learners in Botswana. Based on the issues raised in the paper, some recommendations are made to assist an institution that is preparing for open and distance learning.

1. INTRODUCTION

The understanding of the word 'distance' according to The Oxford English Dictionary (1989) portends 'standing apart', 'detach', 'separation' or 'remoteness'. The term distance education could connote the form of study where there is the element of separation and detachment or aloofness between the learner and the teacher. In other words, teaching and learning between the teacher and learner are conducted at a distance. This therefore embodies the major distinction between this method of education delivery and the conventional face-to-face teaching and learning process. Remoteness is a common feature of this form of education. Consequent upon the fact that the students who enrolled for this type of education are hardly seen at the campus of their institution to enjoy any form of face-to-face interaction with their lecturers, they are sometimes referred to as remote learners.

The concept of distance education often interchangeably called distance learning has been variously defined by associations, organisations and scholars in the field. For instance, American Association of University Professors (2007) perceives distance education as instruction between a teacher and students when they are separated by physical distance and communication is accomplished by one or more technological media. Frank (2008) describes the concept as a field of education that focuses on the pedagogy, technology, and instructional systems design that is effectively incorporated in delivering education to students who are not physically “on site” to receive their education. Frank further affirms that teachers and students may communicate asynchronously (at times of their own choosing) by exchanging printed or electronic media, or through technology that allows them to communicate in real time (synchronously). UNESCO (2016) defined distance education as a form of education in which the instructor and the student are separated in time and space, through forms of online learning, blended learning, with the use of printed resources delivered to students by mail or other tools.

Keegan (1999) has repeatedly modified his definition since 1983 when he made the first attempt. The latest of the modifications seems to provide a more detailed definition. It also takes into consideration some recent development in the field of distance education. For this reason, this paper will adopt Keegan's (1999: 50) definition where he sees distance education as a form of education with the following five characteristics: First, “the quasi-permanent separation of teacher and learner throughout the length of the learning process (this distinguishes it from conventional face-to-face education)”. Second, “the influence of an educational organization both in the planning and preparation of learning materials and in the provision of student support services (this distinguishes it from private study and teach-yourself programmes)”. Third, is “the use of technical media e.g. print, audio, video or computer, to unite teacher and learner and carry the content of the course”. Fourth, “the provision of two-way communication so that the student may benefit from or even initiate dialogue” (This, Keegan notes, distinguishes it from other uses of technology in education); and fifth, “the quasi-permanent absence of the learning group throughout the length of the learning process so that people are usually taught as individuals rather than in groups, with the possibility of occasional meetings, either face-to-face or by electronic means, for both didactic and socialization purposes”.

Australian Christian College (ACC) (2020) sees distance education from the point of view of the numerous benefits it offers and says distance education caters to the diverse needs of learners globally. One of its primary advantages is the flexibility it provides. ACC observes that with distance education, students can learn at their own pace, making it an ideal choice for those with varied schedules or commitments. This mode of learning also eliminates the need to commute, which not only saves time but also reduces the financial burden of transportation and related expenses. Furthermore, distance education opens up a plethora of educational opportunities. ACC asserts that whether residing in bustling cities or remote locales, students have access to high-quality education without geographical constraints and thus democratises learning, ensuring that quality education isn't limited to those within proximity to educational institutions.

Closely interlocked to distance education is the term 'open and distance learning'. In his attempt to unfold the etymology of open and distance learning (ODL), Biao (2012) asserts that ODL was first known as 'distance learning' before it became 'open and distance learning'. Biao believes that the concept 'distance learning' emerged from the idea of 'distance education' which came from 'correspondence education' which itself arose from 'non-formal education'. Biao avers that the motivation for the emergence of ODL was the inability of numerous qualified candidates to access tertiary education in regular or formal tertiary education institutions. This assertion was sustained by McAndrew (2010) who explicates that The Open University when established in 1969 met a challenge where approximately 5% of the adult population was able to attend university in the UK at the time. He recalls that higher education had very limited availability and, while the provision was expanding, many people were being left behind unable to meet entry level qualifications or find the time required for full time study away from employment. The Open University, according to McAndrew, sought to use the technology of the time to offer courses that addressed the distance barrier and the entry barrier to offer relatively large numbers of learners' access to higher education. He concluded that the mission adopted by the OU was to be "Open as to people, places, methods and ideas".

The UK Open University (OU) (2019) and authors like Maxwell (1995) also consider open education as an approach. In a discourse, Bağrıacık and Karataş (2022) gave an account of The UKOU that students have flexible access to the study materials, and they can engage in the activities and assignments from wherever they want. This flexibility and accessibility is identified as "openness" (The Open University, 2019). Similarly, Maxwell (1995) insists that every form of education has a level of openness. Distance education systems are generally considered to be open systems, because students are not required to study in a specific place and time.

In its submission on ODL, The Commonwealth of Learning (1999) – the umbrella body for open and distance learning in the Commonwealth countries, observes that there is no one definition of open and distance learning. The body claims that there are many approaches to defining the term, but confirms that most definitions pay attention to the following characteristics:

- separation of teacher and learner in time or place, or in both time and place;
- institutional accreditation; that is, learning is accredited or certified by some institution or agency. This type of learning is distinct from learning through your own effort without the official recognition of a learning institution;
- use of mixed-media courseware, including print, radio, and television broadcasts, video and audio cassettes, computer-based learning, and telecommunications. Courseware tends to be pre-tested and validated before use;
- two-way communication allows learners and tutors to interact as distinguished from the passive receipt of broadcast signals. Communication can be synchronous or asynchronous;
- possibility of face-to-face meetings for tutorials, learner–learner interaction, library study, and laboratory or practice sessions; and
- use of industrialised processes; that is, in large-scale open and distance learning operations, labour is divided and tasks are assigned to various staff who work together in course development teams.

In what seems to be the genesis of ODL in Africa, Biao (2012) believes the eagerness to accelerate the pace of educational development within their borders and fulfill the aims and meet the targets of various international agreements on education, many African nations started to employ open and distance learning strategies as tool for the 'massification' of education beginning from the late 1970s. Biao notes the process of massification was first directed towards the training of teachers before it was pointed towards other areas of education. Oladokun (2008) lends credence to this when he traced the establishment of ODL in Botswana starting with the first experiment where 15 students were registered with Salisbury Correspondence College to be trained as teachers in the early 1960's. He states that the experiment gave birth to Francistown Teachers' project between 1968 and 1973, followed by the establishment of Botswana Extension College (BEC) in 1973 with a change of focus from training of teachers to provision of Junior Secondary School Certificate courses as well as courses leading to General Certificate of Education. He records the eventual diversification of ODL in Botswana to upgrading Enrolled Nurses to Registered Nursing through distance education, and later degree awarding programmes starting with the Centre for Continuing Education, the outreach arm of the University of Botswana. Of course, ODL expands and assumes the dimension of cross-border education with institutions like University of Derby, University of South Africa and The Management College of Southern Africa etc.) which had visible presence in the country.

Unlike in the conventional system where the educational needs of learners are met through face-to-face classroom-bound and information needs met within the four walls of a campus-based library, ODL system presents a challenge to the library since its students are not only at a distance from their institutions of study, but also scattered. Yet the library and information needs of distance learners should also be promptly met and indeed, the library should not be seen to constitute any form of cog in the wheel of academic progress of distance learners. Thus in their disperse and remote locations, distance learners must be reached and served in the same way as teaching and learning materials get to them.

2. BENEFITS OF OPEN AND DISTANCE LEARNING

Open and distance learning offers numerous benefits, which authors have identified. But Bitonlinelearn (2021) appears to have a fairly good summation of them. It highlights the following points as the need for distance education

- Explosion of knowledge: There is explosion of knowledge because of rapid scientific and technological developments. The formal system of education on account of its rigidity and high cost, finds it difficult to incorporate new changes speedily as desired
- Population Explosion: Unprecedented growth rate of population has resulted in the corresponding increase in students. The formal education system serves a selected and limited number of students
- Varied Needs: Distance learning is needed to satisfy the varied needs of varied students
- Earning while Learning: Distance education is especially needed for those who want to learn while learning
- Desire to Improve Qualifications: There are many people who want to improve their education qualification while they are in jobs. Distance learning provides opportunities to such people to improve their qualifications
- Geographical Isolation: People may be geographical isolated because of distance or because a communication system has not been developed
- Social Isolation: People may be socially isolated or disadvantaged due to financial, physical, emotional or family circumstances
- For Different Ages: Distance learning can be used to teach people of different ages and to teach courses from a wide range of discipline areas
- Universal Education: Distance learning is needed to achieve the cherished goal of the nation for universalization of education
- Democratic Aspirations: Distance learning is needed to meet the great demand for democratisation of education from those sections of society that are neglected

- Self–Improvement: Distance learning is needed from the point of view of self-learning and self-improvement of an individual who, otherwise is deprived of receiving proper education
- Boon for In-Service Aspirants: Open universities are a boon for in-service aspirants. They can improve their educational qualifications and by doing so, they can brighten up their chances of promotion
- Easy Access: It provides opportunities to large number of people who had previously been denied such opportunities.

3. ALLIED TERMINOLOGIES AND ORGANISATIONAL MODELS FOR DISTANCE EDUCATION

Distance education has some allied terminologies borne out of the practices of the system of education. Adekanmbi (1998) confirms that as a result of the variety of media used, different forms of distance education may emerge. Some of the terminologies include open learning, correspondence education, home study, external study, independent study, flexible learning, online/virtual learning or e-learning.

It should be noted that the system of education also has three identified organisational models for institutions operating distance education. These are single, dual and consortia modes. The single mode involves institutions founded for the purpose of offering distance education only e.g. University of South Africa, Zimbabwe Open University, Botswana Open University. The dual mode is the institution that provides both the traditional face-to-face and distance education. Examples of dual mode system can be found at the University of Botswana, University of Namibia, where distance education run side-by-side with full-time face-to-face programmes. Consortia mode involves groups of autonomous institutions (educational, publishing, broadcasting), which agree to combine to offer distance education. This mode is hard to come-by in Africa. Example is Western Governors University in the USA.

4. DISTANCE LEARNERS' INFORMATION ENVIRONMENT

Irrespective of the mode of learning, learners need to be motivated or assisted to learn by boosting their information environment. They need to have a guarantee that their information needs will be met by the library department that reserves the mandate to do so. In the digital era, it is obvious that the pedestrian approach of the traditional library service that consults and assist learners within the four walls of the library would not be appropriate for distance learners and not help the ubiquitous distance learners' information environment. Taking a brief discourse on the architecture of the Joint Information Systems Committee (JISC) in the UK, Powell and Lyon (2002) express the information environment as a "set of networked services that allows people to discover, access, use and publish resources within the … heterogeneous collection of information resources and services (bibliographic, full-text, image, video, geo-spatial, datasets, etc.) of particular value to the further and higher education communities". Similarly, JISC (2007) contends that information environment "can be characterised as the set of network or online services that support publishing and use of information and learning resources".

Perhaps for reasons of the escalating development in information and communication technologies in the world, a new epithet "hybrid" is added to the concept to reflect the latest development. Sompel, Hochstenbach, and Pessemier (1997) seem to agree with this avowal when they note that due to the Internet-explosion and increasing availability of digital content …, the spectrum of the information environment has diversified far beyond the traditional print-oriented library. Thus it is common today to hear of hybrid information environment (HIE).

In a document written for the UK Office for Library and Information Networking (UKOLN), Russell, Gardner and Miller (1999) describe a hybrid information environment as "one where an appropriate range of heterogeneous information services is presented to the user in a consistent and integrated way via a single interface". The aim of the information environment as argued by JISC is "to help provide convenient access to resources for research and learning through the use of … resource management tools and the development of better services and practice". JISC (2007) further elaborates that the information environment aims to allow discovery, access and use of resources for research and learning irrespective of their location. Reiterating the importance of information environment in the lives of users, the Committee believes that information environment must be fit to serve the needs of students, teachers and researchers in further and higher education into the future, adding that it should "offer the user a more seamless and less complex journey to relevant information and learning resources".

5. STATEMENT OF THE PROBLEM

Open and distance learning operating either as single-, dual- or consortia- mode in any institution of learning is a system of education embraced worldwide for reasons of its numerous benefits. But as the system receives the support of governments and people in all the countries where it is established, it has a lot of drawbacks! Learners are known to suffer from high failure or low pass rate and withdrawal or discontinuance of participation in distance programmes. Bağrıacık and Karataş (2022) observed that while the demand for open and distance education is increasing, it also faces high dropout rates in Turkey. Studies have revealed that distance education suffers high attrition rate when compared with face-to-face on-campus programme. In a comparative study of face-to-face and virtual education at a Public University in Peru by Chamorro-Atalaya et al (2023), the results indicate an increase in the average rate of failure from 25% to 34%. In other words, the results are equivalent to 242 students failed during the context of face-to-face education, and 438 students failed during the context of virtual education. In a doctoral dissertation on adult learners enrolled in virtual classroom, Smith (2010) observed that dropout rates among distance learners fluctuate between 40-80%.

Perhaps a more dreaded scenario was observed in the study of Simpson (2013) where he raised the same fundamental problem at the heart of international distance education – the problem of student retention and dropout! Figure 1 presents a comparison of completion rates in some conventional and distance institutions across the world.

The graph below, culled from Simpson (2013) study, revealed that the graduation rates for the distance institutions appear to vary between 0.5 - 20% compared with more than 80% for full-time face-to-face education in the UK. Whilst not discarding the possibility that other distance institutions could be doing much better, including private ones, Simpson observed that the University of Phoenix, which is one of the largest private providers in the USA, has only a 6% graduation rate on its distance programmes.

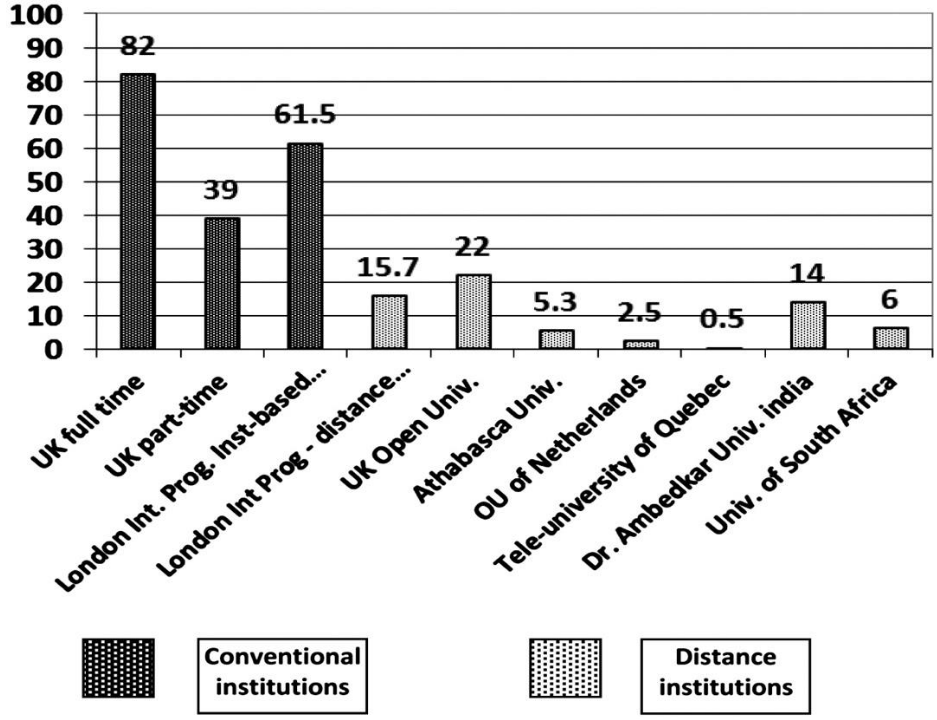

Figure 1. Graduation rates across a variety of higher education institutions (Simpson, 2013).

In their paper titled '*why do open and distance education students drop out?* The findings from the interviews Bağrıacık and Karataş (2022) conducted with 40 participants revealed that students decide to drop out mainly due to four main reasons: internal reasons, external reasons, student characteristics, and student skills. Whilst it is significantly noticeable that ODL programmes are phenomenally increasing, librarians seem to be confronted with the challenges of offering library and information service that is at par with what the on-campus students enjoy. Simpson calls for motivation and refers to the advocacy of a group he calls the Retentioneers that proactive support must not be denied distance learners. A number of questions arise from this advocacy. How much of effort do distance teaching institutions and their arms, including the libraries, make to be familiar with distance learners' characteristics to be able to provide them better service? What learning motivation will a distance institution put in place for the learners to assist them not to fall by the way-side? What proactive support do distance teaching institutions offer? How much of 'internal' and 'external' challenges of distance learners are known and assisted on by distance institutions? To what extent will the libraries of these institutions assist in motivating the distance learners and offering parity library and information services to them the same way as on-campus students receive?

6. OBJECTIVES OF THE STUDY

The main objective of this study was to examine the preparation for library and information service delivery in aid of open and distance learners in the digital era. Specifically, the study aims to:

- Examine the concept of open and distance learning in readiness for library and information service delivery
- Determine the distance learners context and characteristics to enable the library gauge how they can best be assisted
- Explore the motivating and strategic means through which distance learners can have access to library and information resources and services in their remote locations

7. METHODOLOGY

The paper is based on in-depth literature review and the author's experience as practicing information practitioners shouldered with the responsibility of assisting the off-campus students, especially distance learners, as well as educators in the field of library and information studies.

8. DISTANCE LEARNERS CONTEXT AND CHARACTERISTICS

Studies have shown the context of distance learners and their varied characteristics, culminating in the idea depicting the heterogeneity of this group of students. As such, distance learners cannot be treated as homogeneous group. Notwithstanding, it has been observed that many distance learners do share broad demographic and situational similarities that have often provided the basis for profiles of the "typical" distance learner in higher education" (Thompson, 1998). Galusha (2012) states that distance learning is student-centered learning, therefore, knowing the characteristics and demographics of the distance learners helps in understanding the potential barriers to leaning. Although students' characteristics and needs may not guarantee success in a distance education course or program, it is easy to defend these factors as contributing to success

It is observed that the demography of distance learners may have some bearing in their effort to meet their information needs. For instance, the learners come from different households and communities that may be rural or urban, poor or rich. Nyirenda (1996: 3) observes that characteristics of learners in this category will "include sex, age, marital status and family size, place of residence (whether rural or urban), social status and responsibilities, income and financial resources" among others. Each of these factors is capable of influencing the information environment of the learners. For instance, for somebody that lives in a place that does not have electricity, accessibility to information and technological devices like computer, telephone and the Internet facilities will be hampered. The problem of digital divide could be more pronounced in people living in the socio-economic divide and environment where one has all the facilities at his disposal and the other does not. It is therefore important to note that the demography of these learners may have some impact in their effort to meet their information needs.

Related to the above is the varying degree of knowledge of information and communication technology (ICT) as well as information literacy skills which distance learners possess. Some do not even know how to write emails. Extant literature has established that distance learners may suffer from deficiency of these skills. Norris (2001) has noted that the chief concern about the digital divide is that the underclass of info-poor may become further marginalized in societies where basic computer skills are becoming essential for economic success and personal advancement, entry to good career and educational opportunities, full access to social networks, and opportunities for civic engagement. This seems to account for the assertion of Amrous, Daoudi and Ettaki (2013) when they insist that in the digital age, characterized by rapid technological change and proliferating information resources, the need of information literacy has notably increased. The trio avows that although information literacy is significant for students of all educational levels, it has become even more significant for e-learners. They therefore advised that e-learners/distance learners should acquire information skills, learn how to learn and use appropriate learning strategies.

Probing further into the locational dynamics influencing their information environment, Oladokun (2012) in a study affirms that distance learners in Botswana significantly fall into different locations in terms of where they lived and carried out their studies. Whilst many lived in metropolitan/urban areas which offer a much better and richer information environment, some of them lived in rural locations where information environment can be considered poor and cannot be favourably compared with those in urban areas. The result further shows that more females were also located in cities and towns (considered as urban or metropolitan areas) as well as village (rural areas) than their male counterparts. Nyirenda (1996) lends credence to the view that the environment in which the learner undertakes their studies affects learning one way or another. Those living in remote villages may also not have easy access to postal and transportation services which can make it difficult for them to easily receive materials that can be of advantage to them in writing their assignments, tests etc. unlike those that live in urban areas. Kamau (1998) expresses the view that distance learners from their remote locations may also experience lack of facilities such as study centres, schools, libraries and laboratories which may hinder learners' progress. Thus, rural-urban dichotomy is clearly visible, even as information divide between the rural areas and urban areas is distinct.

As distance learners are ubiquitous, the feeling of isolation has been seen as concerning and one typical trait known among most distance learners. Kamau (2005) in a treatise indicates that isolation is one of the characteristics of distance learners. As if to influence their environment, she pleads that "distance learners also need human support from tutors, mentors and fellow learners to reduce the feeling of isolation". Oladokun (2008) also suggests that as distance learners go about their studies by distance mode in various scattered locations across the country, it is assumed that accessibility to appropriate information resources and services would reduce the effect of distance and isolation that can be experienced in this type of learning mode. Another means of curtailing the disadvantages of isolation is to make use of colleagues and friends to bridge any existing gap that may arise. In a study on help-seeking strategies used by high-achieving and low-achieving distance education students at the Open University of Hong Kong, Taplin et al. (2001) were able to establish that for personal problems, including isolation, self-motivation, test and examination anxiety, friends and fellow students (colleagues) were clearly the most frequently approached for help. In the high achievers' group 43% claimed they spend time with friends and colleagues.

Since many of distance learners are adult students, Oladokun (2012), in his study of distance learners at the University of Botswana, confirms that these students are usually involved in other major social roles, which is often one of the reasons why such learners opt for distance education. This is in line with the observation of Simpson (2013) when he declares that distance learners *juggling with the demands of work, illness, bereavement and other life experiences, adding that distance students have many calls on their time and energy which must affect their progress.* Distance learners may have full- or part-time jobs, or could be community leaders, (single) parents, etc who hardly live in an information-rich environment. The findings revealed that 280 or 77% of the respondents indicated they were working and 203 (55.8%) were parents and 24 (6.6%) were community leaders. He concludes that the responsibilities and circumstances of such roles might affect their access to and use of information resources either positively or negatively.

In the study of the characteristics of distance learners of the University of Nairobi, Omito and Kembo (2015) confirm that majority of distance learners respondents are adults, aged between 36 and 40; majority 111 (96.5%) of distance learners were employed, most of the learners have some work experience, and most of them, 102 (88.7%), were found to be married. It was also concluded that: distance learners cuts across gender (male and female) almost on equal measure

It has already been established to a large extent, that interpersonal communication and face-to-face interaction in learning group are somewhat eliminated in distance education. Keegan (1999: 8) quotes the German scholar, Peters describing these characteristics as "cultural imperatives for education in East and West". These traits of face-to-face interpersonal communication as known in the conventional education are now being recreated in distance delivery mode with the virtual or electronic system, in which the Internet or WWW plays an active role. It is evident that distance learners can be found everywhere and anywhere – in metropolitan as well as non-metropolitan areas. Though it may not be detailed enough, Jagroop (2023) appears to make some effort to sum up the characteristics of open and distance learners when he listed the following:

- The learner may be of any age range, from young children to senior citizens. The learner does not necessarily need to be an adult.
- The learner can be a part of several organizations. He or she could be a worker or not, a member of the family, or a student at a formal institution.
- Learning is a part-time secondary activity
- The student assumes the role that he previously had.
- It could be difficult to make contact with their classmates.
- Learners contact with the institute is infrequent, and often takes place across the distance.

Arising from above, Oladokun (2008) raised a number of questions: What knowledge and skills do the learners have? Do they have the ability to use modern ICT? How skilled are they? What information facilities and resources are available to them? As some institutions may want to provide information through digital or electronic means, do the learners have the capability to use the facilities effectively and efficiently if available? How conducive is the environment of the learners to access the needed information? Norris (2001) possibly has remoteness of distance learners and people that engaged in cross-border education in mind when he proposes three types of digital divide. These according to Norris include: social (within countries), global (between countries) and democratic (those unable to use ICTs to take part in public life).

9. LIBRARY AND INFORMATION SERVICES FOR DISTANCE LEARNERS

One of the aims to this study is to explore the motivating and strategic means through which distance learners have unfettered access to library and information resources and services in their remote locations. In this section therefore, the practice of library and information services in several parts of the world where ODL takes place shall be reviewed. The views of some authors on the importance of these services in distance learning environment will also be considered.

In a digital era, what form should library service take to ensure that distance learners especially are not marginalized? Lim and Van Dyk (1997) of Monash University in Australia have some experience to share. They affirm that the various components of virtual library service model established enables users to search the Library's online public access catalogue (OPAC), renew loans, place holds on items out on loan, display digitised images of the e-reserve collection, request inter-campus or inter-library loans, make requests directly to commercial document delivery services and access a range of online databases. In addition, through the Monash Library Home Page, students can access a number of journals and Monash library guides and communicate with reference librarians electronically. They avow that users could seek assistance to access the range of information resources provided, whilst the more sophisticated ones are able to bypass librarians to use the information resources directly.

Meacham and Macpherson (1997) writing under the theme, *overcoming the tyranny of distance*, roll out various library and information services which their institution, Charles Sturt University, Australia offered to distance learners of the institution. These include information and reference service, use of other libraries, possibility of students' requests of services by phone, facsimile, post or e-mail. Toll-free phones and after-hours answering facilities are also provided. Other services include reciprocal arrangements among three university libraries in Australia which offer distance education support and free photocopy of not more than one article from a single issue of a periodical. While the university pays forward mailing costs, students pay for return of items. Literature searches providing lists of citations are provided to enable students to access materials in the university or other libraries.

At the distance teaching institution of Athabasca University (AU) (2024) in Canada, Library provides Search DISCOVER - the main search tool, where users can access a variety of resources including most of the subscribed journal databases, select open access journals and resources, e-book collections, and books and media. On the website, tutorials and guides are created for the users to assist them to navigate the research process and library designed resources. The library also provides regular webinars focused on orientation to the library, using specific library tools and resources, and on specific subjects. Library Information Desk staff are available to assist with conducting research for assignments, loaning materials from the library's physical collection, and in learning how to use the library's online resources. Users can contact library staff and make requests by email, phone, and chat or by filling out a web form. Library services are also provided through social media such as Facebook and X (formerly Twitter).

At Virginia College, USA that operates distance learning, *MacDonald* (2010) indicates that Libraries provides both synchronous and asynchronous support with telephone line/live chat and email. A dedicated email address was created for the service, and, during hours of live coverage, turnaround time is generally under five minutes. MacDonald confirms that customers having immediate information needs tend to select one of the synchronous contact methods: telephone or live chat via instant messaging. The distance library service maintains a dedicated telephone number from a cellular service provider. Using the telephone, the librarian attempts to teach learners information literacy skills especially on how to locate information themselves. Described as probably the most innovative and effective approach to offer library support service to distance learners in the new digital era is the application of screencasting software. MacDonald defines a screencast as a digital recording of computer screen output with accompanying customized audio narration. From the range of open source screencasting programmes available, Virginia Libraries select a programme called Jing® which is a freeware version of TechSmith®

In Africa, some encouraging scenario was found in the service to distance learners of African Virtual University (AVU). Kavulya (2004) confirms that AVU library has a digital library consisting of e-journals, e-books and online archives to facilitate access to worldwide resources by students. Though the study confirms that all students obtain user identification, whether they are all able to access the facilities from their various locations as and when required is another matter. Whilst there is room for improvement at Botswana Open University (2023), library services offered, among others, include email-reference services made through enquiries@staff.bou.ac.bw; Information Literacy training on how to find information easily and speedily offered as per the respective library schedule or by request; and research support. In South Africa is located one of the world's mega distance teaching institutions, University of South Africa. According to Hartzer et.al (1998), the library supplies copies of recommended materials that are usually required to be consulted at specific stages during the course. They point out that the library has built up a large collection of books, known as the Study Collection, to assist in meeting this requirement. In order to meet the information needs of its numerous students in South Africa, Unisa maintains some branch libraries in regional offices apart from the main library. The university also maintains relationship with some Municipal libraries where limited book collections are kept. Students access the collections either through a personal visit to any of the libraries or have the library materials posted to them. Using the latest information technology, the entire collection is accessed through an *opac* system with terminals located not only in the main library but also throughout the main campus and branch libraries. The University of Botswana (UB) operates a dual mode system. Oladokun (2002: 298) observes that the library and information service being developed for distance learners follows the model of UNISA. Operating under the Customers and Extension service unit, the UB Library maintains a small collection of some recommended materials in some regional centres where the students meet for occasional residential sessions. The entire library collection is also accessible through an *opac* system. Further, electronic databases provide references to periodical articles in a wide variety of subjects. It thus means that students with access to the Internet can access some of these databases and indexes, to which the University of Botswana Library subscribes. Such databases include EbscoHost, Emerald and SA ePublications.

10. CONCLUSION AND RECOMMENDATIONS

It is thus far significant to note that open and distance education programmes would need to go along with a well-planned library and information support service to ensure quality and value of learning. Simpson note a group called the Retentioneers believe that students most often drop out because of lack of proactive support. Effective library and information service should be seen as part of the proactive support.

When an institution is planning to establish a distance teaching programme, its library must also prepare and avoid some pitfalls that make some commentators' refer to distance teaching institutions as 'failure factories'. Effective library and information support service will single out the library as an entity that motivates and assists distance learners to learn and succeed. In this respect, the library must boost the information environment of distance learners with appropriate resources. It becomes a dilemma for a student to register for a degree programme with glee only to become demotivated and prematurely drop out after wasting a lot of time and resources for reasons of inadequate support from the library. In preparing library and information service for the ODL programme, the following suggestions are offered.

- Distance teaching institution should be acquainted with the spread of their students and ensure adequate opportunities are guaranteed for them to access information resources and services
- The identified librarians who will serve in the outreach unit/section/department should be familiar with what ODL or distance education is about
- The characteristics of the (distance) learners such as described in this paper must be very well known
- Whist a distance teaching library may be in collaborative partnership with other libraries to assist in serving the learners, the use of information and communication technologies cannot be dispense with to assist in library service
- In the digital era, the use of ICT, social media and mobile telephony including its functionalities, instant messaging, emailing system, e-literacy skills training, live chat with a librarian etc. are essential and should be applied in getting across to the learners at specified times
- From the range of options and practices described under *Library and Information Services for Distance Learners*, librarians should be able to pick assorted models considered suitable for the learners and the institutions
- In the times of great changes that digital era presents, distance learners librarians should be alert with the emerging technological development and applications and endeavor to adapt and adopt them for the benefit of the ubiquitous learners

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PROBLEM AND PROJECT BASED LEARNING: AN ADVANCEMENT IN ENGINEERING EDUCATION IN AFRICA CONTINENT

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Abstract: Problem-Based Learning (PBL) and Project-Based Learning (PjBL) are educational techniques where scholars engage with real world problems and situations through complex projects. In this learning approach students work together to carry out projects, using their creativity and class room knowledge to find practical solutions to a given problem, demonstrating their understanding in the arear of study. PBL and PjBL have emerge as innovative approach in engineering education which aim to transform the traditional lecture-based learning paradigm into a student-centred learning. PBL and PjBL are acclaimed for their efficacy in developing critical thinking, problem solving and team building competencies. In the context of engineering education, this teaching and learning strategies have demonstrated an improvement in students' engagement in scholarly activities, intrinsic motivation and career readiness. Despite the growing popularity of PBL and PjBL globally, the unique educational landscape and socio-economic challenges in African countries necessitate a closer look at how these approaches are implemented and their actual impact on student proficiency. Therefore, this study investigated the theoretical foundations, benefits, and challenges of implementing PBL and PjBL in engineering education in some African tertiary institutions. The study employed a mixed-methods approach, combining a comprehensive literature review with surveys administered to students and educators from specific African tertiary institutions. Its primary objective is to offer valuable insights to policymakers, educators, and researchers interested in enhancing the standard of engineering education across Africa.

Keywords: Problem-Based Learning, Project-Based Learning, Engineering Education, Active Learning, Curriculum Design, African Educational Development

1. INTRODUCTION

As knowledge becomes an essential driver of human, social, and economic development, the role of higher education and research, especially in science and technology, is gaining global prominence as a key contributor to knowledge creation [1]. The advancement and application of knowledge in engineering and technology are essential for fostering sustainable social and economic development. These disciplines are pivotal in addressing fundamental human needs, reducing poverty, and promoting sustainable growth, while also contributing to narrowing the ''knowledge gap'' [2]. As the demand for skilled engineers continues to rise in Africa, the need for innovative educational approaches in engineering education has never been more critical [3]. Conventional teaching methods, which rely on passive learning and rote memorization, have fallen short in preparing students to address complex, real-world problems. To meet this growing need, Problem-Based Learning (PBL) and Project-Based Learning (PjBL) have emerged as innovative educational approaches that foster active learning, critical thinking, and student collaboration as displayed in Figure 1 [4].

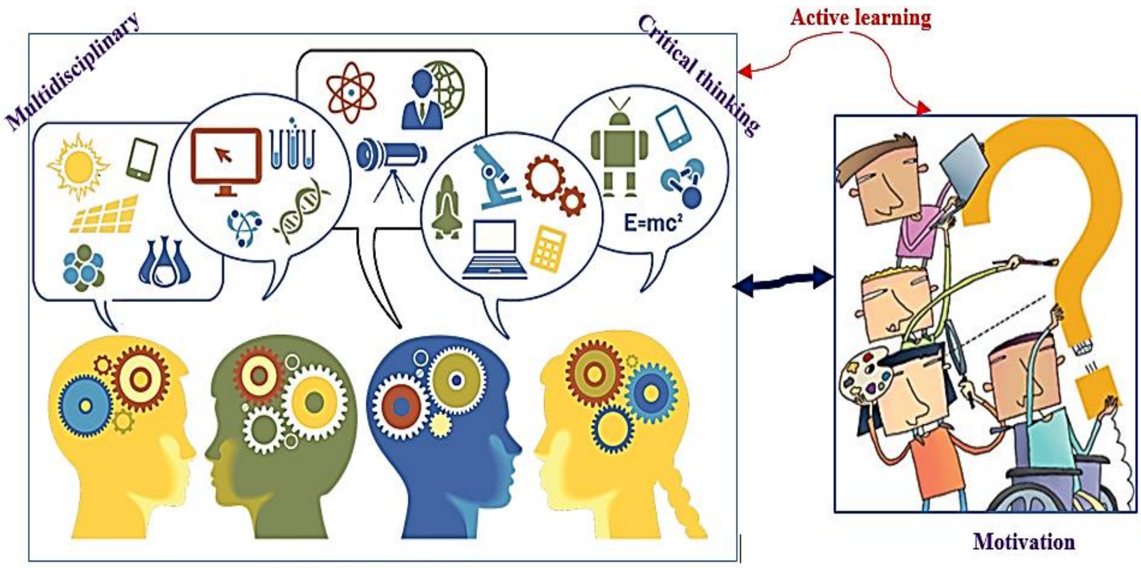

Figure 1. Elements of student-centered learning.

The primary goal of PBL and PjBL is to establish a student-centered learning environment that actively engages learners in the educational process. Student-centered classrooms typically experience higher levels of engagement and self-directed inquiry. Research identifies seven key reasons why PBL effectively motivates learners, which includes: 1) students gain autonomy, 2) classrooms become collaborative communities, 3) students work on real-world projects, 4) instructors provide constructive feedback, 5) students get up and move, 6) projects present rigor, and 7) students are given space to fail [5, 6]. With PBL, instructors give students the time, space, and support they need to persevere, learn, and succeed. As a result, students cultivate a sense of passion and resilience, becoming lifelong learners.

PBL and PjBL promote holistic approach to education by boosting the cognitive development, Emotional stability and Practical knowledge of Engineering students, as shown in Figure 2, there by gives quality engineering education needed to grow employable engineering graduates.

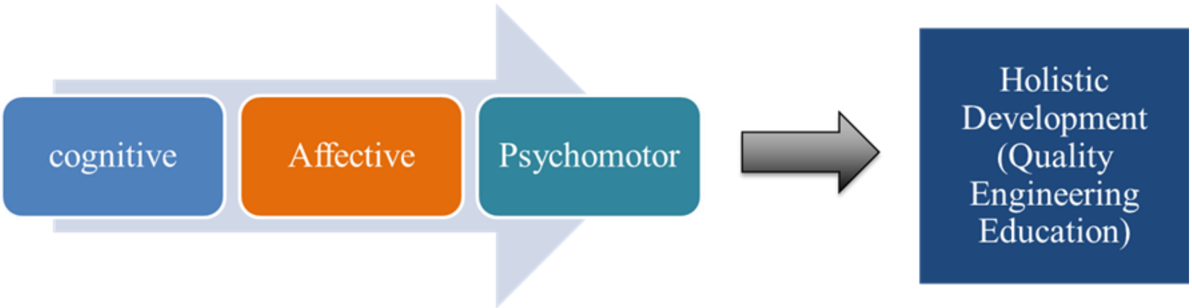

Figure 2. The role of PBL & PjBL in three domains of learning in education.

These methods have been effectively implemented across various global settings, showcasing their potential to nurture essential skills like teamwork, communication, and analytical thinking. However, the implementation of these approaches in African higher education institutions encounters distinct challenges, including limited resources, large class sizes, and a shortage of trained facilitators. By embracing these innovative teaching methods, African universities can cultivate a more dynamic learning environment that encourages creativity and critical thinking while also addressing local issues through contextualized learning experiences. This paper aims to examine the current state of PBL and PjBL in engineering education across Africa by reviewing relevant literature and analysing case studies. It will explore both the opportunities these approaches present and the challenges that must be addressed. Through an evaluation of best practices from institutions that have successfully integrated these methodologies into their curricula, this paper seeks to offer insights into how PBL and PjBL can act as catalysts for educational reform on the continent. Ultimately, this study emphasizes the need to reimagine engineering education in Africa to better equip graduates for the complexities of an increasingly interconnected world.

2. LITERATURE REVIEW

Table 1 below shows the concurrent studies on Problem Based Learning and Project Based Learning giving a comprehensive overview of the benefits of Implementing PBL and PjBL in engineering education. The table showcases different research methods used in related studies, offering a clear understanding of the current landscape of PBL and PjBL in Engineering education. This summary underscores the importance of advancing these approaches across various areas of engineering education. By presenting key insights from recent research, the table suggests compelling reasons for promoting these methodologies. A detailed examination of the data, including trends and patterns, follows in subsequent sections, helping to identify emerging themes and highlight how PBL and PjBL are evolving in engineering educational practice. This analysis will guide further improvements and innovations in engineering pedagogy.

Table 1. Related works on PBL and PjBL in advancing engineering education.

Authors	**Research methods**	**Impact of PBL on Engineering student's proficiency**
Beagon et al., [7]	- Survey or Questionnaires - Review of Related studies	- Communication - Team work - Problem solving
Bozic et al., [8]	- Survey or Questionnaire - Comparative Studies	- Creativity - Critical thinking - Self-directed learning - Team work
Mekovec et al., [9]	- Survey or questionnaires	- Critical thinking - Problem Solving - Team work
Lutsenko [10]	- Review of Related Studies	- Self Directed Learning - Problem Solving
Murzi et al., [11]	- Qualitative Interview - Review of related studies	- Communication - Self-directed learning - Creativity - Problem Solving
Necchi et al., [12]	-Observation or monitoring -Survey or questionnaire	- Critical Thinking - Problem Solving
Ragonis et al., [13]	-Survey or questionnaire -comparative studies	- Creativity - Problem solving - Team work
Rodriguez et al., [14]	-Survey or questionnaire -Reflective assignments	- Problem Solving - Project Management - Team work
Chen et al., [15]	-Survey or questionnaire -Interview	- Communication - Team work - Metacognitive satisfaction - Problem solving
Murzi et al., [16]	-Survey -Focus Group	- Problem solving - Student Motivation
Lavado-Anguera et al., [17]	-Review of Related Studies	- Critical thinking - Team work - Student Motivation

Lara-Bercial et al., [18]	-Longitudinal study	- Problem Solving - Project Development - Student Motivation
Naveh et al., [19]	-Review of Related Studies	- Critical Thinking - Team work - Crearivity
Vilma et al., [20]	-Review of Related Studies	- Critical Thinking - Team work - Communication - Self Directed Learning - Student Motivation
Flavia et al., [21]	-Survey/Questionnaire -Review of Related Studies	- Student Motivation - Metacognition - Team work - Communication - Problem solving

2.1. Literature Review Scope

Figure 3 depicts a seven-year trend study of PBL and PjBL in engineering education from 2018 to 2024. This historical period was selected to reflect the recent developments in these pedagogical methods. Analysing these years reveals valuable insights about how PBL and PjBL have been used, their usefulness in increasing student engagement and learning outcomes, and the expanding significance of these approaches in preparing engineers for complex, multidisciplinary challenges in the evolving world of technology. The period in question marks essential educational developments that will influence future of engineering teaching and learning processes.

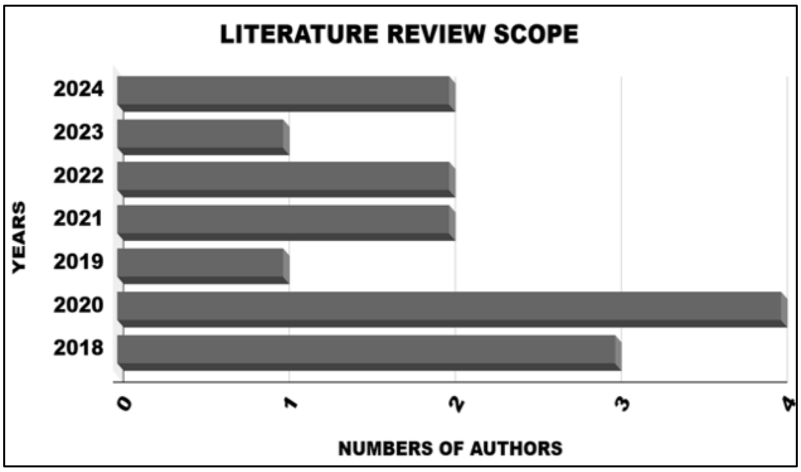

Figure 3. Literature Review Scope.

2.2. PBL & PBjL Impacts in Engineering Education as identified in Related Studies

In analyzing the impacts of PBL and PjBL on engineering students' proficiency, various benefits emerge from the literature review. As illustrated in Figure 4, the implementation of these pedagogical approaches significantly enhances several key competencies such as Problem solving which was supported by 22.4% of related studies, Team work (20.4% of concurrent research), Critical thinking (12.2%), Communication (10.2%), Student motivation to learning engineering concepts and principles (10.2%), Self-directed learning and Creativity (8.2%), project management and metacognition captured 4.1% of related works. Ultimately, the findings emphasise the numerous benefits of PBL and PjBL, indicating their efficacy in building a well-rounded skill set required of engineering students.

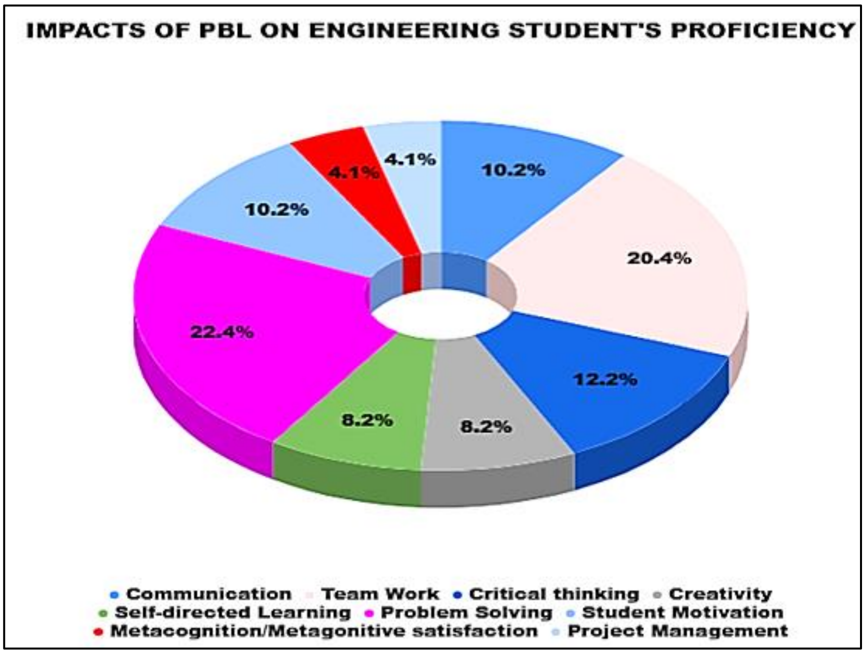

Figure 4. Identified benefits of PBL & PjBL in engineering education.

2.3. Dominant Research Methods for PBL & PjBL in Engineering Education

Figure 5 shows the different research methods used in concurrent studies on advancing PBL and PjBL in engineering education. Survey/Questionnaire prevailed with 37.5% of usage in related studies, 29.2% employed the use of related works review to find out the trends in advancing PBL and PjBL in engineering education, 12.5% employed the use of comparative studies and focus group, 8.3% utilized observation and longitudinal studies, 8.3% used qualitative interview and 4.2% employed the use of reflective assignments. This implies that the prevalent method used in related works was survey/questionnaire alongside Review of related works, the justification for their prevalence is discussed below:

a. Survey/Questionnaire

- Survey/Questionnaire promotes interaction with learners allow researchers to collect direct feedback from students and instructors involved in PBL and PjBL environments [14].
- It can be tailored to focus on specific aspects of PBL/PjBL, such as student engagement, problem-solving skills, or teamwork.
- It can be easily distributed online, making them accessible for gathering data from remote or large groups.
- It captures perceptions, attitudes, and satisfaction levels, which are essential in understanding the subjective effectiveness of PBL/PjBL [16].
- Surveys can be administered and collected quickly, making them useful for time-sensitive research projects.

b. Review of Related Works

- Reveals the current trends in PBJ & PjBL in Engineering Education Literature reviews provide a broad perspective on how PBL/PjBL has been applied in different branches of engineering education, offering insights across disciplines [20].
- Helps to identify research gaps in engineering education highlighting areas where PBL/PjBL approaches are under-researched in engineering education, suggesting where new research is needed [17].
- Reviewing past studies helps set benchmarks for how PBL/PjBL can be integrated into engineering programs, aiding curriculum development.
- Justifies the relevance and effectiveness of PBL/PjBL in engineering education by anchoring the study in established research. It offers evidence-based support for implementing these learning methods.

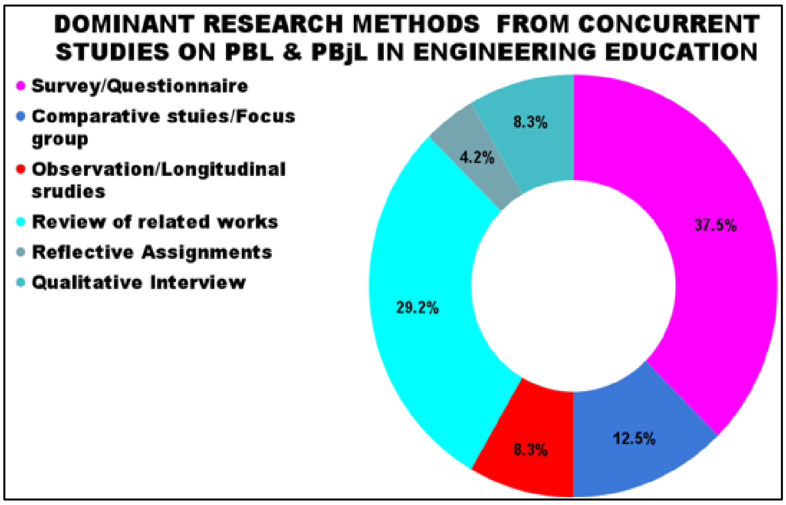

Figure 5. Dominant research methods in advancing PBL &PjBL in related works.

3. METHODOLOGY

This research employed a systematic and mixed-method approach to examine the theoretical foundations, benefits and challenges of implementing PBL and PjBL in African tertiary engineering education. The methodology is structured as follows:

3.1. Study Objectives

The key objective of this study is to investigate the implementation and outcomes of PBL and PjBL in African engineering education. Specifically, it aims to explore the benefits of these pedagogical methods in improving critical thinking, problem-solving, and team collaboration skills. Further, the study seeks to understand the challenges associated with adopting these learning strategies in engineering education across Africa.

3.2. Formulation of Research Questions

To guide the study, the following research questions were developed.

- How are PBL and PjBL implemented in African engineering institutions?
- To what extent did students endorse PBL as a means to enhance engineering education?
- What are the benefits of implementing PBL and PjBL in African engineering education?
- what are the challenges of implementing PBL/PjBL in engineering education?
- What are the proposed solutions for enhancing PBL/PjBL in African engineering education?

3.3. Comprehensive Literature Review

An extensive review of existing studies on the application of PBL and PjBL in engineering education was conducted. This review provided a conceptual framework on how existing studies have been carried out, and identifies the theoretical foundation of PBL/PjBL, highlighting the most prevalent benefits of this method in engineering education.

3.4. Target Population

This study targeted engineering students from tertiary institutions in some African countries with active or emerging PBL/PjBL programs. These countries include Botswana, Nigeria, Ethiopia and Kenya, ensuring a comprehensive understanding of the varying experiences and challenges across different social-economic and institutional contexts.

3.5. Mixed-Method Research Design

A mixed-methods approach, combining quantitative and qualitative data was employed to gain a comprehensive understanding of PBL/PjBL's impact. After an extensive review of existing studies, survey was designed and administered to students to gather data on their experiences with PBL and PjBL. This comprises question related to perceived benefits, challenges and areas of improvement for effective implementation of this pedagogical method.

3.6. Data Analysis

The method employs frequency distributions using tables with percentage in presenting data collected from the questionnaire. The survey data was statistically analysed using software like PowerBI. Descriptive and inferential statistics was applied to identify trends, correlations and patterns in the responses. This helped in measuring the overall impact of PBL and PjBL on engineering student proficiency, motivation and career readiness.

3.7. Data Collection and Simulation

This study utilised primary data. The primary data was obtained using a questionnaire. The questions were designed to assess the perceived effectiveness of PBL and PjBL in increasing student engagement, their personal experiences with PBL and PjBL, the specific challenges engineering student encountered, and their perspectives on factors that can help improve the implementation of PBL/PjBL in their respective institutions and across African.

4. RESULTS AND DISCUSSION

This section provides the results of the distributed survey, including a full analysis of the benefits, students' recommendation, obstacles, and potential solutions towards effectively integrating PBL/PjBL in African engineering education, each which is properly discussed in the subsections below.

4.1. Benefits of implementing PBL/PjBL in engineering education as identified through survey

Figure 6 Below shows the different benefits of PBL/PjBL as stated by engineering students through the survey analysis, 22.3% of the sample respondent identified Problem Solving as a key benefit of implementing the pedagogical approach in engineering education, 19.3% of respondent stated that PBL/PjBL help enhance their Collaboration and Teamwork, 16% of respondents identified Creativity and Innovation as the benefit of implementing PBL/PjBL in engineering education, 14.5% each of survey respondents identified Enhanced Critical Thinking and Enhanced Real World Relevance and Application, and 13.4% stated that PBL/PjBL Promotes Active and Engaged Learning Environment. These findings highlight the relevance of PBL/PjBL in developing the skills required for success in the engineering field.

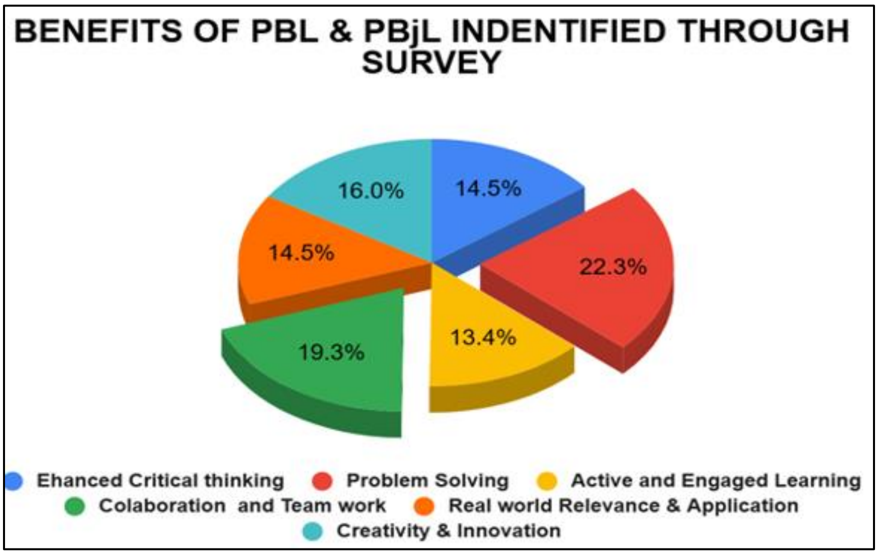

Figure 6. Benefits of PBL/PjBL as identified by respondents.

4.2. Analysis of students' recommendation for the implementation of PBL/PjBL in African engineering education

Following the identification of PBL/PjBL benefits by students, Figure 7 shows their recommendations for its implementation in African engineering education. The analysis reveals that 90.1% of respondents strongly endorsed PBL/PjBL as a valuable approach for advancing engineering education on the continent. A smaller portion, 2.8%, provided an average recommendation, indicating that PBL/PjBL could be beneficial but with certain reservations. On the other hand, 7% of the students did not recommend PBL/PjBL, suggesting that it might not be the most suitable method for improving engineering education in Africa from their perspective. These findings reflect a broad consensus in favour of PBL/PjBL implementation.

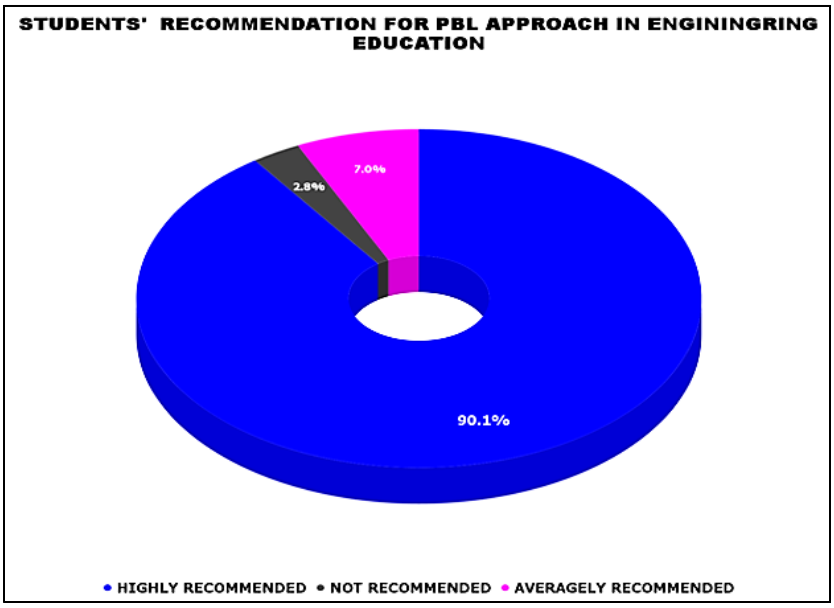

Figure 7. Students recommendation for the integration of PBL/PjBL in engineering education.

4.3. Analysis of the challenges of implementing PBL/PjBL in engineering education in Africa as identified in survey

In addition to the students' recommendation for integrating PBL/PjBL in African engineering education, they highlighted several significant challenges hindering its effective implementation. As illustrated in Figure 8 the most pressing challenges include Difficulty in adaptation, with 11.3% of respondents expressing concerns. This indicates that students often struggle to transition from traditional learning methods to PBL, which requires a shift in mind set and skillset. Similarly, 12.5% of respondents pointed out the lack of institutional support, suggesting that educational institutions may not provide adequate resources, training, or infrastructure necessary for PBL's success. This lack of support can lead to frustration and disillusionment among students eager to engage in more active learning methodologies. Limited instructor expertise in PBL/PjBL approaches, cited by 13.8% of respondents, further compounds this issue, as educators may lack the training to effectively facilitate PBL experiences.

Additionally, curriculum and cultural constraints (15.6%) highlight the need for educational reforms that align with contemporary engineering practices and methodologies. Without addressing these systemic issues, PBL cannot be effectively integrated into the educational landscape. Industrial collaboration constraints, reported by 17.5% of respondents, signify the importance of partnerships between educational institutions and industry to provide real-world context and resources for students.

Ultimately, the most significant challenge identified was the lack of adequate laboratory equipment and materials, with 29.4% of respondents indicating that insufficient resources hinder practical, hands-on learning experiences essential to PBL. Addressing these challenges is crucial for fostering an effective and sustainable PBL/PjBL environment in African engineering education.

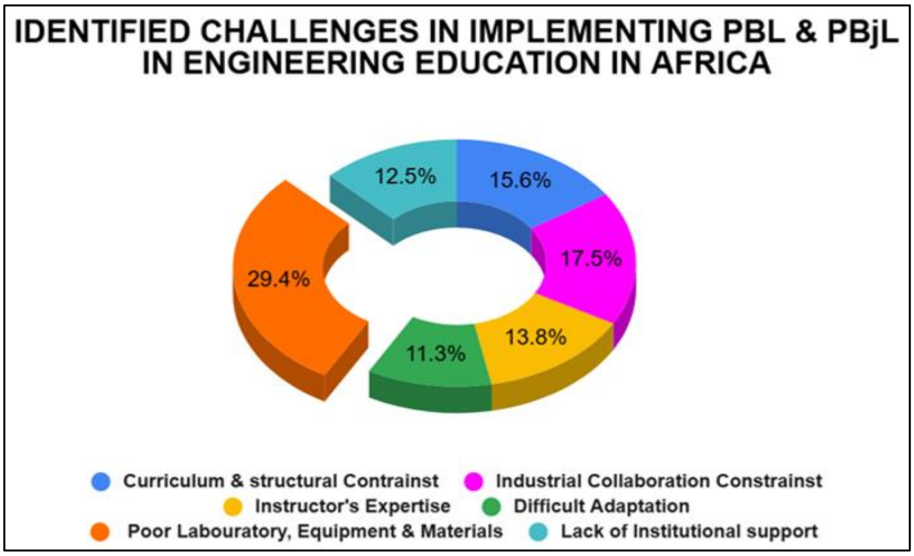

Figure 8. Challenges of implementing PBL/PjBL in engineering education in Africa.

4.4. Analysis of proposed solution to challenges limiting the implementation of PBL/PjBL in African engineering education

The proposed solutions to effective implementation of PBL/PjBL as identified through survey, as illustrated in Figure 9, includes:

a. Access to advanced laboratory equipment: 25.9% of the students emphasize the need for adequate resources, such as sophisticated laboratory, funding, and materials, to support PBL/PjBL initiatives.
b. Institutional support and culture: 14.8% of respondents suggested promoting a culture that prioritizes collaboration, nurtures creativity, and encourages ongoing innovation. This approach would integrate PBL into the core curriculum, allowing students to participate in real-world problem-solving with the essential institutional support for success.
c. Technology integration such as Machine learning and Artificial intelligence: 18.5% of respondent advocate incorporating AI and ML to personalise learning, real-time problem solving, automate feedback, and improve simulations, hence making PBL more effective and relevant to modern engineering concerns. This ensures a more engaging and practical learning experience.

d. Adequate curriculum integration and design: 16.7% of the respondents suggested curriculum revisions that integrate PBL/PjBL approaches across engineering disciplines in African education.
e. Professional development for instructors: 14.8% of the students recommended professional training programs for instructors to better understand and implement PBL/PjBL methodologies.

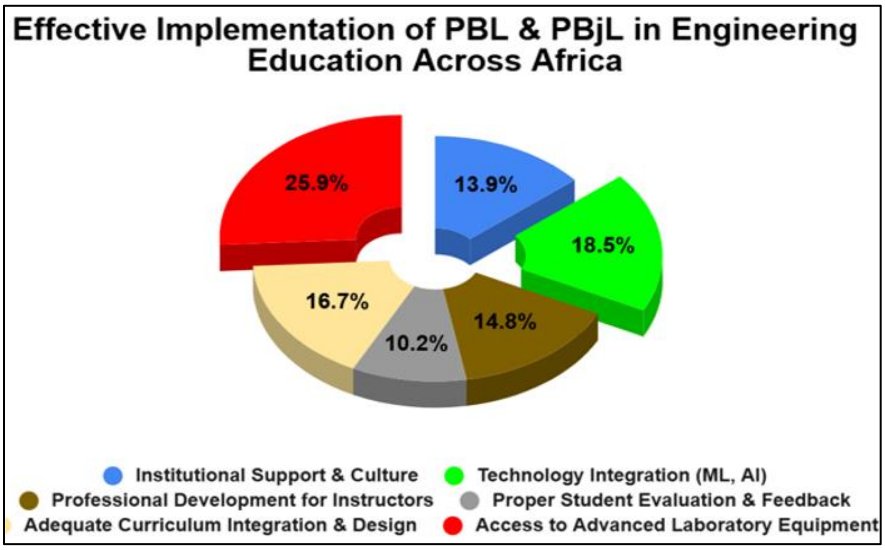

Figure 9. Effective implementation of PBL/PjBL in engineering education in Africa.

5. CONCLUSION AND RECOMMENDATIONS

This study thoroughly examined the implementation of PBL and PjBL in Engineering education within African tertiary institutions. These approaches have emerged as innovative and effective strategies for developing critical thinking, problem-solving abilities, teamwork, and career readiness among engineering students. By engaging students in real-world problems and projects, PBL and PjBL bridge the gap between theoretical knowledge and practical application, making education more relevant and impactful.

The study revealed that PBL and PjBL, when implemented effectively, improve student engagement and intrinsic motivation, critical-thinking and problem-solving skills are identified as the most prevalent benefits to engineering students in Africa. However, various challenges were identified, such as inadequate resources, lack of curriculum integration, limited access to laboratory equipment etc. These obstacles hinder the effective implementation of the learning strategies and affect their over impact. Nevertheless, with the right policies and commitment, PBL and PjBL hold great promise in transforming engineering education and preparing engineering students in Africa for the demands of the global workforce.

Based on the findings of this study, the following recommendations are proposed for stakeholders, including policymakers and tertiary institutions, to enhance the adoption and effectiveness of PBL and PjBL in African engineering education.

1. Policymakers
    - Invest in educational Infrastructure: Government and educational authorities should invest in upgrading the infrastructure and resources necessary for the effective implementation of PBL an PjBL, like providing access to technology, lab equipment, and materials that students need to complete hands-on-projects and engage in problem-solving activities.
    - Curriculum Development Support: Policies should encourage the development of flexible curricula that integrate PBL and PjBL. Educational authorities should work with institutions to ensure that engineering programs are designed to facilitate student-centered learning approaches.
    - Funding for Innovation: Funding initiatives should be established to support universities in adopting innovative teaching methods like PBL and PjBL. This can include grants for pilot programs. educator training, and the creation of project labs and maker spaces where students can work on real-world projects.
2. For institutions
    - Interdisciplinary Collaboration: Institutions should encourage interdisciplinary collaboration where students from various engineering disciplines can work together on complex, real-world problems. This fosters a more holistic learning experience, preparing students to tackle multifaceted challenges in their career.
    - Partnerships with Industry: The establishment of partnerships between universities and industries can provide students with practical experience through internships, real-world projects, and access to professionals who can mentor them during PBL and PjBL activities.

DECLARATION OF INTEREST

The authors state that they have no recognized financial conflicts of interest or personal relationships that could be perceived as influencing the work presented in this paper.

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DATA AVAILABILITY STATEMENT

Data will be made available on request.

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OPPORTUNITIES AND CHALLENGES OF USING THE ENGINEERING EDUCATION DEGREE SHOW TO ENHANCE PROBLEM-BASED LEARNING

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Abstract: Organising an engineering education degree show is a challenge and a transformative opportunity. These events serve as a beacon of student innovation, a catalyst for industry-academia collaboration, and a spotlight on academic institutions. This concept paper takes the 2024 Mechanical, Energy, and Industrial Degree Show as a case study to unravel these complexities. While degree shows are mainly seen as a platform for students to showcase their technical skills and creativity, they also serve as a gateway for direct interaction between faculty, industry professionals, and potential employers, bridging the gap between academic knowledge and real-world application. Thus, this paper presents how an engineering degree show can potentially enhance the problem-based learning (PBL) initiatives at the university. While the benefits of such events are undeniable, their organisation requires meticulous planning and coordination. Similarly, graduating students also require different attributes to cope with the demands of a degree show organisation. The challenges, such as securing funding and sponsorship, engaging industry stakeholders, managing logistics, and supporting students in preparing their exhibits, are usually enormous. Additionally, promoting the event to attract a diverse audience and evaluating its success are critical components that require strategic execution. This concept paper assesses the degree show and unravels vital skills and competencies students gain from it, with a particular focus on how it promotes PBL outcomes. It suggests strategies to help future organisers and students assemble a successful degree show to enhance problem-based learning. By addressing these challenges, institutions can better prepare students for professional practice and foster stronger connections with industry. The solutions proposed in this concept paper can benefit other universities in organising and hosting successful degree shows. The article also introduces new perspectives on how engineering degree shows can effectively support problem-based learning outcomes.

Keywords: Engineering Education, Degree Show, Event Management, Academia-Industry Collaboration, Student Innovation, Project-Based Learning

1. INTRODUCTION

Organising an engineering education degree show involves numerous challenges and opportunities. These events showcase student innovations, foster industry-academia collaboration, and make academic institutions more visible (Ramírez-Mendoza et al., 2018). By demonstrating the institution's commitment to excellence in education and research, these events can attract prospective students, faculty, and funding opportunities (Hudspith, 2001). This article explores the inaugural degree show hosted by a relatively new university in Sub-Saharan Africa, offering a unique case study to understand the complexities of organising and staging such an important event. The study aims to expand the literature on project and problem-based learning, highlighting how degree shows can positively support these learning methodologies.

While many may consider degree shows as the output of the student's journey, this article will argue that it is more than just an event to showcase projects but a catalyst of the year-long meticulous process of conceptualising and manufacturing a significant project as a constellation of accumulated knowledge. Degree shows highlight the innovative projects and solutions developed by students, which can reflect the quality of education and research within the institution (Rajlich, 2010; Bourne et al., 2005). It is essential to provide a platform for students to demonstrate their technical skills and creativity through projects and presentations. The shows also allow students to apply theoretical knowledge in practical scenarios, demonstrating problem-solving skills (Vliet, 2005). They also provide a platform where students, faculty, industry professionals, and potential employers can interact, thus bridging the gap between academic knowledge and real-world application. Interaction with industry professionals can provide students valuable feedback and networking opportunities (Blake, 2003).

Despite their benefits, organising such events involves meticulous planning and coordination. These include securing funding and sponsorship, ensuring participation from industry stakeholders, managing logistics, and providing adequate student support in preparing exhibits. Additionally, promoting the event to attract a diverse audience and evaluating the outcomes to measure its success are critical components that require strategic thinking and execution. Addressing these challenges can prepare students for professional success and foster stronger connections with industry partners.

This concept paper analyses the challenges faced in organising the degree show and proposes solutions, offering insights that can enhance the planning and execution of similar events in the future.

1.1. Research Questions

1. What are the primary challenges and effective strategies in organising an engineering degree show?
2. How does the engineering degree show promote problem-based learning outcomes?

2. LITERATURE REVIEW

2.1. Degree show vs. engineering education

Engineering education degree shows are pivotal for showcasing student innovation, fostering industry-academia collaboration, and enhancing the visibility of academic institutions. Zavbi and Vukašinović (2014) highlight that academia-industry collaboration through project-based learning and teamwork is essential for building technical and professional competencies in engineering students (Zavbi & Vukašinović, 2014). Like degree show projects, Melsa, Rajala, and Mohsen (2009) discuss how initiatives such as the American Society for Engineering Education's (ASEE) projects help advance the scholarship of engineering education, fostering innovation and enhancing the global preparedness of engineering graduates (Melsa et al., 2009). The value of problem-based approaches is emphasised through initiatives like Serve-Learn-Sustain (SLS) at the Georgia Institute of Technology. Students embark on sustainability challenges through collaborations with community partners in projects, thus enhancing their problem-solving skills and real-world impact (Hirsch et al., 2023). Similarly, Aizpun, Sandino, and Merideno (2015) also present a university-industry collaborative approach, showing its benefits for students and industry through real-world projects and practical applications (Aizpun et al., 2015).

Previous studies emphasise that industry-academia collaborations facilitate shared knowledge creation and joint innovation. For example, Kunttu (2017) elaborate that collaborations effectively enhance learning and innovation development through mechanisms like student projects and tailored degree courses. Similarly, in Martins et al. (2014), the authors demonstrate that collaborative projects involving industry and academia significantly increase student motivation and practical experience. Nevertheless, some studies indicate that degree show events often face funding, logistical planning, stakeholder engagement, and resource management challenges. Smith and Jones (2019) state that effective event management in academic settings requires comprehensive planning, adequate funding, and active stakeholder involvement. Brown et al. (2020) emphasise the importance of industry partnerships in providing financial support and enhancing the quality of student projects.

Moreover, Soltani, Twigg, and Dickens (2012) conclude that it is essential for the industry to sponsor students and some degree programs to maintain a close relationship `between students, academia and future employers, ensuring graduates possess the right skills and knowledge after graduation (Soltani et al., 2012). Therefore, the literature above emphasises the significance of the degree show in advancing engineering education.

2.2. Degree shows vs. Problem-based learning

Although engineering education degree shows are often taken as events rather than a semester-long process, they involve students tackling real-world problems, enhancing their problem-solving skills. According to Andersson (2012), students at the KTH Department of Machine Design develop product prototypes in close cooperation with industrial partners, which helps them understand the practical applications of their theoretical knowledge (Andersson, 2012). Integrating PBL in engineering courses improves student engagement and learning outcomes. Salleh and Yusof (2017) discuss how individual industrial PBL projects at Universiti Teknologi Mara Malaysia resulted in excellent grades and positive feedback from students and participating companies (Salleh & Yusof, 2017). Similar successes have been reported in Botswana. For example, Major and Mulvihill (2017) explored the effectiveness of PBL in teacher education and found that it significantly enhanced educators' ability to prepare students for real-world challenges. Likewise, Oladiran et al. (2009) documented the successful implementation of PBL in engineering education through international team projects, which helped students develop critical problem-solving and collaborative skills.

Therefore, it is clear that PBL, amongst other benefits, enhances various professional skills such as teamwork, communication, and project management. Gavin (2011) reports that PBL modules in civil engineering at University College Dublin developed students' problem-solving, innovation, group-working, and presentation skills, which employers highly value. These benefits are echoed by Oladiran and Uziak (2013), who noted that students in Botswana engaged in final-year engineering projects improved their practical and professional skills. PBL projects often involve collaboration with industry, providing students with insights into their future working environments and making their education more relevant to industrial needs. The benefits of these collaborations are highlighted by Kunttu (2017), who notes that such partnerships foster shared knowledge creation and innovation development (Kunttu, 2017). This is further evidenced by the work of Oladiran and colleagues, who have demonstrated that industry partnerships are essential for effective PBL, resulting in enhanced student learning outcomes and better preparation for the workforce (Oladiran et al., 2010).

Developing and testing prototypes is a crucial component of PBL in engineering education. Students gain hands-on experience, which is essential for understanding the design and manufacturing processes. This is emphasised by Andersson (2015), who found that using model-based design and actual prototypes significantly enhanced students' learning experiences. Oladiran et al. (2012) highlighted the importance of hands-on learning work on e-learning course delivery for mechanical engineering students in Botswana, noting the critical role of practical engagement in student success. Final year projects are integral to engineering education that employ PBL strategies. Thambyah (2011) discusses the design of learning outcomes for final-year projects, emphasising the importance of aligning these projects with industry needs and real-world applications. Literature on peer and self-assessment in group projects underscores the value of these capstone experiences in preparing students for professional practice (Oladiran et al., 2010).

While PBL offers numerous benefits, we cannot ignore the challenges, such as increased workload for students and faculty, the need for adequate resources, and effective integration into the curriculum. Kwan (2016) suggests careful planning and evaluation to address these challenges and maximise the benefits of PBL in engineering education. Oladiran (2011) supports this view, suggesting that PBL's successful implementation requires significant resource investment to ensure its effectiveness.

Therefore, in this article, we hypothesise that an engineering education degree show can effectively support, enhance and promote problem and project-based learning outcomes. Through real-world applications and industry collaboration, this approach enhances students' problem-solving skills, professional competencies, and readiness for industry challenges. However, effective management, resourcing and robust industry partnerships are essential to maximising their impact. To some extent, evidence shows that PBL integration in engineering education in Botswana has strengthened ties between academic institutions and industry, leading to more innovative and practical engineering solutions (Oladiran et al., 2009; Oladiran et al., 2010).

Nevertheless, more work still needs to be done to further cement PBL in engineering education, and engineering degree shows seem to be the answer to address the existing PBL challenges highlighted above.

3. METHODS

3.1. Report of the 2024 MEI Degree Show

The analysis is based on the detailed report of the 2024 MEI Degree Show, which highlights the planning, execution, challenges, and solutions. Data was gathered through participant observations, student feedback, faculty and industry stakeholders, and financial records. The primary focus areas included funding and resources, venue and infrastructure, project quality and support, workforce for setup, promotion and branding, industry and alumni engagement, event timing, sponsorship acquisition, and internal coordination.

3.2. Likert Scale (Quantitative)

A questionnaire was distributed to the organising team of the 2024 Degree Show to gather feedback on their perspective of the organisational process. This included preparations leading up to the show, the day of the event itself, and activities post-event. Key areas of focus included funding and resource management, venue and infrastructure logistics, project quality and support, workforce allocation for setup, promotion and branding efforts, engagement with industry and alumni, event timing, sponsorship acquisition, and internal coordination. Using a Five-Point Likert Scale, the survey collected responses ranging from "Strongly Agree" to "Strongly Disagree." This quantitative data was then visualised in Likert charts presented in Figures 5-14. This presentation offers a comprehensive overview of the organisers' perceptions of the 2024 Degree Show. Table 1 details all the questions presented under each respective area.

Table 1: Qualitative analysis questions of the 2024 Degree Show.

Funding and Resources:
a) The university allocated enough funding and resources towards organising the 2024 MEI Degree Show
b) The department allocated enough funding and resources towards organising the 2024 MEI Degree Show
c) Funding and resources were effectively managed throughout the degree show.
Venue and Infrastructure:
a) The chosen venue was suitable for showcasing the projects presented in the degree show.
b) The infrastructure (e.g., lighting, display setups) was sufficient to enhance the show
c) Overall, the venue and infrastructure met or exceeded expectations.
Project Quality and Support:
a) The quality of the projects presented in the degree show was high.
b) Students were provided Adequate support and guidance when developing their projects.
c) Participants felt well-supported in showcasing their projects during the degree show.

Workforce for Setup:
a) A sufficient workforce was available to set up and organise the degree show.
b) The setup process was efficient and well-coordinated.
c) Overall, there were no significant issues related to the workforce during the setup phase.
Promotion and Branding:
a) The degree show was effectively promoted to the target audience.
c) The branding and marketing efforts enhanced the visibility and attractiveness of the degree show.
c) Participants were satisfied with the level of promotion and branding for the event.
d) The show was highly attended
Industry and Alumni Engagement:
a) Industry professionals were adequately engaged in the degree show.
b) Alumni were adequately engaged in the degree show.
c) The involvement of industry added value to the degree show experience.
d) Participants found the interactions with the industry beneficial and enriching.
Event Timing:
a) The timing of the degree show was convenient for students
b) The duration of the event was appropriate for showcasing the projects.
c) Overall, the timing of the degree show was well-planned and executed.
Sponsorship Acquisition:
a) Sufficient sponsorships were acquired to support the degree show financially.
b) The sponsorship acquisition process successfully secured the necessary support.
c) The committee were satisfied with the level of sponsorship acquired for the degree show.
Internal Coordination:
a) Coordination among internal stakeholders (e.g., school, staff) was effective throughout the degree show.
b) Communication and collaboration within the organising team were well-managed.
c) Overall, internal coordination contributed positively to the success of the degree show.

4. FINDINGS

4.1. Funding and Resources

The results from the organising committee about the funding and resources used for the show are shown in Figure 1.40% strongly disagreed, 40% disagreed, 10% remai ned neutral, and just 10% agreed with the university's distribution of funds and resou rces for the 2024 MEI Degree Show. These numbers show that a sizable portion of r espondents are not happy with the lack of funding from the university. A similar trend is observed regarding the department's allocation of resources and funding for the show. In the final section, respondents were asked about the effective management of funding and resources throughout the show, with 70% in agreement and 10% strongly agreeing with the prudent management of resources, while 10% remained neutral.

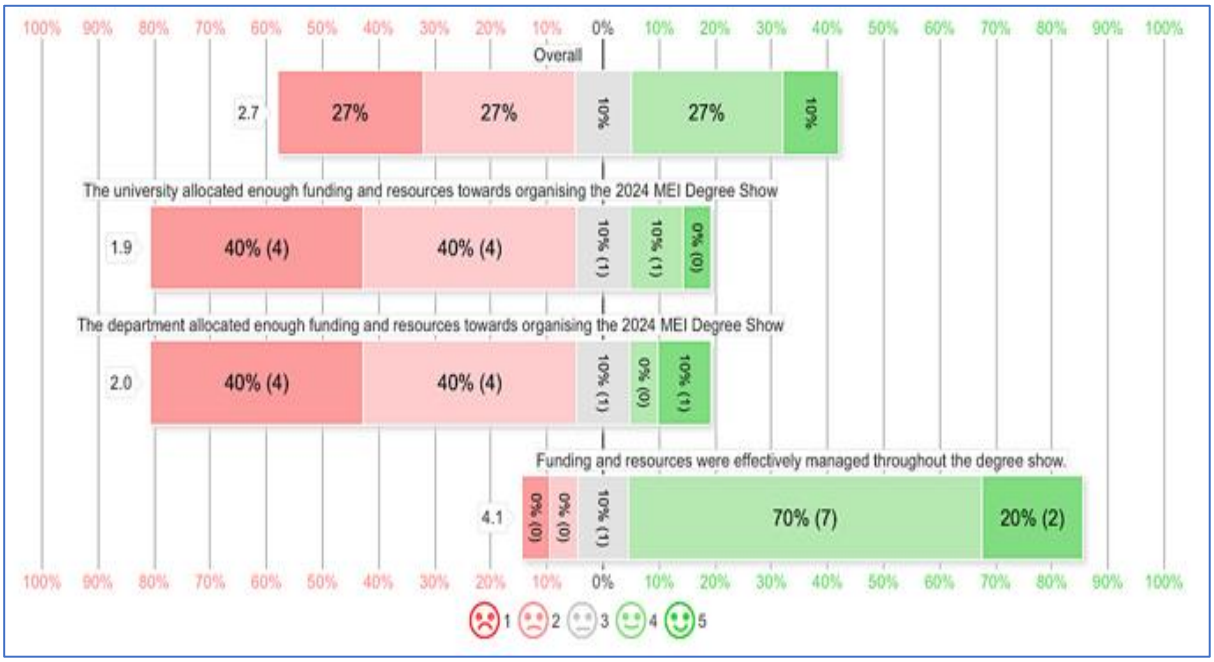

Figure 10. Funding and Resources.

4.2. Industry and Alumni Engagement

The responses from the organising committee regarding 'Industry and Alumni engagement' are depicted in Figure 2. A significant majority of respondents expressed agreement when asked whether industry professionals were adequately engaged in the degree show: 80% agree, 10% strongly agree, and only 10% disagree. Contrarily, when asked about Alumni engagement, a more significant portion of respondents indicated dissatisfaction with the level of engagement: 20% strongly disagreed, 30% disagreed, 20% are neutral, and only 30% agreed. Respondents also queried whether industry involvement added value to the degree of experience, with 100% agreeing. Most respondents perceived interactions with the industry as beneficial and enriching: 50% agree, 30% strongly agree, and 20% remains neutral.

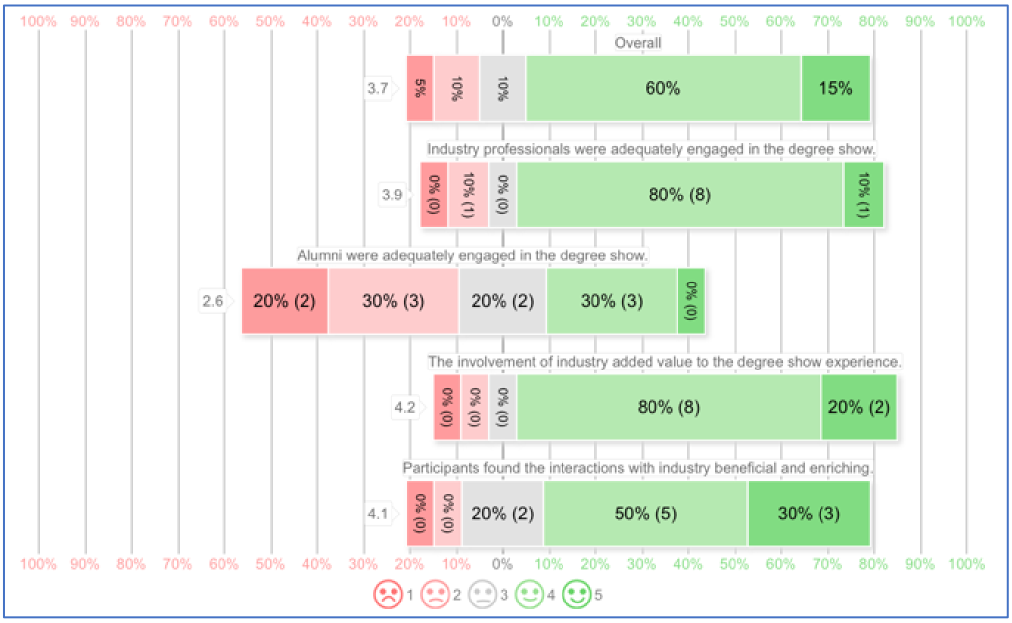

Figure 11. Industry and Alumni Engagement.

4.3. Internal Coordination

Figure 3 illustrates the committee's responses regarding internal coordination within the hosting institution's committee. Three specific questions were posed: (a) 'coordination among the internal stakeholders (e.g. school, staff) was effective throughout the degree show', (b) 'communication and collaboration within the organising team well managed' and (c) 'overall internal coordination contributed positively to the success of the degree show'. The data presented in Figure 3 indicate a predominant consensus among respondents across all three questions, with a minimum of 70% expressing agreement.

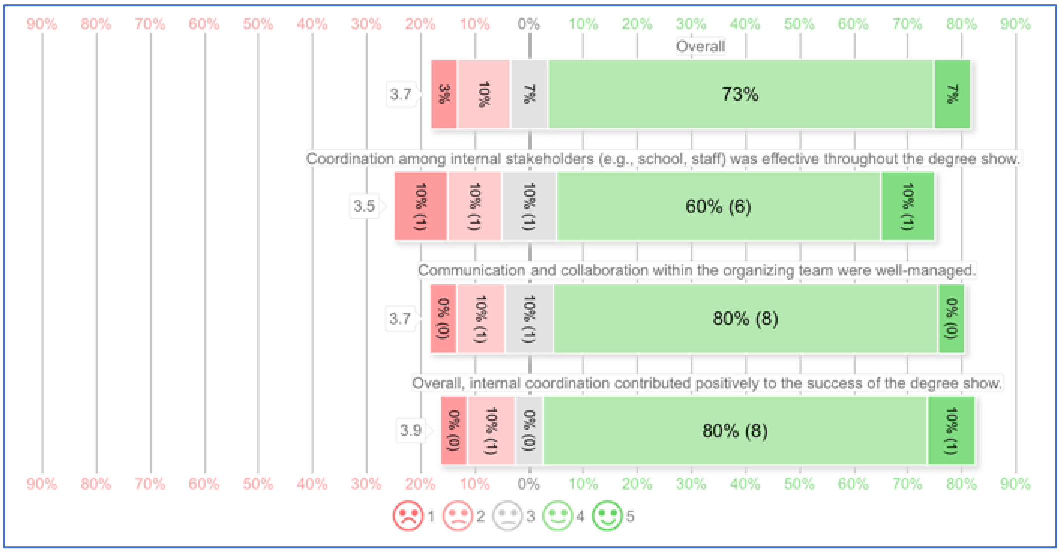

Figure 12. Internal Coordination.

4.4. Manpower Setup

The organizing committee was also surveyed regarding the adequacy of manpower for setup, with results presented in Figure 4. In response to the question of whether sufficient manpower was available for organizing the degree show, 22% strongly disagree, 22% disagree, 22% remains neutral, and 33% agree. Regarding the efficiency and coordination of the setup process, responses included 11% strongly disagree, 33% disagree, 11% are neutral, 33% agree, and 11% strongly agree. Finally, when asked if on 'overall, there were no significant issues related to manpower during the setup phase', 33% disagree, 33% strongly disagree, 11% remains neutral while 44% are in agreement. These results show that there was a shortage of manpower to help with the project stall setup.

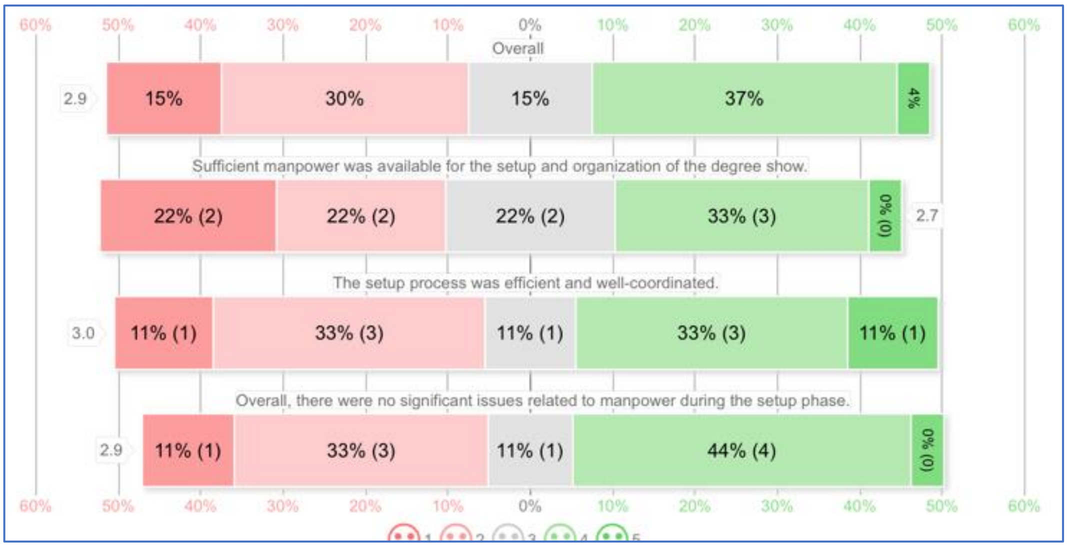

Figure 13. Manpower for venue setup.

4.5. Project Quality and Support

Figure 5 presents the committee's responses regarding project quality and support provided to students in preparation for the degree show. Respondents were consistently aligned across all three questions. When asked about the quality of projects presented in the degree show, 80% agree, 10% strongly agree, and 10% remains neutral. Additionally, respondents were asked about the adequacy of support and guidance provided to students for their project development, with 40% agreeing, 20% strongly agreeing, 20% remaining neutral, and 10% in disagreement. Lastly, regarding whether participants felt adequately supported in showcasing their projects during the degree show, their responses are as follows: 50% agree, 20% strongly agree, 20% remains neutral, and only 10% strongly disagree. These results show that students were adequately supported throughout the semester to complete their projects.

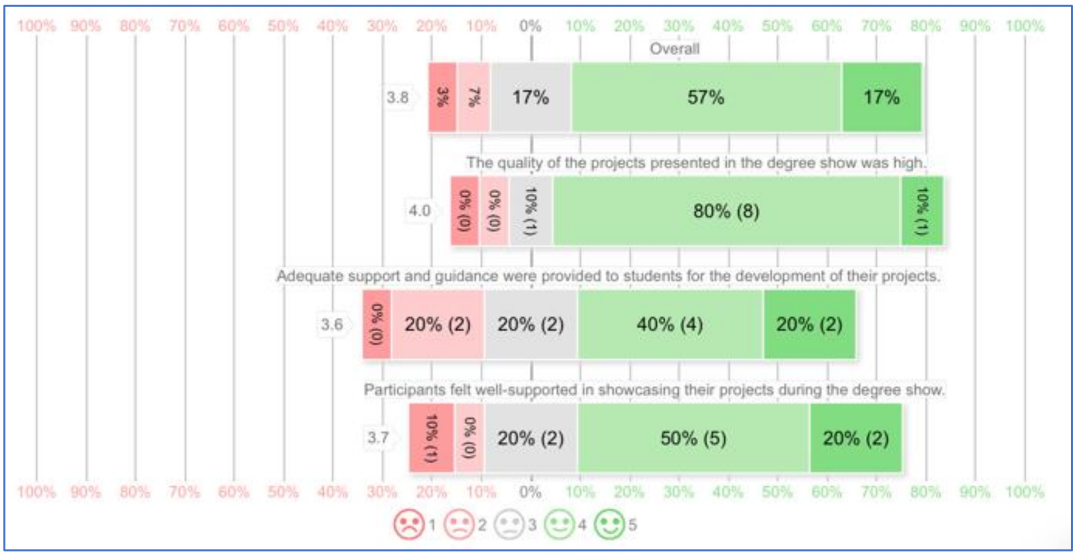

Figure 14. Project Quality & Support.

4.6. Promotion and Branding

The organizing team was also queried with a series of questions pertaining to 'promotion and branding', and the outcomes are summarized in Figure 6. In the first query, respondents were asked whether 'the degree show was effectively promoted to the target audience', 20% agree, 20% strongly agree, 20% remains neutral, and 40% disagree The subsequent query focused on whether branding and marketing efforts enhanced the visibility and attractiveness of the degree show, with 50% in agreement, 10% strongly agreeing, 10% remaining neutral, 20% disagreeing, and 10% strongly disagreeing. In the third query, correspondents were asked whether 'participants were satisfied with the level of promotion and branding for the event', resulting in 50% agreement, 30% remaining neutral, and 20% disagreement. Finally, respondents were asked whether 'the show was highly attended, with 60% in agreement, 30% strongly agreeing, and only 10 disagreeing. These results show that promotion and branding activities were successfully executed.

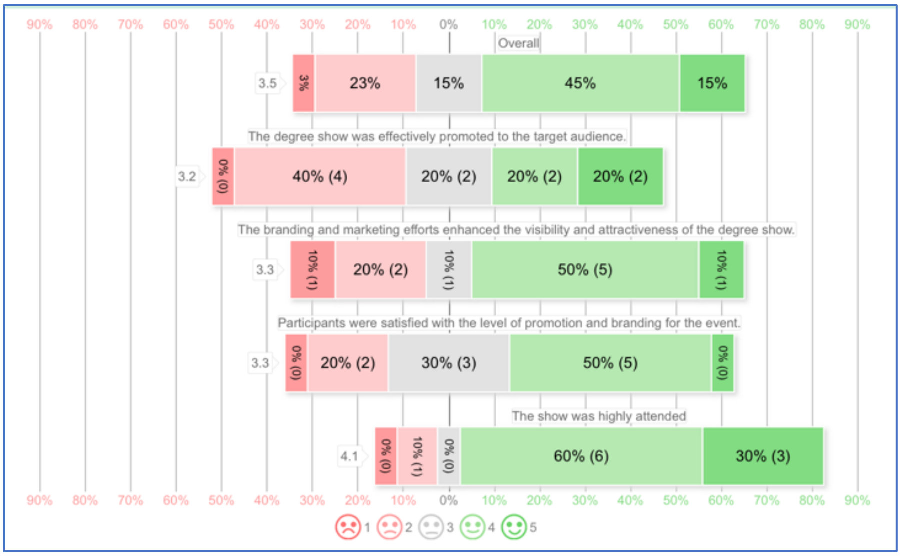

Figure 15. Promotion & Branding.

4.7. Sponsorship Acquisition

The committee was also queried about whether 'sufficient sponsorship was acquired to support the degree show financially'. Results in Figure 7 show that 50% disagree, 20% strongly disagree, while only 20% agree and 10% strongly agree. Secondly, they were asked if 'the sponsorship acquisition process was successful in securing necessary support'. Results indicate that 50% disagree, 10% remaines neutral, while 30% agree and 10% strongly agree. Lastly, the committee was asked if they 'were satisfied with the level of sponsorship acquired for the degree show. Responses indicates that 40% disagree, 20% strongly disagree, 10% remain neutral, while 20% agree and 10% strongly agree. These results show that the sponsorship acquisition was inadequate. The committee targeted to raise BWP 200k but only managed to attract a quarter of the amount.

Figure 16. Sponsorship Acquisition.

4.8. Venue and Infrastructure

The organizing committee were queried on whether the chosen venue was suitable for showcasing the projects presented during the degree show. The results in Figure 8 indicate that 60% strongly agree, 30% agree, and 10% strongly disagree. Secondly, the committee assessed whether the infrastructure—such as lighting, displays, and setups—was adequate for enhancing the show. The results show that 30% strongly agree, 60% agree, and 10% disagree. Lastly, the committee was asked to evaluate whether, overall, the venue and infrastructure met or exceeded expectations. The results showed a similar trend: 60% agree, 30% strongly agree, and 10% remains neutral. These results show that although there was limited manpower to setup the venue and stalls, the committee was successful in setting up the venue to host the degree show.

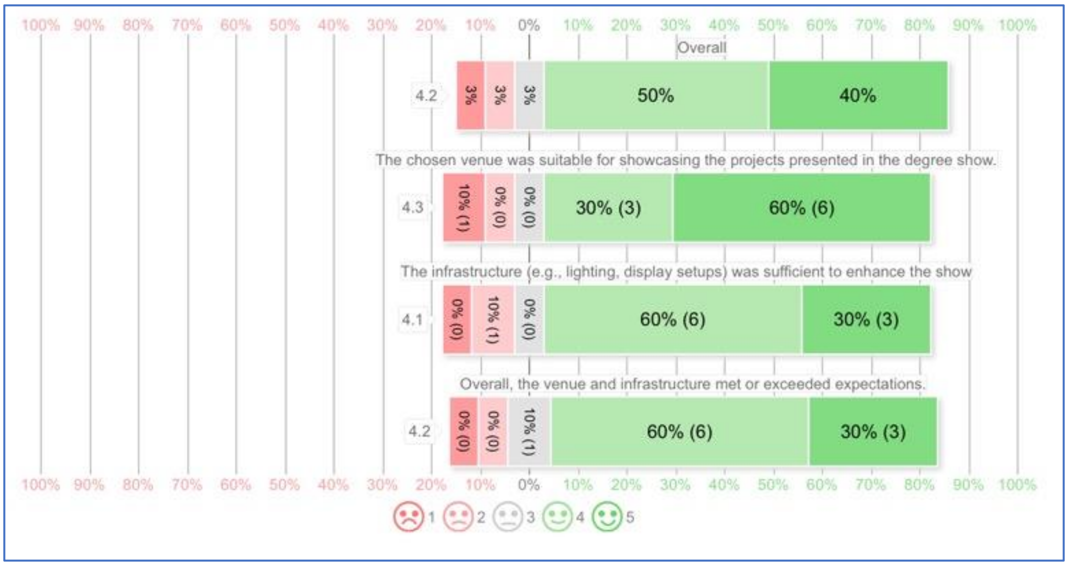

Figure 17. Venue & Infrastructure.

4.9. Event Timing

Additionally, the committee was presented with three questions regarding the timing of the event. The first question enquired whether the timing of the event was convenient for the students. Results in Figure 9 show that 30% strongly agree, 30% agree, 20% disagree, and 20% remains neutral. The second question addressed whether the duration of the event was appropriate for showcasing the projects. The results indicate that 30% strongly agree, 50% agree, 10% strongly disagree, and 10% remain neutral. The final question asked whether the timing of the degree show was well-planned and executed. The results reveal that 20% strongly agreed, 50% agreed, 10% strongly disagreed, and 20% remained neutral. These results show that the timing of the show was appropriate.

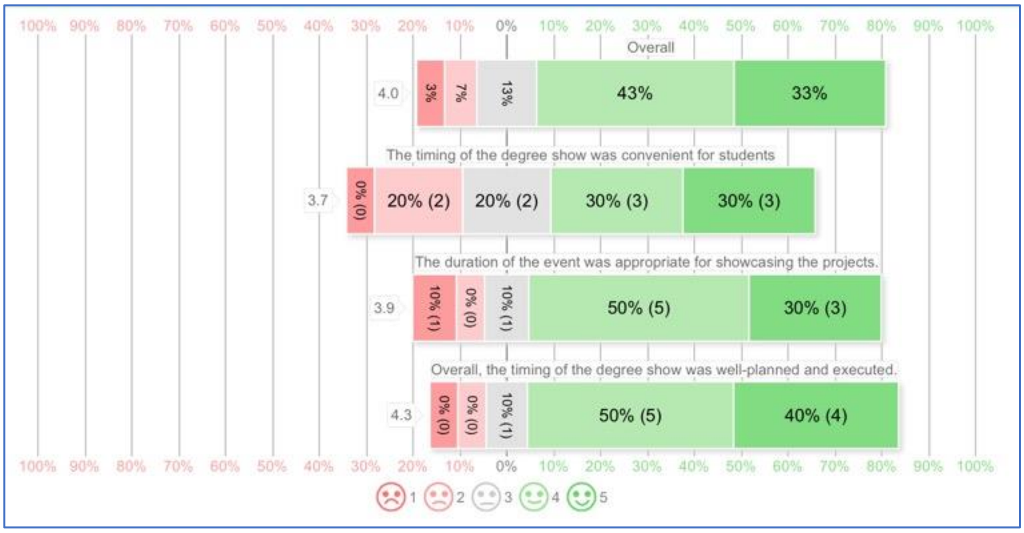

Figure 9. Event Timing.

5. DISCUSSION

5.1. Degree show vs PBL

Our findings show that the degree significantly improves the problem-based learning process. Figure 10 shows key areas that lead to the success of a degree that promotes Problem-based learning. Unlike the common belief that degree shows are events rather than a process, we present our degree show framework in Figure 10 to highlight key factors that contribute to a successful PBL experience for students.

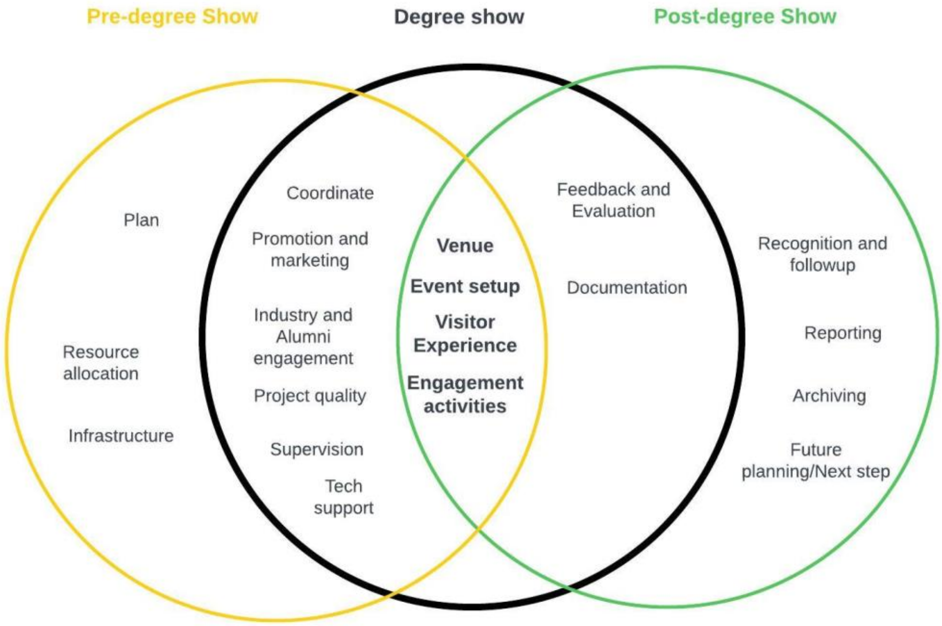

Figure 10. Degree Show Organisational Factors.

5.1.1. Pre-Degree Show

During the first semester, the organising committee, initially composed of the staff members, found it important to co-plan the event with students. Figure 10 illustrates that planning, resource allocation, technology support and infrastructure are the most important factors to consider early during the first semester. Our findings suggest that involving students during the planery stages helps them build skills in planning, resource allocation (budgeting), and infrastructural design. These skills are key in planning and organising engineering projects and events, which students cannot learn in normal classroom settings.

Regarding coordination and supervision, our study found that dividing students in different groups and allocating them roles, they were motivated and able to take responsibility in coordinating and supervising others. This coordination also included making follow-ups with the committee executive prior to the degree show event day. These findings add to what other authors reported with regard to how engaging with real-world activities outside the classroom motivate students and build key competencies to ready them for the industry (Hirsch et al., 2023; (Aizpun et al., 2015; Soltani et al., 2012). Figure 10 also shows that involving students in promotion and marketing activities prior to the show is paramount. We found that students are more adaptive, creative and versatile to social media than staff members. Thus, to promote PBL, students were given tasks related to promulgating information about the show on social media platforms. This was important to hone promotion, marketing and problem-solving skills in them to take advantage of social media and learn how to use it for events professionally. Andersson (2012) supports our findings by reporting that real-world projects help students develop problem-solving skills through practical application of theory. More than 70% of respondents on our survey show that the pre-show coordination was satisfactory.

One other important aspect of the pre-degree show was engaging industry professionals and alumni. . Although we did not get enough alumni participation prior to the show, we were able to engage industry partners towards the event day to help us with final preparations to the show. We observed that students were quite excited to engage with industry people, especially during the final setup of stalls and project preparations. This engagement was vital for students to practice their presentation skills before the show. This kind of interaction is key to helping students hone their presentation skills and confidence. Our findings are in line with Blake (2003), who emphasises how valuable degree show events are in promoting student-industry collaborations. Our results show that 100% of students interviewed indicate that industry involvement adds value to the degree show.

Supervision and project quality form the epicentre of the degree show. However, this has to be done pre-degree show. Thus, we found that it is important for students to be closely supervised to stay on course- throughout the semester to ensure that they deliver good-quality projects. Based on our findings, more than 80% of the students agreed that they had adequate support from the supervision team prior to the degree show. While supervisors are responsible for motivating and ensuring that students turn up at workshops, it is impossible for them to be always there for students. Thus, the honours lie withthe students' self-motivation. We found that the degree show was another source of motivation for students to take their projects seriously because of its collaborative nature, thus agreeing with Martins et al. (2014), who argue that students are often motivated by collaborating with others. Therefore, the degree show helped students to collaborate, plan and coordinate their projects activities to produce good quality work.

As shown in Figure 10, there are other factors to be considered pre-degree show that lie at the centre, which must be done pre-degree show, during the degree show and post-degree show. During the pre-degree show, our study found that involving the students in venue selection and preparations, event setup in terms of project display, stage and sound system and sitting arrangements was paramount. We also found that it is important to consider visitors and other engagement activities that will take place during the show. Students gained experience and skills in organising and setting up stalls, stages, sitting arrangements and PA systems.

When evaluating the event and venue setup, more than 60% of the respondents agreed that it was satisfactory. We found that involving students enhances professional teamwork, communication, and project management skills. These findings agree with Gavin (2011) and Oladiran and Uziak (2013), who report that allowing students to collaborate with the staff, community and industry in organising the show develops students' problem-solving, innovation, group-working, and presentation skills, which employers highly value.

5.1.2. During Degree Show

On the day of the show, students presented their projects to the guest of honour and the public. This was a momentous experience for the students, where they gained experience and skills in pitching their ideas to potential investors and employers. This was a rare opportunity which they did not get during the normal teaching and learning process, thus accelerating and emphasising PBL. As a result, ninety (90%) of participants found the quality of projects on the showcase to be high, which positively advertised the students and their capabilities. This is emphasised by Andersson (2015), who found that using real prototypes significantly enhanced students' learning experiences. Furthermore, the show was a marketing vehicle through which the university could advertise its intellectual prowess, engineering degrees, and the quality of its eminent graduates.

As shown in Figure 10, although there are many factors indicated, students concentrated more on their project stalls during the degree show by engaging visitors and pitching their ideas, promoting and marketing their work, and collecting feedback. These interactions with visitors were key as students also gained experience by observing how industry partners displayed their merchandise and stalls, and streaming events live on social media and other events. The 2024 MEI Degree Show facilitated good interaction between industry and the university since 90% of participants were satisfied with the involvement of industry partners.

5.1.3. Post-Degree Show

During the post-degree show, students’ involvement is minimal as indicated by the factors highlighted in Figure 10. However, some student's projects were further refined based on the feedback they got from the visitors and displayed in other venues, such as the BIUST spotlight event held in Mahalapye and the National Science week held in Tlokweng village. We found these post-degrees show events highly beneficial to students in emphasising problem-based learning since students could pitch their ideas to a larger audience further.

5.2. Improvement areas

The 2024 MEI Degree Show highlighted several critical areas for improvement in organising engineering education degree shows. Adequate funding and resource allocation are essential to ensure the quality and success of student projects. 70% of respondents are highly satisfied with how the organising committee managed funding and allocated resources for the show, despite 40% agreeing that both the department and the university did not adequately fund the show. Smith and Jones (2019) state that effective event management requires adequate funding. Oladiran (2011) supports these results by highlighting resource investment to ensure its effectiveness. This indicates that despite the limited funding of the show, the committee still managed to achieve the best results with the available funds.

Effective stakeholder engagement, including industry partners and alumni, can provide necessary support and enhance the event's impact. Over 50% of the respondents are dissatisfied with the number of alumni who attended the show. Since alumni are an important aspect of linking graduating students with industry expectations, there is a need for improvement in involving alumni.

Scheduling the event at a less busy academic period can allow students to focus more on their projects. The 2024 MEI Degree Show could only run within the semester as students were due to write their final exams soon after and leave for the academic break. Therefore, the degree show was optimally timed to fit into the academic calendar. However, 20% of participants disagreed that the degree show was optimally timed, and this is because the show had to occur during the last week of teaching, during which most final assessments before the exam occur. This put too much strain on students, as they had to juggle their assessments with the degree show.

Moreover, explicit internal coordination and defined responsibilities can streamline the planning process, reducing delays and improving efficiency. At least 80% of respondents reported that neither the department nor the university funded the MEI 2024 Degree Show. This means the committee had to rely on external funding to finance the show. Despite this, at least 50% of the committee reports that the sponsorship acquisition process was not sufficient to secure funding for the show, and in fact, 60% are dissatisfied with the level of sponsorship acquired for the show. The committee, therefore, needs to improve its sponsorship acquisition process, and support from expert offices in the university is required. Support at the institutional level can prompt commitment from the offices that deal with sponsorship acquisition on behalf of the university.

The university provided the venue for the degree show, and participants found it highly suitable for hosting the show and showcasing students' projects. Both the infrastructure and the fixtures received a 90% satisfaction rate for suitability for hosting the show. Despite this, there are some (44%) dissatisfaction with the process of setting up the venue and the availability of manpower. More commitment from relevant offices is required to ensure that any issues are ironed out and the setup can happen seamlessly. Support at the institutional level can prompt the commitment required.

6. CONCLUSION

The main aim of this study was to explore the opportunities and challenges of using engineering degree shows to enhance problem-based learning. Our study found that engineering degree shows can successfully drive problem-based learning and build important skills and attributes such as problem solving, motivation, effective communication, innovation, and collaboration in students before they join the workforce. Nevertheless, we also found that organising an engineering education degree show involves multiple challenges that require strategic planning, resource management, and stakeholder engagement, amongst other factors. Thus, our study provides valuable insights into overcoming these challenges. The degree is a multidisciplinary endeavour and requires commitment from different actors.

Recognition of the benefits of degree shows, not only for students and their faculty but also for the university-wide community, should motivate more robust support for degree shows. Support at the institutional level can circumvent reluctance to prioritise the show over other academic and university businesses.

Future degree shows can achieve tremendous success by addressing the identified issues and implementing the proposed solutions, benefiting students, faculty, and industry stakeholders. This concept paper can guide academic institutions to enhance their engineering education degree, which shows effectiveness and impact and accelerates problem-based learning outcomes.

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ENGINEERING EDUCATION AND ENTREPRENEURSHIP EDUCATION: COMPLEMENTARITY, OPPORTUNITIES AND CHALLENGES

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Abstract: Due to the downturn of global economies, high global unemployment rates, and dwindling economies at country specific levels, the increasing demand for soft skills, engineering education has shifted from the typical and traditional technical paradigm to a multidisciplinary approach. This has presented some challenges for engineering education. One of the challenges or opportunities is the inclusion of entrepreneurship education into the technical engineering curriculum. Although engineering graduates have the technical education and expertise, they are expected to become supervisors, managers and business owners. As such they are entrusted with resources (human, material and financial) to efficiently utilise and meet the goals of their respective organisations. Also, during the period of their study, engineering students may discover innovative ideas or design new experimental prototypes, which require further development and upscaling into full products that are ready for marketing. These require incubation, management and entrepreneurship skills. Therefore, there is the need to include entrepreneurship education in university engineering curricula. However, there is still an unending debate among engineering institutions and researchers on whether to include, and/or the extent of the inclusion of entrepreneurship and management modules in the engineering curricula. Furthermore, students in engineering entrepreneurship programmes gain insights into designing for end users working in, and managing interdisciplinary teams, communicating effectively, thinking critically, understanding business basics and solving open-ended problems (Byers, Seeling, Sheppard, & Weilerstein, 2013). Therefore, this study was designed to discuss the role entrepreneurship education plays in engineering education. The study first documented the existing and available literature on entrepreneurship education and engineering education, followed by examining the engineering students' perceptions on entrepreneurship education in their engineering education curricula. The results indicated that, globally, many engineering institutions have in different ways infused entrepreneurship education into their curricula. However, research findings and participating engineering students have opposing views on the benefits and impacts of entrepreneurship education on future job prospects or owning self-business. The result of this study has implications for schools of business and engineering education.

Keywords: Engineering Education, Entrepreneurship Education, Engineering Curriculum, Innovation, Engineering Intention

1. INTRODUCTION

Due to the current global economic crisis and its associated high unemployment rates and dwindling economies, there has been a need to critically retool engineering education to mitigate the socio-economic challenges of the day for developing, as well as developed economies. The knowledge and skills required by the present and future jobs are changing, and consequently, the education system at all levels must respond and adapt to the new challenges (Grecul & Dene, 2017). Therefore, there has been an increasing call to shift engineering education from the typical and traditional technical paradigm to a multidisciplinary approach. This has presented both challenges and opportunities for engineering education. One of the challenges or opportunities is the inclusion of entrepreneurship education into the technical engineering curricula. Entrepreneurship is viewed as the capacity and willingness to develop, organise and manage a business venture along with any of its risks to make a profit. The most obvious example of entrepreneurship is the starting of new businesses (Karim, 2016). Entrepreneurship education is "the content, methods and activities supporting the creation of knowledge, competencies and experiences that make it possible for students to initiate and participate in entrepreneurial value creating processes" (Nair, Sundar, & Paramasivam, 2020).

Globally, Innovation and entrepreneurship education are increasingly becoming important to create jobs or make university graduates more efficient and effective managers or owners of start-up businesses. Students in entrepreneurship programmes gain insights into designing for end users working in, and managing interdisciplinary teams, communicating effectively, thinking critically, understanding business basics and solving open-ended problems (Byers, Seeling, Sheppard, & Weilerstein, 2013). Engineering students may also discover innovative ideas and develop prototypes which require further development into a full product, ready for marketing. These require product incubation and packaging, which are part of entrepreneurship education. Therefore, many countries have recognised the need to include entrepreneurship education in Science, Technology, Engineering and Mathematics (STEM) programmes. "The gap between real-life situations and the classroom theories and concepts can be bridged with the help of entrepreneurship education for students with different specialised fields. Bringing students from non-business fields closer to the business school is the approach of some institutions that aim to educate students in an entrepreneurship classroom characterised by diversity" (Grecul & Dene, 2017). The ability of engineering institutes to train quality manpower is not enough; their educational programs must be geared towards enhancing the students' creativity, original thinking, leading qualities and initiatives. These require entrepreneurship training alongside engineering education.

However, despite the above recognition, there is still an unending debate among engineering institutions on whether to include, and/or the extent of the inclusion of entrepreneurship and management modules in their various engineering curricula. Some institutions are still hesitant to include entrepreneurship education in STEM programmes and others are debating on the degree and nature of inclusion, either as compulsory, electives or optional courses. There are still those who are debating on whether the courses should be run by their business schools or in engineering faculties (Shekhar & Huang-Saad, 2021).

The current study is designed to discuss the role entrepreneurship education plays in engineering education. The study first documented the existing and available literature on entrepreneurship education and engineering education. This was followed by examining the entrepreneurship programme offered by the School of Business and Professional Development (SBPD) in Botswana International University of Science and Technology (BIUST).

The literature review was centered around the following four general thematic areas;

i. The importance of entrepreneurship education in engineering programmes or curricula.
ii. The extent of inclusion of entrepreneurship education in engineering education.
iii. Opportunities and challenges of entrepreneurship education into engineering education curriculum
iv. Engineering Students' perceptions on the inclusion of entrepreneurship models in their study pack.

2. METHODOLOGY

This research used published and available literature on the topic. One hundred and fifty publications were downloaded. There were 50 conference papers and 100 journal articles. These downloaded conference proceedings and journal articles were carefully scrutinised based on their appropriateness and relevance to the research topic and the four thematic areas stated above. Finally, only nine papers from conference proceedings and 40 refereed journal publications were selected. While some covered more than one thematic area, there were others that addressed only one of the thematic areas.

3. FINDINGS

3.1. The importance of entrepreneurship education in engineering education

Globally, the importance of entrepreneurial training in engineering education has been widely accepted by most universities. This acceptance comes because of the need to develop a wide range of soft skills such as innovative, creativity, and problem-solving skills to assist future engineers to succeed in today's technology-driven economy (Dominguez, et.al, 2021). Increasingly, graduates are expected to adapt their complex problem-solving skills to align with the modern-day multidisciplinary practices of engineering and know how to integrate their science and engineering skills training to enhance industrial and leadership practices (Creed, Suuberg, & Crawford, 2002). This implies that current day engineers must be able to effectively communicate, work in multidisciplinary positions, solve complicated management problems, while maintaining a sustainable, cultural, social and economic environment (Dominguez, et. al, 2021). The inclusion of entrepreneurship education in engineering education curricula is hinged on the above premise. "Entrepreneurship education is one of the platforms that the engineering institutions have adopted to expose students to practices and mindsets deemed critical for their growth and success upon graduation" (Shuman, et al., 1999).

Entrepreneurship education programs have a positive impact on improving attitudes towards self-employment amongst engineers, and it is no longer enough to come out of school with a purely technical education; engineers need to be entrepreneurial to understand and contribute to the context of market and business pressures (Byers, et. al, 2013). Entrepreneurship education should be a pre-requisite for engineers who start companies soon after graduation. It enhances their experience in product design and development, prototyping, technology trends, and market analysis (Neck & Greene, 2011). These skills are just as relevant for success in established enterprises as they are in start-ups. It has been shown that students with entrepreneurial training who join established firms are better prepared to become effective team members and managers and can better support their employers as innovators (Duval-.Couetil, Reed-Rhoads, & Haghighi, 2012), and it teaches engineering students the knowledge, tools, and attitudes that are required to identify opportunities and bring them to life (Kishore, 2021).

The inclusion of entrepreneurship education in engineering training programmes can lead to the production of graduate entrepreneurs who can contribute to a country's competitiveness, by facilitating or creating new jobs and engaging in the development of innovative products and services (Facey-Shaw, et al., 2019). Esparragoza (2009) suggests that through fostering entrepreneurship, creativity and other skills, engineers have the potential to develop new technology which is key for economic growth and innovation. Facey-Shawet. al, (2019) state that entrepreneurship education positively contributes to entrepreneurial intention, which in turn motivates engineering graduates to start businesses and improve the image of entrepreneurship as a career option.

Jarrar & Anis (2016) posited that the integration of entrepreneurship educationm into the engineering curriculum can have a significant positive impact on design, investigation, problem analysis, life-long learning, communication skills,individual and team work, and economics and project management. Vieira and Rodrigues (2014) indicated that entrepreneurship education creates awareness in engineering students such that its inclusion can broaden their career prospects and choices, while also recognising that entrepreneurs have a positive image in society. It is considered a fostering factor of entrepreneurial intention and could raise the awareness, knowledge, and abilities necessary to start a business (Draksler & Sirec, 2021). Entrepreneurship bridges the gap between real-life situations and the classroom theories and concepts.

Students who take part in entrepreneurship programmes at undergraduate levels gain insights not available from traditional engineering education, such as understanding and designing for end users, working in and managing interdisciplinary teams, communicating effectively, thinking critically, understanding business basics, and solving open-ended problems (Kishore, 2021). The author also confirms that Entrepreneurship education and programmes will not only aid the institutions to create industry-ready entrepreneurs, but also steer the students towards being independent while securing their careers, which accentuate the need for self-dependence as well, while simultaneously catering to accelerate a country's economy (Kishore, 2021)Entrepreneurial intentions serve to mitigate the challenge of job scarcity by promoting self-employment and fostering the establishment of new ventures (Bomani, Gamariel & Juana, 2021; Mambali, Kapipi, & Changalima, 2024; Neck & Greene, 2011). Yi and Duval-Couetil(2018) reported that entrepreneurship education leads to the motivation, creation and solution, of personal interest and managerial effectiveness among engineering students.

Hassan, et al, (2017) stated that creativity, communication skills, motivating and managing employees, leadership, high ethical standards and strong sense of prefessionalism, dynamism, agility, resilience and flexibility and lifelong learning are skills that can be gained from entrepreneurship and other inter-disciplinary courses. The Global Entrepreneurship Monitor (GEM) study showed that entrepreneurship has the potential to create jobs and generate wealth in a nation's economy, and that economic growth and development are linked to entrepreneurship (Barba-Sanchez & Atienza-Sahuquillo, 2018; Barba-Sanchez & Atienza-Sahuquillo, 2012), and Thurik, Carree, van Stel, & Audretsch, (2008) confirm that there is a close relationship between self-employment and reduction in unemployment rates during periods of economic recession, and the establishment of Technology-Based Companies (TBCs). A comparative study between graduates whose course focusses on entrepreneurship and graduates who do not focus on entrepreneurship courses showed that graduates focusing on entrepreneurship were employed within organisations on a full-time basis and were more satisfied with their employment opportunities (Cho & Lee, 2018). Students receiving entrepreneurial training before the beginning of their professional careers have favourable future career prospects (Creed, Suuberg, & Crawford, 2002). According to Holzmann, Hartlieb, and Roth (2018) entrepreneurship education helps engineering entrepreneurs to increase the speed of knowledge transfer from engineering education to the public, the ease of access to novel technologies, the perception of entrepreneurs and the connotation of entrepreneurship within a society. It also increases the ease of hiring and retaining well-trained staff, the degree of bureaucracy to start a business, the size and proximity of expert networks to support information and knowledge exchange, and access to financial capital in the individual founding phases. Furthermore, it helps university students to prepare for future job uncertainties as job requirements change in response to technological advancements; encourages creativity, innovation and collaboration; improves students' problem identification and problem-solving skills (Holzmann, Hartlieb, & Roth, 2018).

It is evident from the research findings of Adamec and Hrmo (2023) that entrepreneurship education supports the motivation of youths to actively create an entrepreneurial environment, and it intensifies the link between business and academia. Miller et. al. (2011) found that students who participate in entrepreneurship education programmes are 73 percent more likely to start started a new company, 23 percent more likely to create new products or services, and 59 percent more likely to have high confidence in leading a start-up.

The above literature shows that the inclusion of entrepreneurship education in the engineering education programmes improves the entrepreneurial skills and mindset change for engineering graduates, improves the job prospects or create jobs and makes them to become efficient and effective employees.

3.2. The integration of entrepreneurship education into the engineering curriculum

The importance of entrepreneurship education justifies its inclusion in engineering education curricula, which makes engineering students work in interdisciplinary programmes. "Working in interdisciplinary contexts demands new competences, and requests for 'T-shaped' engineers. T-shaped-engineers refers to those who have deep knowledge in one engineering discipline and general knowledge and competences that help them form bridges with other disciplines" (Route, Holgaard, & Kolmos, 2024).

Various approaches have been used to integrate entrepreneurship into the curriculum for technical students, including specialised courses, for example, Technology Entrepreneurship for Engineers and Computer Scientists (Facey-Shawet. al 2019). Current teaching practices in entrepreneurship education involve a wide range of activities and programs such as developing a business plan, business simulation, lectures, case studies, guest speakers and role models (Joao & Silva, 2020). The integration of entrepreneurship education into the engineering curriculum requires optional programmess in leadership and innovation spanning several courses including seminars and presentations on entrepreneurial experiences (Doboli, et. al, 2014).

Recommendations to foster entrepreneurship among engineering university students include start-up exhibitions of successful entrepreneurs as role models, workshops on idea generation and business plan creation, and inter-university business plan competitions (Barba-Sanchez & Atienza-Sahuquillo, 2018). However, programmes can vary according to the objectives required by individual universities (Duval-.Couetil, Reed-Rhoads, & Haghighi, 2012). Certain programmes will focus on increasing entrepreneurship concepts, while others will focus on innovation and its aspects (Duval-Couetil et al., 2016). For the integration of entrepreneurship and innovation in engineering education to be successful, faculties will need to change their viewpoint and be willing to contribute or at least agree to modifications in the engineering curriculum (Byers, et.al, 2013).

In some universities entrepreneurship is taught within the engineering faculties The other way is either the entrepreneurship courses are taught within the engineering faculties, as practised in Havard University or taught in the School of Business as in Massachussettes Institute of Technology (MIT) (Hassan etal., 2017). The authors also outlined the pedagogical methods of incorporating entrepreneurship into engineering education. The first is by developing technical entrepreneurship case studies that are designed to be integrated into existing engineering fundamental courses. These case studies are intended to provide engineering students with entrepreneurial role models and to show the future engineers how those models require them to use their knowledge of a specific engineering topic covered in typical undergraduate courses to create successful business ventures. In a related study, Pradhana, Khan and Litvinova (2022) confirmed that, in order of priority, engineering students would like to learn how to prepare business plans, work in teams, be exposed to inter-disciplary items, to be engaged in project-base learning, work on case studies, pitch and present business ideas, be engaged in new venture or start-up competitions, internmships, listen to guest speakers, coaching or mentoring, and seek seed capital (Pradhana, Khan, & Litvinova, 2022).

3.3. Students'perceptions on the integration of entrepreneurship education in engineering curriculum

Various research reports show that numerous universities have adopted various forms of entrepreneurship education programmes which are typically offered as either electives, optional or compulsory courses. To create suitable programmes that will encourage students to seek out entrepreneurship education programmes, it is expedient to understand the factors that influence participation in such a programme. Therefore, this section examines engineering students' perceptions of the inclusion of entrepreneurship education courses in their curricula.

A study by Facey-Shaw et. al (2019) reports that about 71 percent of science and engineering students in a Jamaican university were interested in starting a business and greatly considered the entrepreneurship courses useful should they start a business. When asked to examine their involvement in the student-based entrepreneurship club and the business model competition hosted on the university campus, it was revealed that only six percent of students attended the club and approximately 15 percent participated in a business model competition session, indicating that outside of the formal course on entrepreneurship, these students do not appear to be gaining additional information on becoming entrepreneurs through these informal activities.

Mosly (2017), and Souitaris, Zerbinati and Al-Laham (2007) found that inspiration proved to be most strongly associated with an increase in entrepreneurial intention, particularly among undergraduates who are very unlikely to start a business immediately after graduation. The authors concluded that if the target is to increase the number of students who become entrepreneurs, then the inspirational aspect of the program must be purposeful. The report also provides evidence that entrepreneurship education can have a positive impact on the, entrepreneurial mindset and activity.

According to Duval-Couetil, Reed-Rhoads and Haghighi (2012) a very high percentage of engineering students who have done one or more entrepreneurship courses agree that entrepreneurship education broadens their career path prospects and choices (82%) against 69% of students who have taken no entrepreneurship courses. They are also more interested in becoming entrepreneurs (59%) than their counterparts (34%) and have an idea for a business product or technonoly (46% against 32%). Although students in both groups were most interested in working for a medium or large-size business, or attending graduate school, there were significant differences between the two groups of students in terms starting their own businesses or working for a small business or startup company (43% against 34%), but both groups were against working for a non-profit organisation or serving in the military (Duval-.Couetil, Reed-Rhoads, & Haghighi, 2012). Students who perceived themselves as having entrepreneurial experience reported that they possessed entrepreneurial attributes and skills such as creativity, ambition, determination, passion, and confidence in decision making.

According to Taks etal. (2014) students perceived entrepreneurship studies as a first step to self-directed learning, a preparation for work life, a path to possible self-employment, and a context for developing leadership and responsibility for group achievement. Shekhar and Huang-Saad (2021) added that students' confidence in their communication and public speaking skills and self-employment as opposed to working for an established company informed their decision to register for entrepreneurship education programmes.

Udo-Imeh et al. (2016) found out that curriculum and course contents are critical to the achievement of course outcomes, and Ozaralli & Rivenburg, (2016) identified that theory-based approach to entrepreneurship teaching and the non-involvement of practical entrepreneurs are responsible for the low interest in, and poor perception of students to entrepreneurship in Turkey.

3.4. Challenges

Although the importance of entrepreneurship education has been emphasised and has led to many countries and universities including it in their various engineering programmes, there is an inconclusive report on the evaluation of the potential benefits of teaching entrepreneurship to engineering students. The degree to which entrepreneurship plays a role in contemporary engineering students' academic programmes or career paths is largely unknown (Duval-Couetil, Reed-Rhoads, & Haghighi, 2012). Bilau and Santos (2023) stated that it is likely that obstacles may arise when the university is divided into schools and their respective departments work with significant independence. The lack of cooperation or coordination between schools or departments can be a compromising obstacle for the integration of entrepreneurship education into engineering programmes. When the change is driven by an external recommendation, the team responsible for modifying the curricula may not be equally committed since the introduction of the new curricula unit often requires either the suppression or merging of core courses within the programme to satisfy the total credit requirement of the engineering programme (Byers et al., 2013), and in most schools, faculty members who teach entrepreneurship have never had any contact with the realities of the business world; hence, their handling of the entrepreneurship courses may dampen students' interests (Bilau & Santos, 2023).

Different researchers emphasised the difficulties of evaluating the benefits or importance of teaching entrepreneurship. In their research, Colette, Hill and Leitch (2005) stated that there is not much empirical evidence to show that the completion of entrepreneurship and management courses increases an individual's chances of starting a business. In a similar study, Matlay (2005) stated that the real contribution that management and entrepreneurship courses have on postgraduate entrepreneurship activities remains unclear, and various authors such as Barringer, Jones and Neubaum (2005), Fayolle, Gailly, & Lassas-Clerc, (2006); in Barba-Sanchez and Atienza-Sahuquillo (2018) have corroborated that the degree to which entrepreneurship plays a role in contemporary engineering students' academic programs or career paths is largely unknown. Although more engineering students are being exposed to entrepreneurship education, minimal research has examined engineering students' attitudes toward it, its impact on their learning, or professional competence. This is not surprising given that the integration of entrepreneurship in engineering is a relatively new effort, where definitions of what it means to be entrepreneurial within an engineering programme as well as programme models vary greatly (Standish-Kuon & Rice, 2002; Duval-Couetil, Rhoads, & Haghighi, 2012). Even within the field of management, entrepreneurship education is considered by some to be a relatively new field, still engaged in conceptual and methodological debates (Brazeal & Herbert, 1999) . For example, there is a lack of consensus on the degree to which entrepreneurship is a set of principles, terms, competencies, and skills that can be learned, versus a set of attributes that make one opportunistic, competitive, proactive, risk tolerant, autonomous and innovative (Caird, 1992; Henry, Hill, & Leitch, 2005; Kirby, 2004). The objectives and content of entrepreneurship programmes also vary widely, which leads Henry, Hill, and Leitch (2005) to state that the 'content of syllabi of courses developed by entrepreneurship scholars differs to such an extent that it is difficult to determine if they even have a common purpose' (Henry, Hill, & Leitch, 2005).

The teaching of entrepreneurial skills and entrepreneurial thinking requires the use of pedagogical methods that are not easy to apply in traditional educational environments and settings. Similarly, there is a perceived lack of academic staff to teach such subjects because they do not have the appropriate entrepreneurial experience (Adamec & Hrmo, 2023; Bilau & Santos, 2023). Also, in a situation where the teaching staff in the engineering school stick to the conservative paradigm that engineering students should only acquire technical knowledge, the collaboration of such teaching staff can potentially doom the curricula change to failure (Bilau & Santos, 2023). This implies that the infusion of entrepreneurship education can be more facilitated when both engineering and business faculty members co-exist and plan it well.

Although research evidence highlights both the importance of entrepreneurship education and training during students' study periods, it also confirms that students' entrepreneurial intentions are influenced not only by the university environment, but also by their family background and the society in which they live. The fact that family environment and intergenerational learning have an impact on entrepreneurial aspirations is demonstrated by research findings from those of Kamanova, Pevna, & Rabusicova (2016a) and Rabusicova, Kamanova, & Pevna (2016b).

This section reveals that despite the importance of entrepreneurship education, its inclusion and implementation in engineering programmes is still clustered with challenges and problems that make it difficult to assess its positive impacts on graduate engineers.

4. SUMMARY AND CONCLUSION

The global challenges of economic crisis, followed by high unemployment rates and dwindling economies of both developed and developing economies have led to a paradigm shift in the way engineering education is taught. Several universities have switched from the traditional method of teaching to a new pedagogical approach which prepares engineering graduates for life after university. This article reviewed the relevant literature on the inclusion of entrepreneurship education into undergraduate engineering programmes. The review found that teaching entrepreneurship to engineering students has both opportunities and challenges. The opportunities include increased job prospects, start-up businesses, improved communication skills, ability to work in teams, and many others.

However, the extent to which these opportunities are attained by engineering graduates have not been established by researchers. Also, most of those teaching the courses do not have adequate entrepreneurial experience, and most business schools emphasise academic outcomes as opposed to the practical aspects as well as the promotion of soft skills. Therefore, extended research is required to assess graduate engineers' perceptions about the impact of entrepreneurship education on their postgraduate experiences.

5. FUTURE RESEARCH

There is need to follow-up on our engineering graduates to find out how entrepreneurship courses have assisted them to either find jobs or to start their own

businesses. Further, there is the need to find out whether entrepreneurship courses made them any different from their counterparts from other universities in Botswana.
Secondly, there is need to develop appropriate questionnaires to collect information from current students and faculty staff on their perceptions of infusing entrepreneurship courses in the engineering curriculum in Botswana International University of Science and Technology (BIUST).

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RESPONSIBLE HUMAN AI-COLLABORATION IN HIGHER EDUCATION

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Abstract: As AI tools become increasingly prevalent in educational settings, they offer significant opportunities to enhance teaching strategies, particularly in making complex statistical concepts more accessible. However, these advancements also bring concerns such as algorithmic bias, and the risk of perpetuating misinformation. This paper reflects on personal experiences in integrating AI into a statistics module in a UK higher education context, emphasising the importance of harnessing AI tools to make statistics more accessible while maintaining responsibility as an educator to restrict the potential impact of the use of AI. Through a structured reflection, the paper highlights the transformative potential of AI in education while advocating for a responsible approach that prioritises restricting harm such as misinformation and exercising oversight and control in the human-AI collaboration. The reflection concludes by proposing key dimensions for responsible Human-AI Collaboration in Education.

Keywords: Human-AI collaboration, Education, Responsible, Pedagogy, Statistics.

1. INTRODUCTION

In recent years, the integration of Artificial Intelligence (AI) into various educational practices has transformed the approach to teaching and learning. Educators can collaborate with AI to design lessons, scaffold complex concepts, and provide contextualised examples and case studies, thereby enhancing students' comprehension of challenging topics. Similarly, students can use AI as their learning mate, thereby enhancing their capabilities (Kim et al., 2024). However, despite these benefits, there are instances where AI is misused, such as in assignments. More concerning, it is envisioned that the human-AI collaboration in education involves teachers as passive AI recipients (Kim, 2024). This collaboration is problematic as generative AI's are known to provide misleading information with the potential for misinformation (Monteith et al., 2023). Although AI has the potential to enhance education delivery and outcomes, its potential misuse and the risk of overreliance highlight the need for responsible Human-AI collaboration in education.

The current literature on Human-AI collaboration in education focuses on the collaboration's benefits, challenges and considerations. Human-AI collaborations are largely seen as augmenting educators' and students' abilities thereby enhancing students' learning outcomes (Holstein, Aleven, and Rummel, 2020). In addition, Human-AI collaborations support course design (Paiva and Bittencourt, 2020). While AI holds the potential to augment teachers' abilities, Molenaar (2022) emphasises that AI should augment, not replace, human teachers. Similarly, Luckin (2024) emphasises the need for a balance between harnessing AI and nurturing human intelligence. This is because if not carefully designed, AI lacks inclusivity and diversity of local context and risks propagating harmful inequities (Holstein and Aleven, 2022).

To avoid these risks and associated challenges, there must be control (Kim, 2024), highlighting the need for a responsible perspective on Human collaboration in education. Oravec (2023) stresses responsible and mindful collaboration by students. Similarly, reflecting on a responsible educator-AI collaboration could aid educators in navigating the challenges and considerations to foster a responsible collaboration with AI.

This paper aims to reflect on the responsible use of AI based on my experiences as a graduate teaching assistant (GTA) at a UK higher institution collaborating with AI to scaffold and make an undergraduate statistical module accessible to students. This aim is achieved through a structured reflection. The paper hopes to make contributions by expanding the conversation of effective human-AI collaborations in education to encompass a responsible perspective in educators.

The next section discusses related literature, followed by the methodology and an overview of my experience, leading into the discussion and conclusion of the paper.

2. RELATED LITERATURE

2.1. Benefits of Human-AI Collaboration in Education

The integration of Artificial Intelligence (AI) in education has generated significant interest due to its ability to enhance both teaching and learning processes. A major benefit of AI in education is the augmentation of human capabilities, which allows educators and students to optimise learning outcomes. Holstein, Aleven, and Rummel (2020) discuss how AI can work alongside human teachers, enabling mutual augmentation of their respective strengths in educational settings. This view is reinforced by Kim (2024), who emphasises that teachers collaborating with AI can significantly improve students' subject-matter knowledge while simultaneously building their capacities for learning.

Furthermore, the development of metacognitive skills is a prominent benefit of human-AI collaboration. Hutson and Plate (2023) argue that such collaboration fosters critical thinking and self-reflection among students, essential skills in contemporary education. AI also assists in decision-making, as seen in the work of Paiva and Bittencourt (2020), who highlight the benefits of AI-assisted authoring tools in education. Nguyen et al. (2024) further demonstrate that AI-assisted writing tasks improve students' performance, resulting in higher-quality written work.

Holstein and Aleven (2022) indicate that students learn more effectively when human teachers and AI tutors work together, leveraging real-time data and insights to tailor classroom interactions. However, Molenaar (2022) warns that AI should not replace human teachers but instead complement their efforts, maintaining a symbiotic relationship where both human intelligence and AI can collaborate to optimise learning experiences.

2.2. Challenges and Considerations in Human-AI Collaboration

While the benefits of AI in education are clear, there are significant challenges and risks that must be addressed to ensure responsible human-AI collaboration. One of the primary concerns is the potential for AI to perpetuate biases present in the data it is trained on. Without careful oversight, AI systems could inadvertently reinforce existing inequalities or present biased information, leading to ethical dilemmas in educational settings (Echeverria et al., 2020).

Another challenge is the possibility that educators might become passive participants in the learning process, relying too heavily on AI systems (Kim, 2024). This could result in a decline in educators' ability to engage actively with students and reduce their involvement in critical thinking and problem-solving (Echeverria et al., 2020; Kim, 2024). The literature suggests a need for balanced collaboration where teachers maintain an active role, using AI as a tool rather than a replacement (Molenaar, 2022) Control and accuracy of AI outputs are essential considerations in human-AI collaboration. Echeverria et al. (2020) argue that control should be shared between students, teachers, and AI systems, allowing for adaptable learning environments. Kim (2024) stresses the need for continuous human oversight and control to prevent over-reliance on AI. Tülübas et al. (2023) emphasise ensuring an accurate and reliable output from AI-based scientific queries.

2.3. Need for Responsible Collaboration

The existing body of research emphasises the benefits of human-AI collaborations, but fewer studies provide concrete guidance on how to exercise responsibilities in Human-AI collaborations. Oravec (2023) highlights the need for responsible and mindful collaboration in student-AI collaborations. The study stresses that a responsible collaboration can enable students to benefit more fully from the extensive capabilities of ChatGPT and related generative AI systems. More knowledge is needed to appreciate the responsibilities of educators in their collaborations with AI in educational settings. This study aims to reflect on what responsible collaboration requires in the context of educators.

3. METHODOLOGY

This study employed a structured reflection approach to gather data. Data was collected through multiple methods over a 10-week period alongside my Associate Teacher Programme training to qualify as an associate fellow of the higher education academy in the UK. I collected student feedback using Post-it notes (from 6/8 of my classes) to understand what motivated them to learn, what strategy they found effective for their learning and what would make them more comfortable engaging in class. I received 180 Post-it notes with comments. I removed 41 Post-it notes that were not helpful, e.g. contained one word, broad comments such as “its all good”, and other unhelpful comments to reach 139 Post-it feedback comments.

In addition to Post-it notes, I used focused groups (of three students) from 2/8 of my classes. Additionally, 32 reflection journal entries were recorded to capture my personal observations and reflections throughout the process from 6 October 2023 – 15 December 2023. To analyse the data, I employed thematic analysis to identify patterns and themes (Clark and Braun, 2017).

4. EXPERIENCE

During Michaelmas’ term, which ran from 6 October 2023 to 15 December 2023, I co-led seminars and SPSS workshops for undergraduate students in the Statistical Methods for Business module within the Department of Management Science at a higher education institution in the UK as a Graduate Teaching Assistant (GTA). In this module, 358 students (from accounting and finance) are introduced to statistical concepts through lectures, with practical application during seminars and SPSS workshops, each with approximately 32 students for 1-hour sessions. I co-led the seminars and SPSS workshops with another GTA, which aimed to facilitate the practical application of statistical concepts.

I found that integrating AI tools like ChatGPT, Pi, and Gemini significantly transformed my approach to lesson design, particularly in chunking and scaffolding complex statistical concepts. One of the initial challenges I faced was the lack of student engagement, which prompted me to seek innovative ways to enhance my delivery.

Based on student feedback, I collaborated with AI to design lessons that broke down complex topics into smaller, more digestible steps.

The chunking strategy, suggested by AI, allowed me to simplify statistical problems by focusing on one chunk at a time. This method helped make the material less overwhelming for students, many of whom expressed that statistics felt complex and difficult to grasp. AI tools such as ChatGPT assisted by suggesting logical ways to divide the content, which I further tailored to meet the specific needs of my students. For example, when covering hypothesis testing, I broke down the process into distinct steps, each focusing on a single concept, which was well received by students: "*Working on solutions step-by-step has been helpful for me to grasp the concepts" (std114).*

Similarly, scaffolding was another effective strategy in my teaching approach, where AI helped me structure lessons that gradually increased in complexity. The AI-assisted design ensured that each step was built upon the previous one, allowing students to develop a deeper understanding of the material. This method also empowered students to progressively work more independently. Feedback from students affirmed the value of this approach: *"It helps me understand in depth what each concept means and relates to" (std98).*

However, I also encountered some limitations when using AI for real-world examples. ChatGPT, for instance, occasionally provided hypothetical case studies, which required further validation. I quickly learned that while AI can be useful in generating examples, it is the educator's responsibility to verify and adapt these to the real-world context, especially when accuracy is crucial. For example, when teaching regression analysis, I used the UK's GCSE grade predictions from 2020 as a real-world case study, validating this through official government sources. This enhanced the relevance and engagement of my students, reinforcing the importance of connecting theoretical concepts to real-world applications.

Collaborating with AI not only streamlined my lesson design but also enhanced the overall learning experience for students by breaking down complex ideas into smaller, more approachable parts. However, as an educator, I found it critical to adapt AI-generated content to fit the specific learning context, ensuring that the material was both accurate and relevant. Additionally, I encountered challenges regarding student assessments, as there were no clear guidelines or policies on how to evaluate AI-assisted student essays. This reflection highlights the delicate balance between leveraging AI for efficiency and maintaining human oversight, ensuring that educational content and assessments meet both pedagogical standards and students' needs.

5. DISCUSSION

The integration of AI technologies in education presents both opportunities and challenges. As educators increasingly adopt AI-driven tools to enhance learning, it becomes essential to promote a responsible perspective that balances AI capabilities with human oversight. In this section, I discuss how the dimensions of **Accountability**, **Collaboration**, and **Human Agency** must interrelate to ensure a responsible collaboration with AI.

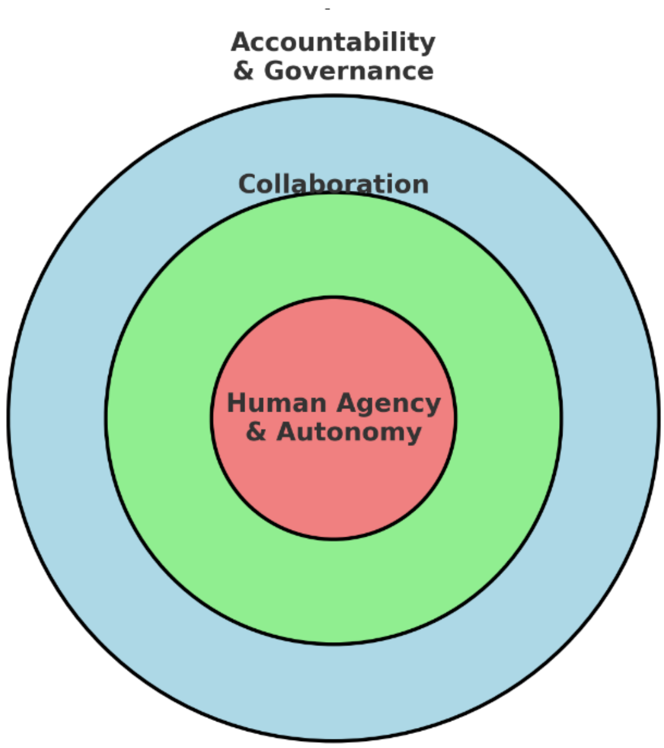

Figure 1. Concentric circles model of Responsible Human AI collaboration.

5.1. Human Agency and Autonomy

At the core of responsible human-AI collaboration in education lies the preservation of human agency. Educators must retain control and oversight of the AI outcomes. As noted by Molenaar (2022), AI tools should support rather than replace human judgment. In my collaboration, human agency played a central role in designing scaffolded lessons. While AI was employed to assist in breaking down complex concepts into smaller, manageable steps, it was the educator's expertise that guided how these steps were structured to fit the learning objectives. AI can automate certain aspects of lesson design, such as identifying logical sequences or suggesting related materials, but the final decisions on how to present and adapt the material to students' needs remain firmly in human hands.

For instance, when designing lessons that chunk content, AI can help by suggesting how to group related concepts or by providing insights into the pacing of lessons. However, the educator must interpret these suggestions and refine them based on classroom dynamics, student needs, and learning goals. This highlights the importance of preserving teacher autonomy, where AI serves as a tool that augments the teacher's ability (Aleven and Rummel, 2020) to design effective instruction without replacing their creative and pedagogical input.

A crucial element of this model is the empowerment of educators. However, educators must have the ability to override, adjust, and guide AI-based recommendations. This dynamic balance ensures that AI augments human capabilities, allowing teachers to focus on more nuanced and creative aspects of pedagogy, while maintaining authority over their classrooms.

5.2. Collaboration

The collaboration layer surrounds the inner circle, indicating that the collaboration is built upon human agency. This layer illustrates how accountability surrounds and safeguards human agency and the collaboration. It emphasises the responsibility to build the collaboration around human control where the educator is not over-reliant on AI but is in control. This guards against the sort of concerning collaborations noted by (Kim, 2024), where educators are passive AI recipients. For example, in my experience, collaboration between the educator and AI involved the use of AI to design lessons that scaffolded complex topics into smaller, more digestible components. The AI provided valuable support by chunking concepts and identifying optimal ways to sequence learning tasks.

However, the educator maintained control over how these chunks were taught, incorporating human insight to ensure that the learning process remained engaging and personalised. This collaborative relationship between AI and the educator was dynamic: the AI handled the more mechanical aspects of lesson design, while the educator shaped the overall flow, adapting the material based on student feedback and classroom realities.

This collaboration allowed for a more efficient design process while ensuring that students benefited from lessons that were logically structured and aligned with their cognitive development. Through responsible collaboration, the AI enhanced the educator's ability to design lessons but did not dictate how the material was delivered, maintaining the central role of human judgment.

5.3. Accountability and Governance

The outer layer of the responsible human-AI collaboration model emphasises accountability and governance. As Luckin (2024) highlighted in their article, there must be policies in place to govern the use of AI in educational settings. Such policies should extend to how to grade students' assessments from student-AI collaborations.

5.4. A Responsible Perspective in Human-AI Collaborations in Education

The interdependence of these three dimensions, Human Agency, Collaboration, and Accountability, forms the foundation of responsible human-AI collaboration in education. As depicted in the concentric circles model (see Figure 1), these layers are not isolated but work in harmony to create a responsible perspective. At the core, Human Agency and Autonomy are protected, ensuring that AI supports, rather than diminishes, the role of educators. Surrounding this core is Collaboration, which facilitates a fluid and productive interaction between human users and AI systems. Finally, Accountability and Governance provide the necessary policies and procedures to ensure educators are accountable.

This holistic model addresses the unique challenges posed by AI in education while leveraging its potential to enhance learning outcomes. By maintaining a balance between human judgment and AI capabilities, the model fosters an educational environment where AI serves as a valuable tool for both teachers and students without compromising the foundational human elements of learning.

6. CONCLUSION

The responsible integration of AI in education requires a careful balance between leveraging AI's capabilities and maintaining human agency. AI's role in assisting with lesson design can significantly enhance the efficiency and structure of teaching, allowing educators to focus on delivering personalised and meaningful instruction. However, the key to responsible collaboration lies in ensuring that educators retain control over the pedagogical process, using AI as a tool to augment their expertise rather than replace it.

Collaboration between AI and educators must be dynamic, with AI providing structured suggestions while educators tailor these insights based on their knowledge of student needs and educational goals. Clear accountability mechanisms must also be in place to ensure that AI-driven recommendations are accurate and free from bias.

Ultimately, responsible human-AI collaboration in education enables a more personalised, efficient, and effective teaching process, but it must always prioritise the role of educators as the guiding force in designing, delivering, and adapting lessons to meet the needs of their students. This thoughtful balance ensures that AI enhances human capabilities in a way that supports the integrity and quality of education.

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EXTENT OF EMBEDMENT OF ENTREPRENEURSHIP ADVOCACY AND TRAINING IN THE ENGINEERING CURRICULUM IN THREE SELECTED UNIVERSITIES IN BOTSWANA

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Abstract: Unemployment has become a major issue where the number of graduates is increasing exponentially while the job market is dwindling. In developing countries, including Botswana, the unemployment rate has remained in double digit figures for almost a decade. In most parts of the world there is a realisation that one of the long-term strategies to overcome the unemployment burden is to include entrepreneurship education and training as part of the tertiary programmes Therefore the question is: how have tertiary institutions and in particular, Universities in Botswana heeded this call? This article discusses results of a study that investigated how selected universities offering engineering qualifications in Botswana have embedded entrepreneurship in their curriculum. A mixed-method approach based on document review and interviews was used in the study. The finding is that while the universities offering engineering programmes appreciated the need for entrepreneurship training, in some cases this did not trickle down to embedding the skills in the programmes or to intensify its advocacy in their training programmes. The recommendation is to urge universities to offer training that offers a holistic development of knowledge, skills and attitudes which promote work productivity and ethics as well as an emphasis on an entrepreneurial (or self-employment) mindset.

Keywords: entrepreneurship, engineering, entrepreneur, unemployment, self-employment, start-ups, job-seeking, proprietor, business, venture

1. INTRODUCTION

Over the past three decades, there has been a greater realisation among world economies that formal employment alone, cannot lift citizens out of poverty. Moreover, the global economic fissures of the last two decades namely the Economic Crisis of 2008, Covid-2019 pandemic and Ukraine-Russia, among others, have caused escalating inflation in many world economies. This scenario has led to shrinking economies, resulting into shedding off a high number of formal jobs leading to a high rate of unemployment. Unemployment has become a major issue, especially in developing countries where the rate has remained in double digit figures. It is also a region where the number of graduates is increasing exponentially while the employment opportunities are shrinking.

The situation above has not spared Botswana, as the unemployment rate in 2023 peaked at a total of 275, 160 unemployed persons, constituting 25.4% of the possible labour force (O'Neill, 2024) as shown in Figure 1(a). Botswana also recorded the third highest unemployment rate in the SADC region (Galal, 2023) as shown in Figure 1 (b). What is worrying in this statistic, is that many of the unemployed are graduates, who are the focus of this article. Out of the total unemployed persons in 2023 (i.e. who were unable to find work despite their qualifications), a total of 47,269 were graduates, constituting 17.2% of the unemployed persons (Statistics Botswana, 2023).

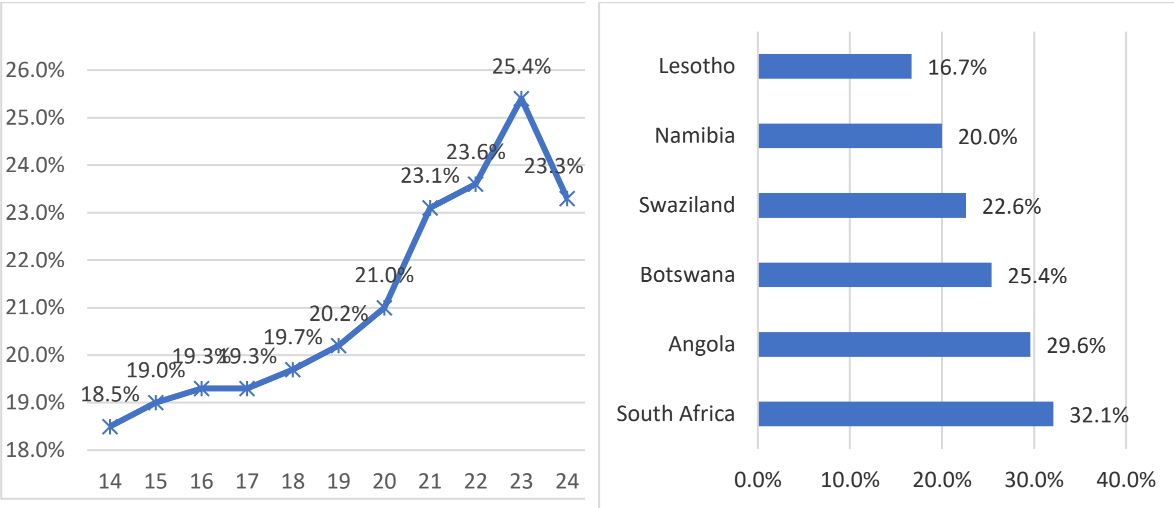

Figure 1. (a) Unemployment in Botswana 2014-24 (Source: O'Neill, 2024) and (b) the highest unemployment rates of SADC countries in 2023 (Source: Galal, 2023).

Various strategies have been proposed to overcome unemployment including improving education and skills to meet job market needs, investing in public employment programmes to create job opportunities, and supporting entrepreneurship and small businesses. However, before the latter materialises, entrepreneurship education and training should be made part of the graduate qualifications. The economic importance of entrepreneurial activities has been widely recognized as a key factor in creating new jobs. Entrepreneurship is thus critical in mitigating socio-economic problems such as unemployment, crime and drugs (Mutarubukwa, 2015). In view of this phenomena, most economies around the world have questioned the efficacy of tertiary institutions in producing graduates who are only seeking jobs instead of those who create jobs or both. A universal understanding exists now that, if tertiary institutions produced graduates who have an entrepreneurial attitude and skills, there is a high propensity for some of them going into self-employment as opposed to "roaming the streets" seeking employment. In view of this premise and the continued pressure from various stakeholders, tertiary institutions across the globe, especially universities, began embedding entrepreneurship training and development in their curriculum. The belief is that graduates would then exit with traditional qualifications (e.g. medical doctor, accountant, lawyer, engineer, etc.) as well as an entrepreneurial mindset. They would then be free to look for formal employment, establish their own professional practice or venture into any business. The latter means an engineer, for example, may establish and manage a construction business or any other enterprise outside the built environment, for example, an agricultural enterprise, a transport service, a manufacturing facility, a training or leisure facility (e.g. hotel or resort), among others. Furthermore, engineers have an opportunity of being at the forefront to participate in a "circular economy". Unlike a "linear economy", where raw materials are extracted from nature, turned into products, and then discarded as waste, a circular economy keeps materials and products in circulation for as long possible(Sanchez-Romaguera, Dobson and Tomkinson, 2016). It minimizes waste and promotes sustainable use of natural resources, through smarter product design, longer use, recycling, reduce consumption of non-renewable resources, as well as regenerating nature (Sanchez-Romaguera et al., 2016). The analytical and problem-solving ability of engineers gives them an added advantage to start and manage innovative enterprises to seize opportunities that a circular economy promises to offer.

Since entrepreneurship is a key element of any economy that hopes to grow and meet the challenges of today and the future, one wonders whether tertiary institutions in Botswana have responded to this call. It is important that tertiary institutions develop training programmes that create and nurture a mindset of entrepreneurship in the economy. Entrepreneurship training has the propensity to provide students with inspiration, motivation, mentorship and understanding of the resources available in the ecosystem to support an entrepreneurial agenda. Such training will give confidence to graduates so that it becomes a way of thinking where opportunities are emphasized over barriers and threats and hence the ability to create a start-up enterprise that generate new ideas and solve high impact problems in the society.

The aim of this article, therefore, is to discuss the results of an investigation into how selected universities offering engineering qualifications in Botswana have embedded entrepreneurship in their curriculum. The article is divided into five sections including this introduction. The second section provides a review of literature highlighting the nature and tenets of entrepreneurship, training and development. The third section describes the approach used to achieve the research aim. The fourth and fifth sections present results and a discussion of findings, respectively. The last section provides concluding remarks and some recommendations on embedding entrepreneurship in engineering training in Botswana.

2. LITERATURE REVIEW

This section provides an overview of the nature of entrepreneurship, entrepreneur and also discusses issues of training and development of entrepreneurship knowledge, skills and attitudes as it relate to engineering

2.1. Entrepreneurship and the Entrepreneur

The concept of entrepreneurship was coined in 1934 by Schumpeter who described it as an act of innovation which disrupts the market through the introduction of something new - a product, a service, a method of production, or a combination of them (Schumpeter, 1934). Key to entrepreneurship is attribute of innovation which spurs creative destruction where the newly created goods, services or methods can competitively hurt the offerings of existing firms (Shane, 2003). Recent definitions have identified the processes of innovation as discovery, evaluation and exploitation of opportunities to introduce new goods, services, or production methods which hitherto did not exist (Shane & Venkataraman, 2000). Therefore, an entrepreneur is a person who originates an innovative idea and commercialises it with a view to obtaining some future income stream. Specifically, an entrepreneur upsets and disorganises markets by using innovations, which appear in the form of, or a combination of: (i) introduction of a new product/service or quality of a product/service, (ii) introduction of a new method of production or delivering a service; (iii) opening of a new market; (iv) utilisation of some new sources of supply for raw materials or intermediate goods; and (v) reorganisation of the industry (Schumpeter, 1934; Shane 2003; Venkataraman, 1997).

Four aspects are worth noting which are summarised in Table 1 and where it is shown that innovation base may foster a number of occupation prospects. First, the entrepreneurial mindset is geared towards starting own enterprise based on an innovative mindset.

Table 1. Possible outcomes of an engineering innovation base.

Base	Innovation mode	Outcome
Engineering Innovation	Inventor	✓ Patents
	Intrapreneur brings forth innovative ideas	✓ Within an organisation in form of products, services and systems
	Entrepreneur may establish	✓ Engineering consulting services ✓ Services related to construction, installation, etc. ✓ Services related to manufacturing, fabrication, etc within the built environment ✓ Any other business outside engineering or built environment

Second, an entrepreneur should also be distinguished from an inventor who creates a product, method or a combination of them (just like an entrepreneur), but has no intention or desire of commercialising it. Pure inventors are normally interested in the ideation but not commercialisation process of their inventions (Baumol, Schilling and Wolff, 2009). On reflection, history is littered with such engineers who are famous for their inventions, for example, among others Nikola Tesla (1856–1943) of the alternating current (Rajvanshi, 2007). It is noteworthy that for some inventors, the furthest they have gone is patenting their inventions from which they earned some meagre income streams in form of royalties. Third aspect is that another term has been coined, "intrapreneurship", to reflect an innovative mindset in an organisation that plays a crucial role in stimulating "internal entrepreneurial" activities to ensure competitiveness and survival (Pinchot, 1985). Intrapreneurship also develops new products, services and production systems as well as improving them but within an existing organisation. Essentially, an intrapreneur is an employee of an organisation who brings about innovative ideas in the entity (however, the focus of this article is on entrepreneurship not intrapreneurship). Fourth, entrepreneurship is not an innate talent, it can be learned and hence can be taught (Colette, Hill and Leitch, 2005; Gibson, and Partington, 2015).) just like other professions. This is where the good news is because if graduates can be to become entrepreneurs, there is potential to reduce the unemployment burden. Fourth, in the recent spate of unemployment, most economies are not really looking for the "traditional cutting-edge entrepreneurs" as envisaged by Schumpeter, but proprietors or business persons who can start, buy, buy into, or inherit a business with the aim of owning it and hence being self- employed. However, they must have the skill, acumen and attitude to manage its operations in a profitable and sustained manner. In this way, they would employ themselves and create jobs for others in the economy. Therefore, the word entrepreneur has been "diluted" to mean a proprietor or a business person (however, use of entrepreneur will continue in this article).

Furthermore, two major reasons have been identified as to why individuals opt to go into self-employment. Brockhaus and Horwitz (1986) identified the first reason as "push (or accidental)" factors as being: (i) the appearance of an opportunity or chance to make money; (ii) lack of job opportunities arising from being fired from work, retrenched, retired or lack of employable qualifications, and work frustrations (e.g. not being promoted); (iii) being enticed by a government policy (e.g. empowerment/affirmative actions, diversification policies, etc.); (iv) taking over a business due to incapacitation or loss of a relative; (v) political upheavals, for example, confiscations or nationalisations of businesses. On the other hand, "pull (deliberate)" factors include, among others, the mindset or desire: (i) to be independent as own boss (freedom); (ii) for self-esteem and recognition resulting from creating a successful enterprise (iii) for doing enjoyable work; and (iv) for serving the community (Stanworth and Curran, 1973).

2.2. Theories and Studies Supporting Entrepreneurship Education

A few theories may explain why individuals deliberately pursue entrepreneurship and hence support entrepreneurship education as a reinforcing agent for luring graduates into entrepreneurship. The risk taking theory, for example, views entrepreneurship education as an enabler in suppressing the risk averseness that may be associated with the uncertainty arising from new venture by improving the ability, capability and the potential of an individual to undertake risks in return for economic benefits. This theory, therefore, perceives entrepreneurship as a mental education that stimulates individuals to take calculated risk in return for a future stream of benefits. Another theory, the need for achievement theory, connects entrepreneurial activity with the need for achievement and economic development. This is to say where on average there is a high level of need for achievement in society, there is a greater amount of entrepreneurial activity. This in turn translates into motivating graduates to have a high need for achievement in life and hence a greater tendency for them to set up their own businesses after graduation. Furthermore, the theory of human capital implores nations to invest in the training and development of the nation's workforce as they are a productive asset similar to the infrastructure network. This is supported by a Botswana report (BTEC, 2008) identified human resource training and development as a key driver of national productivity, efficiency and development. In emerging from stage one to stage two of development, human resource development is emphasised to bolster national productivity. Another critical theory is that of planned behaviour which postulates that a person will start or grow a business if he or she has the intention (mindset), enough information to form a favourable opinion, sufficient support and encouragement and importantly, the belief that he or she has the knowledge and ability to do so. This theory critically supports deliberate entrepreneurial training.

To buttress the above theories there has been several studies that have linked entrepreneurship education and the propensity for individuals to start enterprises. Among them is a study by Hien and Beri (2018), which indicated that entrepreneurship training and teaching at universities in Vietnam promoted entrepreneurship. The programmes in university positively affected the attitudes of students and their capabilities towards starting and running own enterprises. Another study by Ilyes (2021) found that universities in China paid great attention to enhancing students' comprehensive entrepreneurial quality and promoted an entrepreneurial culture among students. This contrasted with the USA where the focus on entrepreneurship education was not emphasized to the same extent and hence why many Chinese graduates are able to employ themselves.

2.3. External Drivers of Entrepreneurship Training

Assuming that entrepreneurship training and development empowers engineering graduates to turn into entrepreneurs, how should it be advocated for by agents external to the universities? Advocacy would provide the impetus to universities to embed entrepreneurship training in their programmes, after all they are supposed to respond to the societal and economic needs of nations. Generally, tertiary education and training is often guided by various instruments that include (i) national policies and strategies and (ii) national and international accreditation requirements for qualifications.

2.3.1. National policies and strategies

Literature was reviewed to identify relevant policies and strategies that guide engineering training and/or entrepreneurship training. In Botswana, the Human Resource Development Council (HRDC) is responsible for providing policy direction on all matters of national human resource development that include co-ordinating and promoting the implementation of the national human resource development strategy. In the National Human Resource Strategy of Botswana (HRDC, 2009) various areas were identified where human resource development should be undertaken. From this strategy the HRDC, from time to time, identifies a list of priority occupations and skills with the latest being Priority Skills 2023/2024 (HRDC, 2023). In this list entrepreneurship was not specified as a separate occupation but was mentioned three times as a soft skill for the occupations of Marketing Managers, Animal Scientist and Digital Transformation Managers. Furthermore, the rest of the list appears to emphasise discipline-related employment and not self-employment. This seems to be a lost opportunity to elevate entrepreneurship training to the national pedestal as it is at a contemporary global level.

2.3.2. Accreditation of engineering programmes

Another form of guidance for possible entrepreneurship training advocacy would come from accreditation bodies. Investigations revealed that most of the Engineering Council of South Africa (ECSA) which is signatory to the Washington Accord. The latter is an Accord, signed in Washington in 1989, as a multi-lateral agreement between bodies responsible for accreditation of tertiary-level engineering qualifications within their jurisdictions and who chose to work collectively to assist the mobility of professional engineers (IEA, 2024). Thus, ECSA's primary role, as empowered by the Washington Accord and the Engineering Profession Act (EPA), 46 of 2000 is the regulation of the engineering profession by accrediting engineering programmes, registration of persons as engineering professionals in specified categories, and the regulation of the practice of registered persons (ECSA, 2024). ECSA reach of accreditation is recognised through a memorandum of understanding between Engineering Registration Board (ERB) of Botswana and Botswana Qualifications Authority (BQA). BQA coordinates the education, training and skills development quality assurance system, from early childhood to tertiary level (lifelong learning) based on the National Credit and Qualifications Framework (NCQF) in liaison with professional bodies like ERB for advice on the accreditation of engineering programmes. In turn, ERB which registers professional engineers, has accepted ECSA's assistance to accredit engineering programmes in Botswana.

The basic requirements for an engineering programme to be accredited by ECSA is that it must conform to the required exit learning outcomes (ELOs) of engineering programmes. The 10 ELOs of ECSA are namely (1) problem solving, (ii) investigations, experiments and data analysis, (v) engineering methods, skills and tools, including information technology, (vi) professional and technical communication, (vii) impact of engineering activity, (viii) individual, team and multidisciplinary working, (ix) independent learning ability, and (x) engineering professionalism (ECSA, 2024). As discussed later, some of the outcomes specified for engineering overlap with those required in entrepreneurship, for example ELO (i), (ii), (viii), (ix) and (x). However, ECSA does not specifically prescribe that an engineer is free to turn into an entrepreneur, but as expected the focus on the professional whether working in an organisation or in a firm of practice providing consulting services.

2.3.3. The KEEN framework

Lack of a specific inclusion of an entrepreneurial mindset in the engineering programmes in US led to the formation of the Kern Entrepreneurship Education Network (KEEN) initiative (Petersen, Jordan, and Radharamanan, 2012). The network forcefully pushed engineering education to embed an entrepreneurial mindset in engineering programmes. The concern was that the engineering ELOs, specified in the Accreditation Board for Engineering and Technology (ABET) accreditation framework (ABET of USA is the equivalent of ESCA in South Africa) directed the programme designers to develop courses that are "right" for the discipline but not necessarily the "right attributes" of graduates in the market (Petersen, Jordan and Radharamanan, 2012). In view of this deficiency, the KEEN initiative defined a framework that defines an entrepreneurial mindset (EM) in the context of engineering based on six elements (i) curiosity (ii) connections, (iii) creating value, (iv) collaboration, (iv) communication, and (vi) character (London, Bekki and Brunhaver, 2018). The elements mean that an entrepreneurial mindset has the curiosity, connections to create value, based on the engineering thought and action, that is expressed through collaboration and communication, and founded on character (Kern Family Foundation, 2018). To inculcate this entrepreneurial mindset elements some universities have embedded specific entrepreneurial courses in the engineering curriculum in which they have translated the six KEEN elements into learning outcomes.

2.3.4. Global Response in Embedding Entrepreneurship in Engineering Programmes

In order to ascertain the extent to which there is a global trend towards embedding entrepreneurship in engineering programmes, an online search and analysis was conducted. The search involved using a combination of the prefix "engineering" and terms that included "curriculum, syllabus, programmes, innovation, entrepreneurship, start-ups, etc". The search was considered random because it did not target a specific university or programme.

The result of the search is summarised in Table 2. There was confirmation that some universities have embedded standalone entrepreneurship courses embedded in engineering programmes. Universities in Asia, and in particular China, recorded the highest most embedment of standalone entrepreneurship courses in their programmes. In fact, some of the engineering programmes had entrepreneurship as a "minor" offering.

Table 2. Universities with entrepreneurship embedded in engineering programmes.

Continent	No. of Universities Scrutinised	Existence of Entrepreneurship Course	Ratio
Europe	20	4	20%
North America	35	11	31%
Africa	24	5	21%
Australia & New Zealand	7	3	43%
Asia	19	9	47%

2.4. Internal Drivers of Entrepreneurship Training in Engineering Education

Internal drivers of training and development programme normally respond to advocacy and calls by eternal drivers as a response by universities to societal stimulus. The response is found possibly in three documents namely (i) a university teaching and learning policy; (ii) programme rationale and, (iii) course curriculum.

2.4.1. The University teaching and learning policy

In responding to external stakeholders and markets, universities around the world develop an overarching statement that provides guidance to the design and implementation of the learning and teaching processes of a university for the purposes of effectively preparing learners for life, work and citizenship including adaptation to change so that they will be able to contribute to economic and social development. Apart from providing guidance on the pedagogical strategies that encourage a student-centred learning , the achievement of learning outcomes through self-directed learning by creating learners who learn how to learn, the policy also specifies the general attributes that a graduate should possess on completion, regardless of the qualification obtained (Michael, and Modell, 2003). This statement comes in form of a policy and may be translated into a strategic plan to guide the development and sustenance of a university's brand in the face of competition in the tertiary market. In some cases, universities state implicitly or explicitly entrepreneurship or self-employment as one of the cornerstone attributes or abilities of their graduates.

2.4.2. The programme rationale

The programme rationale statement should state in general terms, on completion, what type of graduate the programme intends to produce (Harden, Crosby and Davis, 1991). These are broad statements that describe the expected career and professional accomplishments of the early years following graduation that the programme prepared the graduates for. An example of such a rationale statement could be "...the aim of this programme is to produce graduates who are not only seeking employment but who also have a mindset capable of recognising and pursuing business opportunities...".

2.4.3. The course curriculum

Should an engineering programme contain a entrepreneurship course its curriculum should comprises of least five statements namely the (i) rationale (ii) objectives; (iii) learning outcomes; (iv) assessment; (iv) learning activities; and (iv) content (McKimm, 2007). Due to brevity required in this article, two things are noted. First the aspects above are briefly highlighted and second pedagogical strategies will not be exploited.

Rationale states what the course contributes to the programme while learning objectives reflect the specific knowledge, skills, abilities, or competencies that a professor will impart as guided by the entrepreneurship contents. Learning outcomes, on the other hand, are statements specified in a learner-cantered manner, describing what learners must know, be able to do, and values they must develop as a result of integrating knowledge, skills, and attitudes learned in the course. They must be pitched at the right level of learning as guided by Bloom's taxonomy (Bloom, 1956; Krathwohl, 2002

Assessment statements show what the student is learning (formative) and also what the student has learned (summative) in relationship to entrepreneurial knowledge, skills and in particular whether they have developed an entrepreneurship mindset.

Learning activities are tasks carried out by the professor, students alone or a combination of both, during a teaching process with the aim of stimulating understanding and learning of entrepreneurship by students.

Course contents reflect the typical topics which a learner must cover in order to acquire entrepreneurial knowledge, skills and attitudes.

3. METHODOLOGY

In the quest to investigate how selected universities offering engineering qualifications in Botswana have embedded entrepreneurship in their curriculum, four research questions were posited namely: (i) do the universities have an overarching policy emphasising or stipulating entrepreneurship as a graduate attribute or post-graduation occupation?; (ii) do the programmes offered state or make any reference to entrepreneurship as possible post-graduation occupation or skill acquired?; (iii) do the programmes have a standalone course on entrepreneurship?; (iv) if there is no standalone course, is entrepreneurship partially offered as a module embedded in one of the courses of the programme? The quest was to assess the existence of these elements which contribute to providing engineering entrepreneurial knowledge, skills and attitudes but in exclusion of the effectiveness of the pedagogical methods. The reason behind looking for these aspects was to ascertain whether there is a deliberate effort to inculcate a culture and attitude that encourages both the lecturers and students to consider both job seeking and self-employment as post-graduation occupations. To achieve the study's aim and be able to answer the research questions, the research was conducted in two phases. The first phase involved a desk top review of any available documentation relating to teaching and learning policies and curriculum produced by the respective universities offering engineering programmes in Botswana. Preliminary investigations revealed that there are four universities that offer engineering programmes. However, the study involved three of the four universities, and due to confidentiality reasons they were code named UNA, UNB and UNC as shown in Table 3. The selection criteria was based on behind able to find key informants who are willing to participate in interviews.

Table 3. Profile of university and key informants.

Codes for participating universities	**UNA**	**UNB**	**UNC**
No. of engineering programmes offered	10	10	1

Code of programmes	PA1...PA10	PB1...PB10	PC
Key informant designation	Prof and Ass. Prof.	Ass. Prof	HoD
Key Informants code	KA1 & KA2	KB	KC

In addition, it was revealed that UNC offers one engineering programme while UNA and UNB offer 10 engineering programmes each, in the areas of civil, construction, electrical, electronic, mechanical, industrial, mining and mineral engineering. The curriculum content was scrutinised in order to obtain answers to the above research questions

The second phase of the study involved a 40 to 60 minutes interview, with each of the four key informants from the three universities (code named KA1 & KA2; KB ; and KC). The interviews were necessary to fill in gaps that existed in the documentation (for example, in cases of elective courses that were taken beyond the home faculty).The criterion for selecting the interviewees was based on willingness to participate in the study and conversant with the engineering curriculum development and accreditation . This combination was deemed appropriate in providing relevant and useful insights into the study aim.

4. RESULTS AND DISCUSSION

This section presents results and a discussion of findings arising from investigating how the three selected universities offering engineering qualifications in Botswana advocate and embed entrepreneurship training and mindset in their curriculum.

4.1. Advocacy and provision of entrepreneurial training by UNA

A key document from the university, UNA, titled, "Teaching and Learning Policy" was scrutinised. It stipulated that "....The university aims to support students to develop entrepreneurship and employability skills..." It went further to state that "...all the university's academic programmes provide entrepreneurship and employability skills to be achieved by all students." From these assertions, there are three observations which can be made.

First, the policy specifically mentions that the university expects programmes to be designed and delivered in a such a manner that graduates will possess entrepreneurial skills. Secondly, in doing so, it also explicitly differentiates between job seeking and self-employment as post-graduation occupations. Third, it goes further to list other skills that are normally associated with entrepreneurial activity that its graduates should posses namely critical and creative thinking skills; problem-solving skills; communication skills; organisational and teamwork skills; ICT skills; research skills and information literacy; social responsibility and leadership skills; interpersonal skills; cross-cultural fluency; accountability and ethical standards; self-directed and lifelong learning skills. Therefore, it appears that UNA has had the intentions of creating a culture and mindset through its curriculum design and delivery to produce entrepreneurs.

Following on the above, rationale or career path statements from the faculty, departments and all engineering programmes from UNA were also scrutinised to see if they stipulated the acquisition of entrepreneurial skills or even indicate that students could pursue entrepreneurial occupations on graduation. The authors could not find any statement whether at faculty or departments' level that indicated explicitly the desire to train and produce entrepreneurs and in particular. The faculty statement, for example, stated that among its dedicated aims was "...to produce high quality engineering, design and built environment graduates who can adapt to the *work environment* and discharge their duties satisfactorily..."; One of the key informants, KA2, argued that " though we do not say it directly, the skills we provide can metamorphose from employment to self-employment, for example, in our department we have a course which develops a student's ability to carry out investigations, planning, design, evaluation and analysis of a particular engineering problem using the knowledge acquired during the various learning activities .. in addition, many of our courses teach students to be able to formulate, solve problems by applying adequate methods of analysis, design and development, data processing, among others ..... these are the skills an entrepreneur needs..." He further noted"...one hopes that when students graduate, they may either take entrepreneurship courses or may learn 'on-the -job' if they venture into business...but at least have some the required skills...." The comment sounded like business as usual which produced entrepreneurs by accident and not a deliberate attempt to inspire students to pursue the occupation.

On the other hand, in one department, all their four programmes, (out of the ten engineering offered in UNA), students may (since some are compulsory and some are optional) take stand-alone entrepreneurship courses. An interview with one of the key informants, KA1, noted that "... the nature of our branch of engineering envisages entrepreneurship because it is manufacturing related and hence our courses provide students with an understanding of the theories and principles of entrepreneurship in order to prepare them to start and manage projects of an entrepreneurial nature as well as providing a set of critical skills for analysing and assessing entrepreneurial opportunities....the spread of skills includes business organization, funding, and legal aspects in entrepreneurship..." He further added "...we really recognise the need to have extra skills such as ICT, ethics, research & data analysis, communication, team work & networking but time is a challenge..."

4.2. Advocacy and provision of entrepreneurial training by UNB

The authors were not able to obtain a specific teaching and learning policy from university UNB. However, it was observed that the university has a dedicated department which offers business, management and entrepreneurship (BME) skills as an integrated package in the engineering curricula. The idea behind this philosophy was emphasised by participant KB who noted that "...there has been an emergence of hybrid jobs in the 21st century which require a whole set of new skill which combine knowledge and technical expertise from one or more domains. These include other areas, for example, entrepreneurship, innovation, project management, financial management, design, ethics, systems and critical thinking.." He further continued "...therefore, UNB offers specific courses in these areas that include: economics, business, and entrepreneurship; skills for employment and entrepreneurship development; starting and sustaining a business; developing a strategic business plan; innovation, intellectual property rights and commercialization; management and entrepreneurship concepts and principles; engineering project management; organizational design and change; organizational leadership; risk management in science, technology, and engineering; small business accounting and financial; entrepreneurship; sociology, technology & society; and engineering business and society..."

The existence of a dedicated department to offer BME shows the underlying intention of UNB towards the need for entrepreneurship training and mindset. Their statement in one of the documents reinforces this desire (UNB, n.d.)

> . "...the integration of these critical management and entrepreneurship skills in our engineering programmes is key to ensuring that the university produces future graduate leaders, researchers and innovators who have a good grasp of management and entrepreneurial knowledge and skills required to tackle real-world challenges...... the courses therefore provide graduates with the relevant knowledge, skills, attitudes and requisite capabilities needed for formal employment as well as self-employment......the overall aim, therefore, is to ensure that upon completion of their studies, graduates can effectively take up and perform management and entrepreneurship roles in formal and non-formal employment sectors and most importantly to be able to create viable and sustainable business ventures or become innovative intrapreneurs in established business organisations..."

This statement is loud and clear that the UNB seeks to produce both, job seekers and those going into self-employment.

A scrutiny of the programme rationale statements indicated there were only three programmes (PB1, PB3 and PB4) out of ten that stipulated that students will be equipped with skills to pursue entrepreneurship as an occupation, for example, the rationale for programme, PB1, stated that "..you will also be introduced to courses that address mitigating the environmental pollution, entrepreneurship, business management..."; while the statement for programme, PB3 stated that "...you will also be provided with soft skills that allow you to perform in the industry such as entrepreneurship and communication skills..." and PB4 stated "...the course will equip you with relevant skills whether one aspires to be an entrepreneur, an engineer, a social scientist, an economist or a banker....". However, despite the top-down emphasis of UNB, it was a bit disappointing that the rest of the programmes emphasised employment career path for example PB8 noted "...a student may look forward to a secure and well-paid career in a wide variety of organisations..." An omission is stating the rationale or career path statement of a programme does not cultivate the required culture of entrepreneurship mindset.

During the interview with the key informant, KB, from UNB, he noted one challenge that "... most of the programmes have a crowded curriculum and yet there are a number of useful non-engineering courses that compete for space and time.... however, we try our best to infuse these critical courses..."

4.3. Advocacy and provision of entrepreneurial training by UNC

The teaching and learning policy from UNC was silent about entrepreneurship training or mindset apart from emphasising the use of ICT is the teaching and learning. Actually, the document is guides lecturers on pedagogical matters. There is no programme statement relating entrepreneurship either but interesting enough, it was observed that the university offers a fully-fledged compulsory course on entrepreneurship, in its only engineering programme. The aim (or rationale) of the course is stated as "...to teach students to develop a sense and skills required to practice entrepreneurship.... stimulate creative thinking and the development of innovative skills .....in the field of entrepreneurship. Since the course was designed using an ECSA template, it had all the required elements (course rationale, objectives, outcomes, assessment, learning activities and content). Interviewee, KC noted '...while we offer the course, we do not guarantee change of mindset in choosing self-employment as a first choice occupation..". This statement relates to pedagogy which was out of scope for this paper.

5. DISCUSSION AND CONCLUSION

The afore going results have indicated a number of issues relating to the advocacy and training of entrepreneurship in engineering programmes in Botswana. First, both the HRDC strategy for human development and list of priority occupations did not specifically emphasise entrepreneurship as a key focus area. This is contrary to the prevailing situation where the country has a high graduate unemployment rate and yet entrepreneurship has been identified as a mitigating strategy. This advocacy should start at national level and then trickle down to the training service providers. Second the universities should also have a layered advocacy approach where there is a policy which stipulates the need for entrepreneur training and which is repeated for each faculty and department but relating it to the training provided. In addition, these statements should be visible or accessible to students as this is what contributes to mindset change and development. Third, while universities have appreciated the need for entrepreneurship training, in some cases this has not trickled down to embedding the skill in the programmes, for example, in some programmes in UNA (lack of top-down mind set trickle). In others (e.g. UNC), while there is evidence of entrepreneurship training it appears as if it is an island which is not shared university wide (lack of bottom-up appreciation).

In conclusion, since entrepreneurship has become key to economic growth and a strategic instrument for mitigating unemployment, there should be a concerted effort for its advocacy at national level at various policy and strategy platforms. This call should be picked up by tertiary institutions, in particular universities as training service providers, to ensure that entrepreneurship does not remain in policy documents but is embedded and implemented throughout their programme offerings. In particular, learning activities should include those which emphasise entrepreneurship skills and which inculcate the entrepreneurial mindset. Lecturers, if need be, should be inducted in such a way that they inspire and motivate students, to aspire to be entrepreneurs the same way they do with employment career development and achievement. Entrepreneurship should not be the province of a particular faculty but a requirement for all graduates. All these efforts hopefully will aggregate to create a crop of graduates who deliberately and willingly chose entrepreneurship in large numbers on completion of their programmes instead of choosing it by accident.

As a last word, this study did not look into the contents of the entrepreneurship courses and the effectiveness of entrepreneurship training. Building on to this research, authors are investigating the two aspects to identify how the most successful universities in this area impart entrepreneurial skills and mindset to their engineering graduates.

DATA AVAILABILITY STATEMENT

On request

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DECLARATION OF INTEREST

None

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INNOVATIVE LEARNING AND APPLICATION OF SOCIAL MEDIA TECHNOLOGIES IN ENGINEERING EDUCATION: *FINDINGS FROM A SYSTEMATIC STUDY OF BOTSWANA TOP ACHIEVERS IN STEM AND LITERATURE REVIEWS*

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Abstract: Social media is an interactive forum where people may exchange ideas, viewpoints, and information to discuss various topics and express their perspectives. In engineering education, social media is becoming more widely acknowledged and used, and studies have shown that it can involvement, learning, and engagement of the students. To develop policies for the efficient application of social media platforms in engineering education, the main topic of this theory paper is evaluating the numerous field research investigations by compiling the diverse research subjects, social media components that are employed, and analysis methods, among other things. The pieces for this study were obtained from a number of sources, such as Scopus, Science Direct, and Web of References: Science, Wiley Online Library, Google Scholar, IEEE Xplore Library, ERIC. As a component of this literature search, the search phrases used to retrieve articles from these databases are Snap chat + engineering + memes + pages; Youtube + engineering + stem Facebook + Engineering, Instagram + Engineering, and X(Twitter) + Engineering. The review process involved these distinct steps. In the first part a interview in the form of questionnaire were given on Instagram Polls feature to 10 Selected Top achiever programme students. The findings indicate that Facebook, Instagram, and X (Twitter) have been used as a learning environment in a few engineering disciplines, including software engineering, civil engineering, mechanical engineering, and electronics engineering. More than half of the sampled articles used quantitative research designs and descriptive statistics for data analysis, and META Facebook emerged as the most preferred choice of researchers among the sampled articles. Initially, all articles from various databases were gathered and compared to eliminate any duplicates, 10 articles that met the exclusion criteria as articles not focused on engineering, articles in languages other than English, articles with a focus other than Facebook, Instagram, and Twitter, and work-in-progress articles, were removed from the final list. In the second step, these 10 articles were screened based on their titles and abstracts to assess their relevance and applicability to the study. Out of these, 2 articles were selected for further consideration. Articles not meeting the relevance and applicability criteria were excluded from the study. In the third step articles that remained were critically reviewed to extract the relevant information necessary for the analysis.

Information such as research questions, research design, data collection, and data analysis, among others, were retrieved from the articles and consolidated in a separate file. Finally, this consolidated information was further analyzed and synthesized to generate observations and trends.

1. INTRODUCTION

The increasing prevalence of social media platforms (SMP), like X(Twitter), Facebook, Instagram, etc., in students' daily routines has prompted research into the tangible effects of SMPs use in an academic context. Scholars have been collecting evidence to determine whether SMPs can be utilized as a teaching tool [1]. Although many educators are optimistic about SMP's educational potential, researchers are still conducting experiments to ascertain whether students' learning habits have changed due to SMP and the connection between SMP usage and academic performance [2]. Depending on the type of SMP, users can interact with it by adding friends, publishing interesting links, tagging other users in their posts or status updates, leaving comments,use of hashtags liking other users' posts, privately messaging their connections, and in a variety of different ways. Within these SMPs, user interactions aid in developing a user relationship network that represents ties of direct social impact. More than 100 million students use social media, a technology that encompasses various social networking sites like Snapchat,Threads, Facebook, X(Twitter), LinkedIn, Instagram, etc. Recent research has demonstrated how to use network science concepts and data-driven methodologies to quantify social influences in social media [3]. Due to the ease and ubiquity of Social Media tools and ease of accessibility via a laptop, smartphone, or tablet, an increasing number of students are using them [4]. Students can interact with current and previous peers through social media, which also makes it easier to access emotional support and suggests creative activities [5]. This is crucial because, for minority students, making connections is one of the essential components of a fulfilling academic experience. Due to communication barriers or other reasons, minority students are typically less comfortable discussing their thoughts and experiences, so integrating social media platforms encourages the exchange of perspectives more effectively and without discomfort [6]. Despite these advantages, social media integration in education is hampered by several technical challenges, a lack of interest, and privacy concerns. As a result, efficient strategies for integrating social media into STEM disciplines must be developed to improve students' learning and engagement [7].

The use of social media in engineering education has also been on the rise in recent years, and it has become a popular tool for students and instructors to connect, collaborate, and share information [9]. While some researchers argue that social media can enhance student engagement and learning, others suggest that its use may negatively impact learning outcomes[10]. Studies have investigated the impact of social media on engineering education and have found mixed results. A study conducted by [11] showed that social media platforms such as Twitter and Facebook improve student engagement, as students were more likely to participate in class discussions and share course-related information on these platforms. teaching practices, it will be essential to continue exploring the impact of social media on student learning and engagement and to identify strategies to maximize the benefits and minimize the risks.

We also took a look at the use of SMP in education concerns about its potential adverse effects, such as distraction, privacy issues, and cyberbullying This research paper aims to examine the current state of social media use in engineering education, including the benefits, challenges, and potential risks associated with its use. It will also address the primary research question, " current trends of social media platforms usage in engineering education?"

The research aims to answer the questions listed below to explore and classify the articles being reviewed. This study will also explore the ways in which educators can leverage social media to enhance student learning outcomes and provide recommendations for future research in this field.

Q1. Which type of SMP has the most innovative interface for Engineering students?
Q2. Which engineering discipline does Batswana students learn about through SMP?
Q3. Which SMP offers the best ease of use for conducting research work?
Q4. Which sampling methods/ size were used in selecting the Students for the interviews?
Q5. What method of communication was used to conduct the study?
Q6. Which engineering discipline used social media as an educational tool within the context of engineering education?
Q7. Which types of research designs were used in the sampled articles?
Q8. Which topics/concepts were explored in the articles on social media in the sampled articles?
Q9. What methodologies/tools/formats were used in the articles for data collection on social media?
Q10. What sampling methods and sample sizes were used in the sampled articles?
Q11. Which social media platforms were used in the sampled articles?
Q12**.** Which data analysis methods were used in the sampled articles?

2. LITERATURE REVIEW BACKGROUND AND RELATED WORK

Social media activism campaigns to increase gender diversity in the engineering field have been examined using social media applications, such as hashtags on Twitter [11]. Other benefits of incorporating social media include the adaptability of following courses at any time and in any location, as well as the optimum engagement with course materials through peer discussion and opinion exchange [12].Despite the potential benefits of using social media, several challenges have been identified in incorporating social media into engineering education. One of the main concerns is the potential distraction that social media can cause during the class time [13]. Students may be tempted to use social media for personal reasons during class time, which could negatively impact their learning outcomes. Additionally, some students may be hesitant to participate in discussions on social media due to concerns about privacy and security [14]. Several best practices have been proposed to address the challenges associated with using social media in engineering education. According to [8], instructors should establish clear guidelines and expectations for using social media in their courses and provide training and support to help students use social media tools effectively. Additionally, instructors should monitor social media discussions to ensure they are relevant to course objectives and address inappropriate behavior [15].

The social media learning environment is a digital space where individuals can access educational content, engage in learning activities, and connect with other learners and educators (16). With the rise of social media platforms such as Facebook, Instagram, and Twitter, the social media learning environment has become a crucial component of modern education [17].This is due to the widespread availability of these platforms, their accessibility through mobile phones, and their ability to connect people from all over the world. [11]. A recent study found that 94% of university students, including those in developing countries, use Facebook. Students believe Facebook can be effectively used as an online learning environment [7]. Instagram: Instagram has over 1BILLION users, with one-third being students, making it a suitable platform for learning [10]. It offers a visually stimulating platform for sharing and discovering con tent, engaging students' attention, and promoting their creativity. Students can showcase their work, share ideas, and connect with professionals in their field. Instagram features live videos, stories, and hashtags, which can be used to host live events, tutorials, and discussions around specific topics or interests. Studies show that Instagram can enhance students' learning process through visual aids, improve writing skills, aid in project reminders, and promote group work. Overall, Instagram is a promising platform for creating a dynamic and engaging learning environment.X(Twitter): X(Twitter's) fast-paced and concise nature makes it a suitable learning environment for students. With a character limit of 280, X(Twitter) encourages clear and effective communication,while providing access to a vast amount of information from various sources . A recent study shows that architecture, engineering, and construction (AEC) university students utilize Twitter to follow subject matter experts, stay updated on relevant topics, and participate in discussions through hashtags or Tweet deck. Twitter has several advantages in higher education, including access to experiential learning, rigorous discussions, and improved grades

3. METHODOLOGY

The methodology for conducting a systematic study involves several steps to ensure rigor and comprehensiveness in the review process.

The first step involves defining the research question and developing inclusion and exclusion criteria for the articles to be reviewed. This helps to narrow the focus of the review and ensure that only relevant articles are included. Next, keywords related to the research question are used to do a full search of relevant databases like Research gate, Science Direct, PubMed, Web of Science, and Google Scholar. The selected articles / are then critically evaluated for their quality and relevance to the research questions. Finally, a synthesis of the findings from the eligible articles is conducted, and the results are organized and presented in a clear and concise manner.

3.1. Data collection and simulations

We used Xplore and Google Scholar databases, specifically targeting articles with the terms 'Facebook AND Engineering', ' Instagram AND Engineering' and 'Twitter AND Engineering' in the article's title, abstract, or keywords. In this study, a total of 48 articles [7, 8,] were initially reviewed for full text, and after careful consideration and evaluation.

For the second part of interviews we selected 10 Students from the Top achiever Programme, The specific of their courses as well as field of study was provided by DTEF / Ministry of education the sample size was initial of 300 but due to lack of communication and poor reposes it was cut down to 10, the second part of this analysis was done through an instagram Polling through which the students answered the questions as stated in the research,

4. RESULTS AND DISCUSSION OF FINDINGS

Here are the results from the poll and interview run on Instagram and questions to Botswana Top achiever students

Q1. Which type of SMP has the most innovative interface for Engineering students?

80% of the sampled students agreed with the option of Facebook
10% selected twitter (X)
5% chose Snapchat
5% chose Instagram

Q2. Which engineering discipline does Batswana students learn about through SMP?

50% Not STEM related
20% Mining engineering
20% Civil engineering
10% Mechanical Engineering

Q3. Which SMP offers the best ease of use for conducting research work?

60% Instagram
20% Facebook
5% X(twitter)
5% Snapchat

From the above questions we then conducted and further interviews with select Students, we learnt that students prefer Instagram as this is a picture sharing app with many video facility, unlike the other platforms it is well altered the quality of upload is 4k while other apps downsize the uploads to 1080p resolution, we also learnt that students Mainly use the Polls and questions Tag feature to run Interviews and questions to their Audience on Instagram stories this feature disappears in 24 hrs unlike other apps its more interactive in Instagram. Although the audience size is limited to the followers of the individual conducting the poll it is a very interactive option.

What method of communication was used to conduct the study? We used social media to reach out to the students and those who agreed to interviews were then referred to out Instagram pages where we used the video call feature and tags option on live and it was a more interactive session.

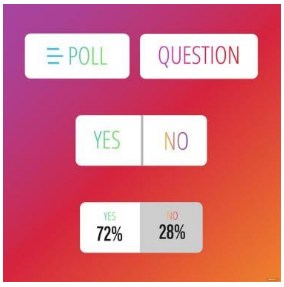

Figure 1. Here is an example of the poll feature in use.

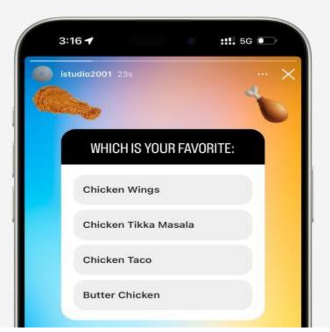

Figure 2. Polls can be yes and no or more detailed.

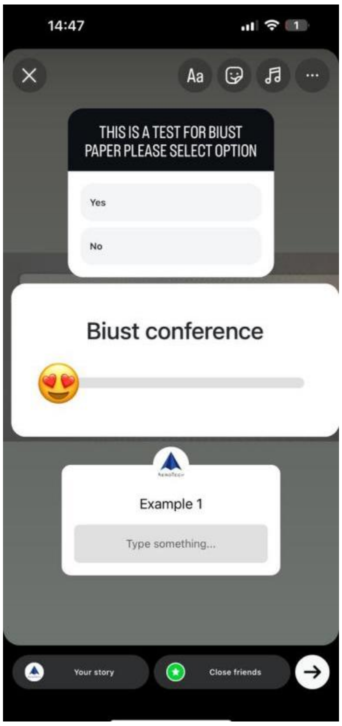

Figure 3. This is a showcase of other features.

We present the findings of the Literature review in this section research questions. The data presented in this section is from the 10 articles that made it to the final synthesis phase.

Which engineering disciplines in the articles used social media as an educational tool within the context of engineering education? in the sample of 10 reviewed articles. Among these, six articles (60%) focused on software engineering. Mechanical engineering and general first-year engineering were the subjects of 20% and 10% of the articles, respectively, while civil and electronics engineering accounted for 10% each. These findings suggest that social media is relevant and applicable in diverse engineering fields, as indicated

Which types of research designs were used in the sampled articles? Table 2 represents the distribution of research designs employed among the sampled articles. Most of the articles (60%) utilized a quantitative research design, and 20% used a qualitative design to investigate the effect of social media usage in engineering education. A few articles (20%) used a mixed design that combined quantitative and qualitative methods.

Table 1. Research Design Number Percentage (%).

Quantitative design	6	60%
Qualitative design	2	20%
Mixed design	2	20%

Which topics/concepts were explored in the articles on social media in the sampled articles?

Electronics Engineering
- Energy Policy
- Fundamental Electronics

Mining oil and gas Engineering
Software Engineering
Freshman Programming Courses
Introductory Programming
Civil Engineering
- Flood Management
- Structural Engineering Course
- Construction Engineering Course

First-Year Engineering - General Science Course
Mechanical Engineering
- Computer-Aided Design (CAD) Solid works
- Mechanics of Materials

What methodologies/tools/formats were used in the articles for data collection on social media? Research Design Data Collection Method Frequency Percentage (%)

Quantitative design 40%
- Questionnaire
- Feedback

Qualitative design 20%
Mixed design 30%
- Questionnaire
- Focus groups
- Analytical

What sampling methods and sample sizes were used in the sampled articles?

Table 2. Sampling Methods Frequency Percentage (%).

Random sampling	6	60%
Convenience sampling	4	40%

Table 3. Sample Size Percentage (%).

1-100	4	40%
101-1000	6	60%

Which social media platforms were used in the sampled articles? Most of the studies used 50 %Facebook as their social media platform, indicating the popularity of this platform. 20% (2 articles) of the articles used two or more platforms, while none of the articles used Instagram as the sole communication medium. Among those five articles, one study used Facebook and Instagram, one study used Facebook and Twitter together,and another study used Facebook and WhatsApp together. Two articles considered YouTube,

Which data analysis methods were used in the sampled articles? along with the frequencies and percentages of their use. The research articles that employed descriptive analyses as their research methods primarily utilized means, variance, and graphs as their data analysis methods. Among inferential analysis methods,

5. DISCUSSION

This study's initial goal was to provide a survey of the literature on social media in engineering education, encompassing works written, Seven research issues were examined, the first of which was concerned with the engineering specialties that employed social media to teach engineering. The findings showed that software engineering, general engineering, and mechanical engineering were the top three engineering specialties using social media. The various research designs for social media in engineering education were identified by the second research question. The most popular study design for most publications (61.90%) was the use of quantitative methodologies. The analysis showed that each article examined a different and distinct issue, with no themes covered in more than one. Future research has the chance to carry out comparable investigations on the same subject or area. It is important to do multiple research studies on the same subject or area for a number of reasons. It first aids in proving the findings' validity and dependability. Confidence in the validity and generalizability of the findings rises when several studies consistently present comparable findings. It also aids in pointing out any disparities or contradictions in the data, which may inspire more research to account for the variations. Second, a more thorough grasp of the phenomenon being studied is made possible by numerous investigations on the same subject. Together, the studies offer a comprehensive picture of the research issue, even though they may concentrate on various factors or topics. This may result in the creation of more complex and nuanced ideas or models. Third, carrying out several studies can assist in identifying areas that require additional research as well as gaps in the current body of knowledge. These holes might be filled by fresh research, which could result in novel findings or uses.

Most research publications concluded that Facebook was a beneficial learning environment for a variety of reasons. It is the most widely used social networking site, which gives students the chance to interact and work together with others who are located around the globe. It has elements that encourage academic communication, knowledge exchange, and resource use, like private groups, pages, and conversations. Second, teachers can easily incorporate Facebook into their lesson plans thanks to its familiarity and accessibility, which increases student participation and engagement. Due to its social aspects, students can help one another and exchange knowledge and experiences through peer-to-peer learning and cooperation. Last but not least, teachers can use Facebook as a venue to publish announcements, assignments, and reminders to keep students informed and current on their studies. It also gives professors the opportunity to interact with their students outside of the classroom, respond to inquiries, and give comments on their assignments.

The examined papers' data analysis highlights the value of network data analysis in the context of social media learning. In order to gain a deeper knowledge of the intricate dynamics of social media interactions, more research in this area is required that employs network data analysis to extract specific insights from participant interaction data . having been students in the Government institution from Psle to Bgcse most students do not have acess to Social media however in University the Exposure to social media is being used by the serveyed students to connect with their peers and conduct research as well as share data in a format that is easy to understand and more accessible,

6. CONCLUSIONS, LIMITATIONS AND CHALLENGES

In summary, the integration of social media into the classroom has the potential to raise student interest, expand their access to resources, and help them communicate with their teachers. Studies have indicated that incorporating social media into the classroom can yield favorable results in terms of student involvement and academic performance. An outline of the research on social media use in engineering education is given in this report. The results show that a few engineering students of Top achiever programme in the field such as software engineering, civil engineering, mechanical engineering, and electrical engineering, have used Facebook, Instagram, and Twitter. Facebook was the favored social media platform, descriptive statistics were used for data analysis, and quantitative research techniques were employed in over half of the sampled publications.

This research study has several limitations, just like any other. First off, this study only looked at Facebook, Instagram, and Twitter. However, there are additional social media sites like WhatsApp, Reddit, YouTube, LinkedIn, TikTok, and WeChat that could have a big impact on engineering education. Subsequent studies could examine alternative social media channels, their use, and their influence on the involvement and education of engineering students. Second, by concentrating solely on these three platforms, the publications that were obtained from various databases using the search terms "Facebook AND Engineering," "Instagram AND Engineering," and "Twitter AND Engineering" may have influenced our findings. Also the Due to small sample size of 10 students and 10 Articles the research conducted was very limited. We could have expanded our search even further by adding more search terms, such "social media AND engineering," in addition to these ones also increasing participants. The third restriction of this study is that it only included articles published between 2019 and 2022. This means that certain significant studies released earlier in the year may have been overlooked, which would have added even more relevant context to the analysis. Investigating the use of all social media platforms in engineering and its effect on student learning is one possible avenue for future research.We had a challenge of submitting this paper online as one author was in Moscow, when trying the email of University we failed to get any response for 3 months however in the comment section of the BUIST Facebook page we managed to reach a member and get their contact and were able to submit, this shows how social media can help in communication even in official capacity when traditional means fail.

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DECLARATION OF INTEREST

Our goal Is to further the involvement of Batswana into STEM and engineering, the use of social media can be a game changer we plan to conduct further studies with bigger sample size in order to understand how best we can utilize social media as a tool for engineering education. So far Africa is the youngest continent and has majority youth uses who mainly focus on meme culture news and entertainment however we wish to turn it into educational content like china has with its Biedu and in house apps

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RESPONSIBLE ENGINEERING EDUCATION PARADIGM AND PEDAGOGY THROUGH THE RESPONSIBLE COMPUTING WINDOW

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Abstract: African Stakeholders in University Engineering Education sector have the responsibility to offer Engineering curricula that produce Socio-Ethically responsible Engineering professionals for the academia and industry alike. A socio-ethically responsible Engineering professional is both technically and socio-ethically equipped, to effectively grapple with socio-ethical dilemmas that arise in the engineering artefacts design and development practice. Here lies a dual challenge! On one hand, African Engineering Education Systems suffer from colonial legacy of being wired to produce job seeking, rather than job creating engineers, who are lacking in the requisite capacity to provide appropriate African engineering solutions to African engineering problems. On the other hand, African engineering academics are ill-equipped to embed Engineering Socio-Ethics into their curricula provisioning, resulting in socio-ethically ill-equipped engineering graduates who are handicapped to fit their engineering practice into socio-economic and cultural realities of the African context. Computing, as a Science and Engineering discipline, shares some commonalities with Engineering from paradigmatic and pedagogical viewpoints, the synergy of which can be exploited in Engineering curricula provisioning. Drawing from their years of experience in Computing curricula provisioning in a number of African Universities, the authors propose a Responsible Engineering Education Paradigm and Pedagogy Framework (REEPPF) through Responsible Computing window. The proposed REEPPF integrates concepts, principles and theories embodied in the Durban University of Technology (DUT) context of curricula embedding paradigms and pedagogies from three sources viz: Engineering Practice Innovation Project (EPIP), Climate Change Literacy for Green Innovation and Entrepreneurship (CCL4GIE), and Computing Socio-Ethics for Responsible Computing (CSE4RC). The proposed REEPPF is posited as having the potential for utility in addressing the identified dual challenge of University Engineering education provisioning in the African context.

Keywords: Responsible Engineering Education, Responsible Computing, Innovation Project, Engineering Practice, Paradigm

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EXPLORING VIRTUAL REALITY APPLICATION IN CONCEPTUAL DESIGN: A PILOT EXPERIMENT WITH ENGINEERING STUDENTS

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Abstract: The development of virtual reality-based technologies brought significant change to the product design and development processes, enabling designers to visualise and interact more naturally with digital concepts in an immersive three-dimensional environment. However, despite these inherent advantages, there seems to be limited research on their integration into industrial design processes, particularly in Sub-Saharan Africa. This paper explores the application of Virtual Reality (VR) in the conceptual design process through a pilot experiment involving postgraduate and undergraduate Mechanical Engineering students. A mixed method approach is employed in this study, involving questionnaires, interviews, and observational data collected from 10 participants. Findings indicate that VR significantly enhances visualisation capabilities, increases engagement, and fosters creative design solutions, with postgraduate students adapting more quickly and demonstrating higher satisfaction. Furthermore, the findings highlight the transformative potential of immersive technologies in the learning environment, providing a roadmap for future utilisation in developing nations. Future research should focus on developing user-friendly VR applications and frameworks to help accelerate the adoption of these immersive digital technologies in design education.

Keywords: Virtual Reality, Conceptual Design, Design Education, Immersive Learning, Spatial Visualization, Mixed-Methods Research, Developing nations

1. INTRODUCTION

The recent technological advancements facilitated the growth of virtual reality technology and adoption across various industry domains, including construction, education, and retail in some developed countries like the UK and America (Bonetti et al., 2018; Lau & Lee, 2015; Wolfartsberger, 2019). The application of virtual reality (VR) technology presents a promising benefit in educational settings (Özgen et al., 2021), providing an immersive environment that may increase engagement, understanding, and retention among learners. Hence this study explores VR in an educational setting with engineering students. The aim is to evaluate to what extent VR supports conceptual design processes.

VR environments provide unique opportunities for active learning, allowing students to manipulate objects, conduct experiments, and explore scenarios in ways that are not possible in a traditional classroom setting. These applications include virtual touring of historical sites, simulation-based learning in a controlled lab setting, and engineering design education (Edwards et al., 2019; George, 2018; Joundi et al., 2020). Students who learn through VR demonstrate higher levels of motivation and interest, as compared to other conventional learning approaches (Jensen & Konradsen, 2018). However, research on the practical use in design education is still limited and this research seeks to investigate how virtual reality technology can enhance the conceptual design processes as highlighted above.

Conceptual design is often defined as an early stage in the product design and development process, which involves the generation of ideas to fulfill certain user requirements. It usually follows after the planning and task clarification stage, establishing the specific functions and constraints surrounding the design process (Cross, 1994; Kannengiesser & Gero, 2017). Conceptual designs can be represented in the form of flow charts or circuit diagrams. However, in engineering design practice where technical aspects like aesthetics need to be considered, sketches or CAD models are used to represent the visual appearance of the principal solution (Shih et al., 2017).

On the other hand, VR is an advanced stereoscopic technology, offering a more natural interaction and influencing the cognitive aspect of humans (E. K. Yang and Lee, 2020; X. Yang et al., 2018). The immersive environment is very critical in the early conceptualisation phase, where understanding spatial relationships and scale has a significant impact on the design. In conventional CAD systems, a 3D model is usually represented on a two-dimensional desktop interface whilst VR allows for three-dimensional visualisation (Horvat et al., 2019, 2022). This significantly improves a designer's spatial awareness and understanding of complex models.

Some studies have shown that immersive digital environments can stimulate creativity by allowing designers to rapidly prototype and visualise their ideas without the need to develop physical models, thereby reducing product development time and costs (Stadler et al., 2020). In addition, the incorporation of other sensory inputs such as tactile feedback provides designers with a sense of realism necessary to refine concepts and make more informed decisions (Ferrise et al., 2017; Schölkopf et al., 2021).

The remaining section of the paper is structured as follows: The next section reviews relevant literature on VR applications in industrial design education, highlighting the research gaps. This is followed by a detailed description of the research methodology, including the participants, materials, and all procedures employed in this study. The results section presents and discusses the findings, highlighting their implications in design education. Finally, the paper concludes by outlining the key takeaways from this study.

2. LITERATURE REVIEW

2.1. Overview of VR Technology

Most studies define virtual reality (VR) as the technology that enables users to interact fully with a three-dimensional computer-simulated environment (Gigante, 1993). The birth of virtual reality technology dates back to the 1960s, with the development of the first computer–connected headsets (Brooks, 2005; Ivan, 1968). Over the past few decades, it has evolved from a futuristic concept to a practical tool used in various fields. VR systems constitute the software that generates the immersive content and hardware components for interaction and visualisation (Anthes et al., 2016). The ability of VR to simulate real-world scenarios makes it a valuable resource for educational purposes.

2.2. Previous Research on VR in Design Education

Previous research has explored the applications of VR technology in educational contexts, thus elaborating how useful VR technology is in design education by promoting a greater understanding of spatial relationships and enhancing design and creativity. To buttress this, some authors have investigated the influence of an immersive virtual environment on designers' creativity (Obeid & Demirkan, 2023; X. Yang et al., 2018). The conclusion drawn from these studies indicated a positive strong correlation between a virtual design environment and creativity attributes (attention, confidence, and motivation). In another study, students who used VR were able to produce more innovative design solutions compared to those using traditional methods such as pencil and paper sketching (Joundi et al., 2020).

Furthermore, comparative studies have been undertaken to investigate the efficacy of VR over conventional CAD tools. Learners in VR-based environments scored better performance metrics as compared to those using CAD software in 3D modeling (Banerjee et al., 2023; Feeman et al., 2018). In the context of assembly training, the CAD model is exported to the virtual environment and visual cues in the form of images or textual data are used to guide the assembly process (Dwivedi et al., 2018). Findings revealed positive feedback and performance from participants using VR as a training modality, compared to those using traditional approaches (Schwarz et al., 2020).

2.3. Theoretical Framework

The theoretical framework for this study is based on experiential learning theory, which states that learning is a process in which knowledge is formed via the transformation of experience (McCarthy, 2010). VR creates a safe learning environment in which students can actively experiment and gain actual experience, resulting in deeper learning and retention. Furthermore, Vygotsky's (1978) social constructivism theory emphasizes the importance of social interaction and collaboration in learning, which can be facilitated via shared immersive experiences.

2.4. Gaps in Existing Research

The applications of immersive digital technologies have received heightened attention, especially in the design domain. However, there is limited applicability in the initial stages of design. Previous research predominantly revolved around the visualisation of 3D CAD models in an immersive digital environment (Hawthorne et al., 2022; Horvat et al., 2022; Wolfartsberger, 2019). Our study contributes to the impact of virtual reality on conceptual design for students at different educational levels. Understanding how VR influences the conceptual design process across different educational groups can provide valuable insights towards tailoring VR-based learning experiences to meet the needs of diverse student populations in different contexts. The study also presents the pedagogical benefits of the technology and prospects for future adoption.

3. METHODOLOGY

3.1. Research Design

The main objective of this research is to investigate the overall usability and effectiveness of VR design tools in geometric modelling. In this study, a mixed-methods approach is used to explore students' experiences, which combines both quantitative and qualitative data. This notion of integrating qualitative and quantitative data in research provides a greater depth and breadth of knowledge which is not always possible when using singular approaches in isolation (Almalki, 2016). Since our study is framed around experiential learning and social constructivism, the mixed method approach provides that avenue to interact with students and construct knowledge based on their experiences and stories.

3.2. Participants

Since the study involves human participation, ethical approval was applied for and granted by the Ethics Committee at Botswana International University of Science and

Technology. It was important to attain ethics approval before we interact with human participants to address issues of informed consent and data protection amongst other things. The participants consist of two user groups: postgraduate and undergraduate students enrolled in Mechanical Engineering. Students were recruited openly by using posters displayed in the University. Interested individuals who volunteered to take part in the study were asked to review the participant information sheet and the consent form prior to the experiment. All questions raised by the participants were addressed before the experiment. Table 1 shows the demographic information of the 10 students that participated in the study.

Table 1. Demographics of participants.

Attribute	Group	Frequency	Percent (%)
Gender	Female	4	40
	Male	6	60
Age group	18-24	6	60
	25-32	4	40
Academic level	Undergraduates	5	50
	Postgraduates	5	50
CAD experience	1-2 years	3	30
	>2 years	7	70

3.3. Setup of experiment

To conduct the experiment with students, we used the Oculus Quest 2 standalone head-mounted display (HMD) VR headset, offering a screen resolution of 1832x1920 pixels per eye, and hand-held controllers. The tracking system consists of sensors, enabling 6 degrees of freedom (D.O.F) for both head and hand motion. The virtual environment was cast on an i7 CPU, 16GB RAM desktop computer, and then onto an LCD projector. The virtual tracking area measured $16m^2$, enabling participants to move more freely and interact with their design solutions, without the constraints of limited space. This area was cleared of any physical obstacles to avoid any collisions. Fig. 1 shows the schematic diagram of the setup for this experiment, adapted from (Speicher et al., 2018).

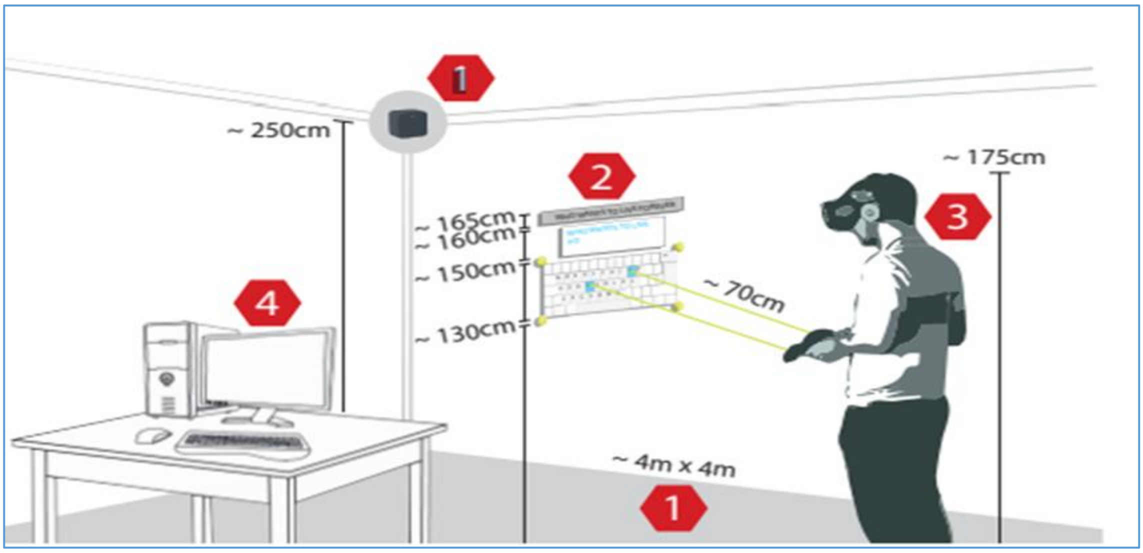

Figure 1. Setup of the VR system: (1) Optical camera at 2.5m and tracking space of 4x4m^2; (2) Virtual environment shown on an LCD projector; (3) Participant wearing a Meta Quest VR headset and controllers; and (4) Desktop PC to capture the digital contents on the headset.

3.4. Procedure

This investigation was carried out in four main phases which are:

- Training
- Modelling
- Post-task assessment
- Data analysis

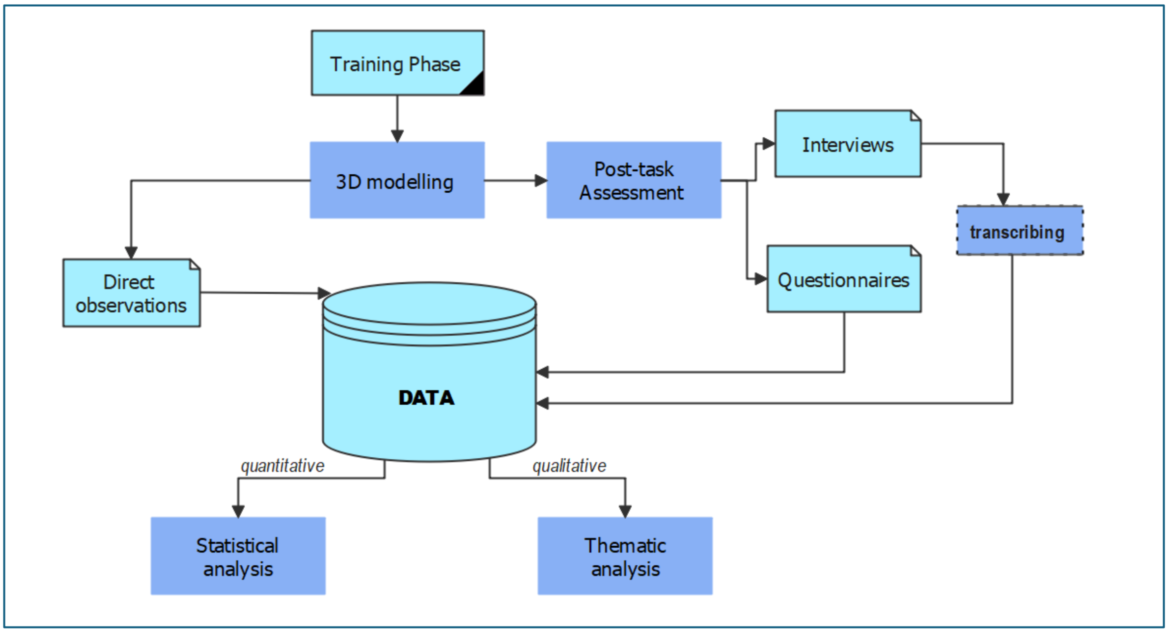

Figure 2. The experimental procedure.

3.4.1. Training phase

All the participants in this study had no prior VR experience. However, they were familiar with conventional computer-aided design (CAD) software, including AutoCAD, Solidworks, and Blender. Since the participants did not have any VR prior experience, we conducted the training sessions a week prior to the experiments. Amongst the many conceptual design software in the VR environment, we opted for the Gravity Sketch software because, in our judgement and experience, its graphical user interface has parametric adjustments and snapping features to assist novice designers in creating more accurate and detailed models than other VR design/modeling software. The other outstanding advantage is that Gravity sketch has the ability to create virtual strokes, using natural gestures without any spatial limits (Lorusso et al., 2020).

During the experimental sessions, participants explored various design features within the graphical user interface. Most students created different polygons and surfaces using the sub-divisional editing tools, enabling geometry manipulation by dragging control loops, edges, and surfaces to create more intricate designs. Fig. 3 shows some of the participants exploring the VR design interface and tools during the training phase.

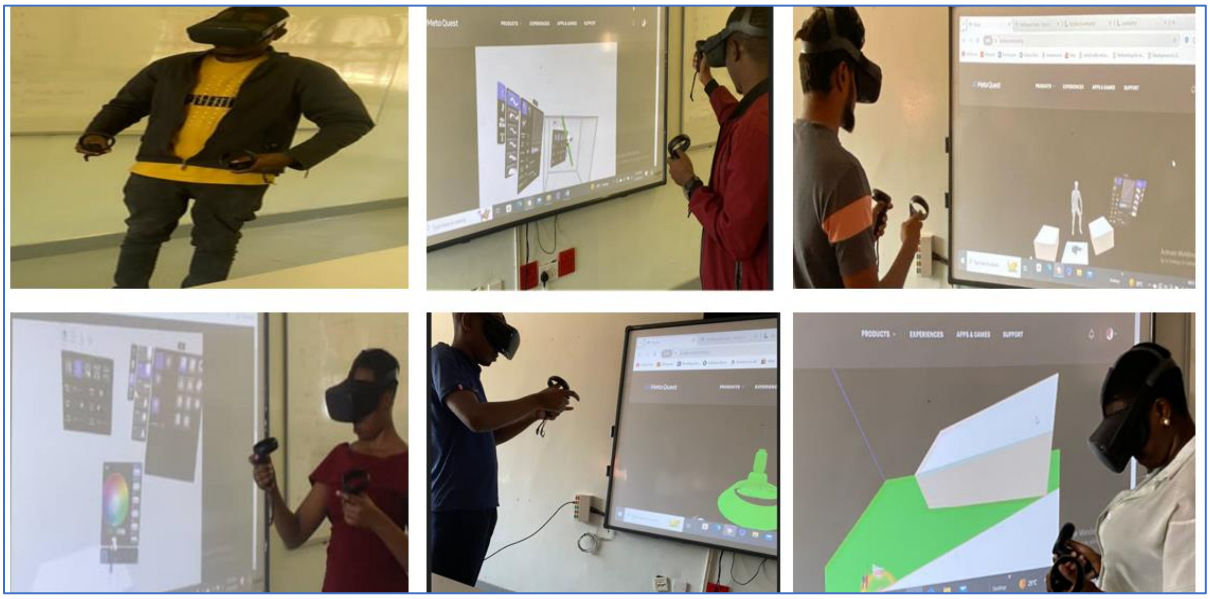

Figure 3. Participants exploring the virtual design environment.

3.4.2. 3D modelling phase

Following the training phase, the modelling phase began by asking participants to create a 3D conceptual design of a chair for either indoor or outdoor purposes. This task was standardized across both groups to ensure comparability. Each participant was allocated a modelling time of thirty minutes. A chair was chosen for this experiment as the student designers had the capability to use digital human models, which can simulate various body postures and movements. The researchers observed the participants' interactions with the digital tools and collected data in the form of notes.

3.4.3. Post-task assessment

The participants filled out a post-intervention survey questionnaire to evaluate their individual experiences and the perceived impact of VR on design conceptualisation. The evaluation metrics included the learning curve, visualisation, and interaction capabilities. Semi-structured interviews were conducted physically, offering more in-depth insights into the students' perceptions of VR design experiences. The interviewees' responses were recorded on audio and later transcribed into text data for analysis.

3.4.4. Data analysis

The quantitative data was analysed using R 4.4.1 software, highlighting the statistical differences between the two user groups. The audio responses from the interviewees were transcribed verbatim and uploaded to NVivo 12 software for thematic analysis. Based on the insights from (Braun & Clarke, 2008), this analytic method provides a more flexible approach that investigates the various viewpoints of participants by classifying, interpreting, and reporting the themes (patterns) emerging from the data, thus leading to more concrete conclusions. Therefore, we adopted this analysis method to develop themes from the qualitative data.

4. RESULTS

4.1. Thematic analysis

Following the guidelines of an inductive approach (Chandra & Shang, 2019), the codes and relevant themes were generated from the experimental data. A visualisation of the main themes and their respective sub-themes is presented in Fig. 4.

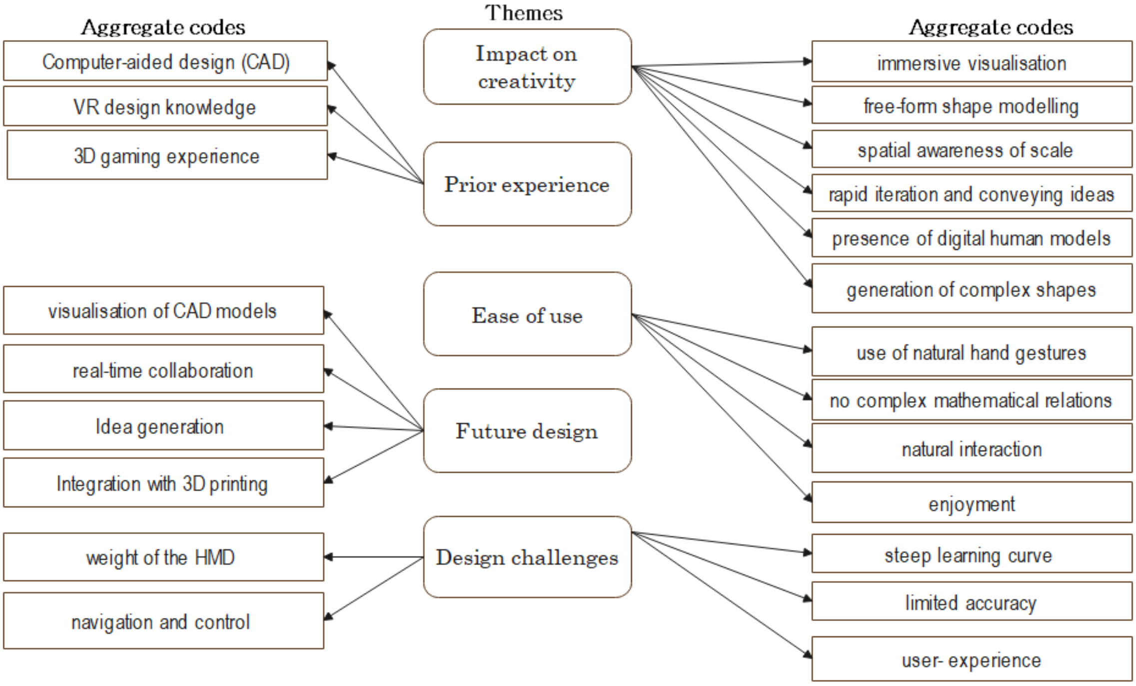

Figure 4. The main themes and sub-themes.

4.1.1. Impact on Creativity

From the analysis of the results, most participants agreed that virtual reality has a strong positive correlation with the creative design process. The chair in Fig. 5 consists of armrests, a decision influenced by the sitting posture of the digital human model (DHM) in the virtual scene. This also indicates that the use of digital models provides designers with a sense of realism, allowing them to creatively explore the products' ergonomics early in the conceptualisation phase. Thus, the conceptual design exercise has enabled participants to identify other benefits perceived by the technology, including the ability to perform free-form shape modelling without any geometric constraints and an increased sense of scale and proportion.

Figure 5. 3D chair design developed based on the sitting posture of the mannequin.

4.1.2 Prior experience

The feedback from participants also highlighted that prior computer-aided design (CAD) experience has an impact on the overall user performance in the virtual environment. All the participants had no prior VR design knowledge, however, they were able to transition to VR design, since they were already familiar with the fundamental principles and workflows of the conventional CAD systems. Some participants also revealed that the prior VR gaming experience enhanced their performance as they were able to adapt quickly to the design interface. This is supported by the following quote:

> *Despite my lack of familiarity with VR in design, my 3D gaming background helped me to completely understand the concept of navigating the interface (P3).*

4.1.3. Ease of use

The analysis from the open-ended interview responses and direct observations gave a clear overview of the overall usability of the technology in the design context. Most responses indicated that VR enhances user interaction and engagement. The following quotes, extracted from the interview data support this statement:

> *I felt like I was in a real environment and was able to interact with my 3D design without any restrictions (P6).*

> *The experience was new and exciting and I would like to explore more VR technology. Interacting in VR felt more natural and this helped me visualize the components better (P7).*

However, other designers expressed their difficulty in using the VR interface. Developing complimentary design applications tailored to help novice VR designers would be a critical step toward future adoption.

> *Gravity Sketch is quite difficult to understand but it needs familiarization. On a scale of 1-10, I will give it a 5 (P2).*

4.1.4. Future design

This theme delineates the envisioned applications of VR technology suggested by the participants. These applications include real-time collaboration, visualisation of CAD designs, idea generation, and integration with 3D printing to produce a physical model from VR design data. This is supported by the following extracts from the interview scripts:

> *I wish to adopt VR in the future, perhaps integrating VR technology with 3D printing (P1).*

> *VR is an interesting tool and I intend to integrate it with SolidWorks. After drawing in SolidWorks, I'll put it in VR and see how the object really looks at all points (P6).*

> *I would like to use VR in the future to model objects that I'll be able to properly visualize. It seems easy to generate ideas there and have something you can build on compared to just sketching in 2D in real life (P3).*

> *The platform supports real-time collaboration, enabling multiple users to work on the same design simultaneously. In the future, I would like to explore the design collaboration option in VR Gravity Sketch (P8).*

4.1.5. Design challenges

The participants' responses and interactions also shed light on the challenges encountered during the design exercise. Most participants revealed the steep learning curve, it took some time to get acquainted with the interaction and navigation of the VR interface:

> *The interface of Gravity Sketch is quite different as compared to the other CAD software like Solidworks and AutoCAD which we are more familiar with. It was quite difficult and challenging to get familiarised with Gravity Sketch for the first time (P5)*

In addition, one interviewee also gave feedback concerning the weight of the head-mounted display:

> *The VR headgear was heavy, and personally, my vision was interfered with for some time (P4).*

Another challenge reported by undergraduate designers is controller usability, resulting in poor designs, as shown in Fig. 6.

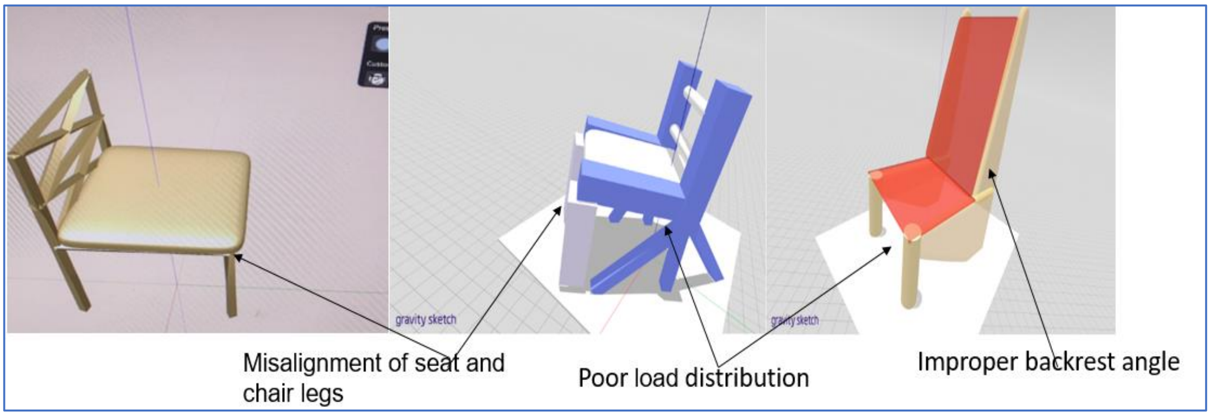

Figure 6. 3D chairs showing design defects developed by undergraduate students.

4.2. Learner's evaluation

The participants evaluated the technology's efficacy in geometric modelling on a 5-point Likert scale questionnaire, **(*Scores 1: poor 2: Fair 3: good 4: good 5: very good*)**. All the scores are positive, asserting values between 1-5 (Joshi et al., 2015). The descriptive statistics showing the overall analysis are shown in Table 2:

Table 2. Overall analysis of each metric.

Metric	**Mean**	**SD**	**Median**	**Min**	**Max**	**IQR**
Presence	3.94	1.1322724	4	1	5	1.00
Interaction	3.68	1.0388377	4	1	5	1.00
Task performance	3.52	0.9739463	3	2	5	1.00
Learning curve	3.28	1.0887177	3	1	5	1.00
Spatial awareness	3.90	0.8864053	4	1	5	1.75
Visualization	4.28	0.7570081	4	2	5	1.00
Usability	2.82	1.0631106	3	1	4	2.00

The findings indicate that participants rated visualisation at the highest level (mean= 4.28; SD=0.7570081), while the lowest is usability (mean=2.82; SD=1.0631106). The low standard deviation value on visualisation indicates that there is little variability in the participants' perceptions of this aspect. The mean value on usability is quite low and this can be attributed to the challenges faced by participants during the design process.

These descriptive statistics also reveal the higher scores on presence and interaction attributes, with mean score values of 3.94 and 3.68 respectively. Although trial sessions were conducted before the experiment, there is a need to improve the usability and learning of VR tools and interfaces. The density plots in Fig. 7 illustrate the distribution of responses between the two user groups.

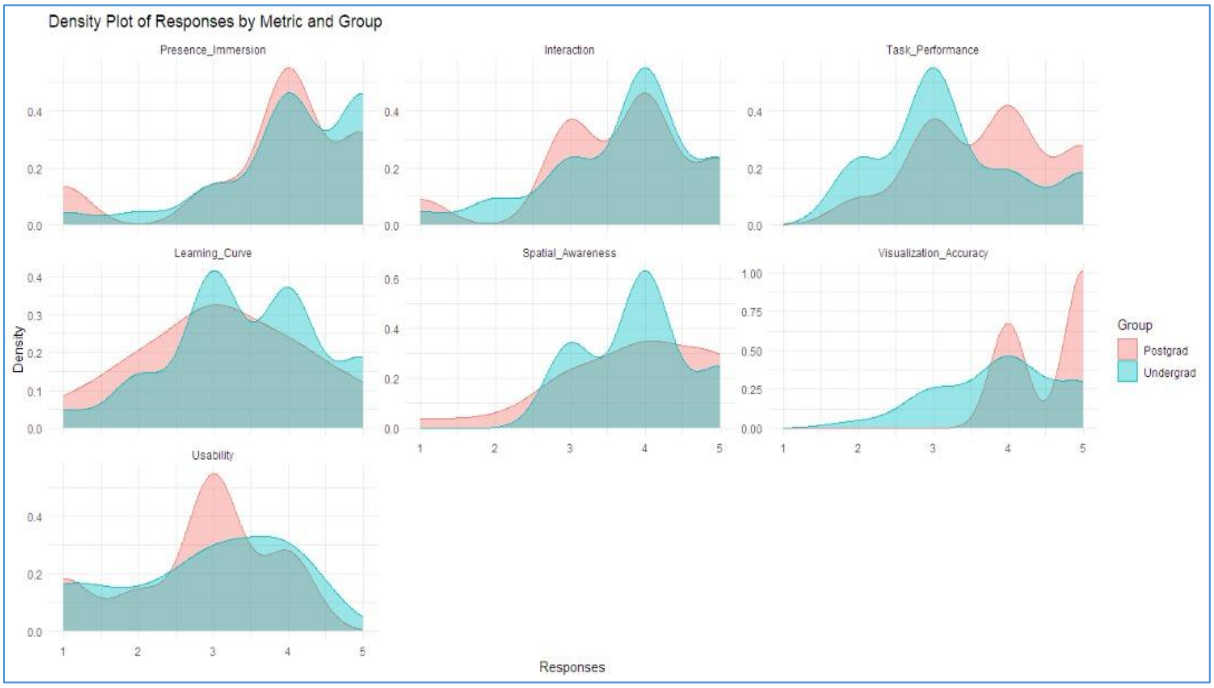

Figure. 7 density plot showing the distribution of responses between the two user groups.

On presence/immersion, postgraduates show a bimodal distribution, indicating diverse experiences, while undergraduates are more concentrated around a high score (4). This suggests that undergraduates may have a more consistent perception of presence and immersion. Both groups rate spatial awareness almost similarly, however, the plot of postgraduates' responses is more skewed to the left side with low ratings. Postgraduates rated visualisation and task performance highly (modal scores 4 and 5), while undergraduates are split between scores 3 and 5, indicating lower satisfaction. Postgraduates rated usability with a moderate score (3), while undergraduates showed a broader distribution, with notable dissatisfaction at lower scores (1-3). Addressing these usability concerns could significantly improve the experience of novice VR designers.

Undergraduates showed the highest level of satisfaction with interaction attributes. This can be attested by the prominent peaks between 4 and 5. On the learning curve aspect, postgraduates' responses show a normal distribution, which is symmetrical about the central value, while the undergraduates' responses are reflected on the multimodal curve, indicating varied opinions.

Overall, the above statistical findings indicate that postgraduates tend to have more positive and consistent ratings, particularly in metrics like presence, visualisation, and task performance while undergraduates’ responses exhibit more variability in their responses, reflecting differences in familiarity, expertise, or expectations. This also suggests that postgraduates performed better in VR design than undergraduates.

4.3. VR design outcomes

All the participants used the allocated 30 minutes for the modeling experiment. Fig. 8 depicts the 3D chairs developed using VR Gravity Sketch software.

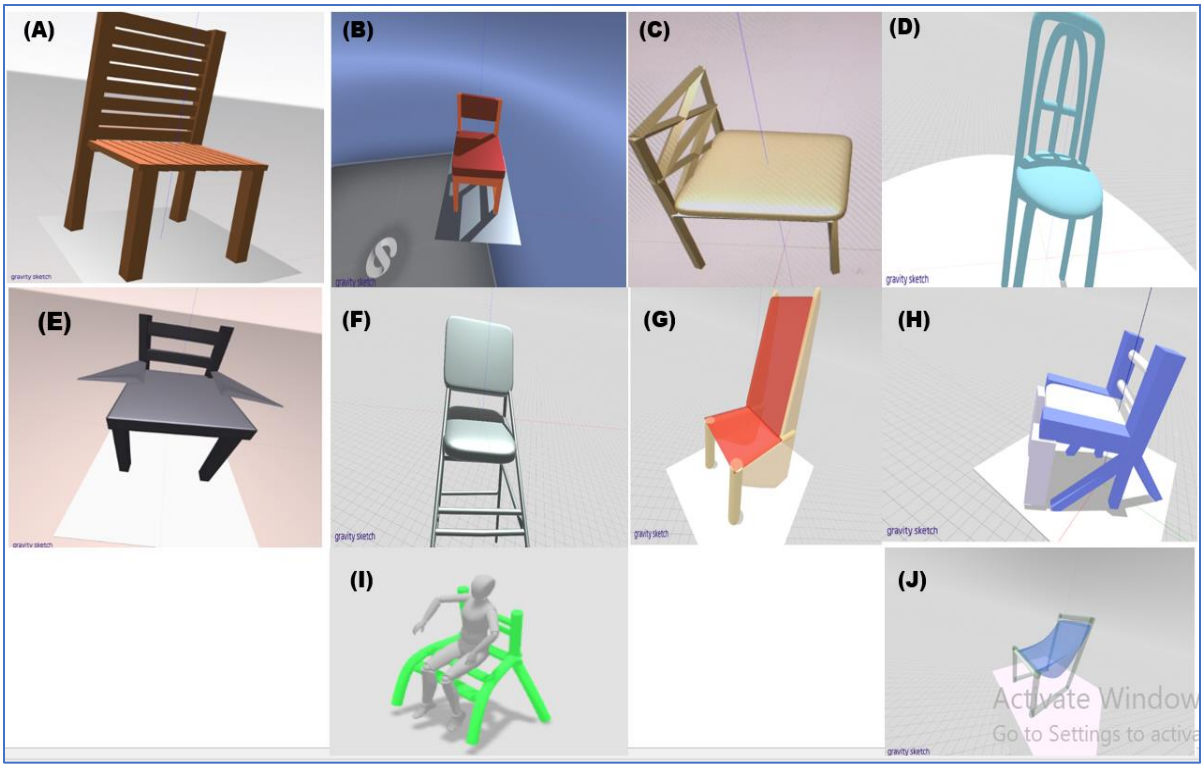

Figure 8. VR design outcomes: postgraduates (A, B, D, E, F) undergraduates (C, G, H, I, J).

The models developed by the postgraduates demonstrate their ability to adapt quickly to VR design tools and have better overall satisfaction than the other group. The sitting postures of the digital human models present in the graphical scene influenced the creative and conceptualisation process of some 3D chair models (E, G, I, and J). However, there is not much complexity and variety in all the chairs developed, as the participants chose simple designs, and they were not yet experienced with customisation options to create complex geometries. This means that prior experience is a key aspect of the VR design process.

Due to navigation and usability challenges, undergraduate models lacked precision and accuracy. Models C and H are the result of the misalignment of the seat and legs. Model G exhibits an incorrect backrest angle and a narrow base, which might cause user discomfort. Furthermore, Models C and H are unbalanced, because of poor load distribution and could potentially lead to lop-sided chairs. Some participants took several minutes of their modelling time, still deciding on the type of chair to design, and Model I is a clear reflection of unfinished work.

5. DISCUSSION

This experimental study has demonstrated the potential of virtual reality technology in the conceptual design process. The presence of an immersive virtual environment enhances design creativity (Feeman et al., 2018; Fleury et al., 2021; X. Yang et al., 2018). In our study, the presence of digital human models (DHM) in the virtual scene helped participants to explore various ideas and to be more creative as they did not have other contextual images for use as reference. This was reflected in several 3D chair designs developed based on the sitting posture of the digital human models.

Prior experience is one of the key dimensions affecting VR design. The work reported by (Banerjee et al., 2023; Berg & Vance, 2017) showed that prior CAD experience results in a more efficient workflow in VR design. All the participants had familiarity with 3D computer-aided design (CAD) and were able to transition to VR design, with those who had 3D gaming experience adapting more quickly. However, there is still a need for a deeper understanding of VR capabilities and adaptation to real-time interaction, and promote more innovative design solutions.

The inclusion of both postgraduate and undergraduate students allowed for comparative analysis. Overally, postgraduates indicated higher levels of satisfaction, as reflected by the evaluation metrics and VR design outputs. Although the majority of the participants managed to develop the 3D conceptual designs, there is a need to address the challenges surrounding usability and navigation. Our study found that students often struggled with using controllers to navigate the virtual design interface. In this regard, previous literature also agreed with our findings (Joundi et al., 2020; Laine et al., 2024). In another similar study, the VR modeling group's perceived usability mean was significantly lower than that of the traditional 3D modelling group (Banerjee et al., 2023). Addressing these challenges would enhance the overall design experience.

VR environment provides a more immersive and engaging experience, necessary for students to fully comprehend the design fundamentals. The findings suggest that the integration of VR technology into design improves students' spatial awareness of scale and proportion. The virtual design environment has provided a realistic sense of depth and distance, participants were observed walking around frequently in space, interacting with 3D concepts. In one user-centric study, the statistical analysis revealed higher spatial perception for participants in VR than in desktop systems (Azarby & Rice, 2022).

Although VR modelling presents an engaging and interesting experience, there is a need for a detailed functional instructional set in the user interface for novice designers (Huang & Lee, 2019). For educators, this means developing curricula that integrate VR technology, providing adequate training, and addressing potential challenges, such as steep learning curves, as outlined in this study.

Exploring collaborative design through shared virtual spaces would significantly enhance user performance. In design, collaborations in various immersive environments hold the potential of aligning different team members' opinions towards a common baseline, resulting in valuable product insights. Previous research has also demonstrated how this digital technology is reshaping human-computer interactions through co-design in multi-user VR interfaces (Gong et al., 2020; Wolfartsberger et al., 2020).

5.1. Limitation of the Study

The study's sample size was relatively small, and the duration of the experiment was limited. Future research should consider increasing sample size and extended study periods to fully validate and expand upon these findings. In addition, future investigations should also focus on exploring the long-term impacts of VR applications in design education, and critically examine how the digital technology compares to conventional CAD software and its transition to the manufacturing industry, thereby promoting innovative products in the Sub-Saharan Region.

6. CONCLUSION

This study contributes significantly to the generation of theoretical knowledge of emerging design technologies. The pilot experiments demonstrate VR's potential in transforming design education, with the ability to bridge the gap between academic concepts and practical applications, offering a more hands-on approach. The immersive and interactive environment allows better visualisation, enhanced interaction, and creative design solutions.

As the technology continues to evolve, its applications within the educational context are also expected to increase. The inclusion of gamification-based techniques in the

VR learning environment presents an interesting avenue that can be explored to foster an understanding of conceptual design education. This project provides the groundwork for future investigations into the use of immersive digital technologies in education environments, with a view to eventually expand to other significant industries within the Sub-Saharan Region.

DATA AVAILABILITY STATEMENT

The data will be made available upon request**.**

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DECLARATION OF INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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ADOPTION AND UTILIZATION OF EMERGING DIGITAL TECHNOLOGIES IN ENGINEERING EDUCATION: A SYSTEMATIC LITERATURE REVIEW WITH A FOCUS ON BOTSWANA HIGHER EDUCATION INSTITUTIONS

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Abstract: The Fourth Industrial Revolution (4IR), with its rapid advancements, has had a significant impact on education, especially in the field of engineering education, where teaching and learning practices are being revolutionized by digital technologies such as Artificial Intelligence (AI), Cloud Computing, and Learning Management Systems (LMS). The adoption and use of these new digital technologies at Botswana's tertiary engineering schools is investigated in this systematic review, which focuses on detecting trends, evaluating advantages and successful outcomes, and analysing difficulties encountered in use. Scoping approach was used to perform the review, which involved analysing literature from credible sources such Web of Science, IEEE, Scopus, and Google Scholar that was published between 2017 and 2024. The results show that virtual classrooms and learning management systems (LMS) are the main topics of research, emphasizing their vital significance in supporting distance learning and raising student engagement—especially during the COVID-19 epidemic. Additionally, cloud computing and artificial intelligence are highlighted, highlighting their potential to offer scalable solutions and tailored learning experiences. However, the review identifies several major obstacles that prevent the full integration of these technologies, such as financial constraints, resistance to change among faculty and staff, inadequate training for educators and students, and infrastructure limitations like frequent power outages and poor internet connectivity. The assessment suggests making deliberate investments in infrastructure development, creating all-encompassing capacity-building programs, and modifying curriculum to take advantage of new technology to address these issues. It also recommends that future research concentrate on exploring the ethical implications of digital tools, especially with regard to data privacy and equitable access, as well as conducting longitudinal studies to assess the long-term impact of digital technologies on educational outcomes and the cost-effectiveness of technology integration. To improve the standard of engineering education in Botswana, policymakers, educators, and institutional leaders must take these findings seriously. The potential of digital technology can be fully exploited by resolving the problems that have been highlighted. This will improve educational achievements in the area and prepare students for the needs of the Fourth Industrial Revolution. Students pursuing engineering degrees will be more equipped to meet the demands of the labour market in the future.

Keywords: Educational Technology Integration, Blockchain, Augmented Reality, Virtual Reality, Artificial Intelligence, Internet of Things, Personalized Learning

1. INTRODUCTION

The Fourth Industrial Revolution (4IR), with its swift advancement, has had a profound impact on many fields, including education, where it has brought about cutting-edge methods of instruction. The integration of these technologies has improved engineering education by allowing for more flexible, dynamic, and successful learning environments. New approaches to content distribution, assessment, and student interaction have been made possible by emerging digital technologies including learning management systems (LMS), cloud computing, artificial intelligence (AI), and cybersecurity tools. These innovations have completely changed the educational landscape (Pinto and Leite, 2020). Adopting these technologies is essential for improving engineering education in Botswana's tertiary education system and bringing it into line with international standards. But there are drawbacks to using these technologies as well, such as poor infrastructure, gaps in digital literacy, and reluctance to change among institutions and instructors (Khan et al., 2022). In reaction to these technological developments, engineering education in Africa is changing, incorporating both technical and non-technical skills necessary for the modern workforce. A balance between established engineering competences and newly developed soft skills is required by the 4IR, and digital technologies like artificial intelligence (AI), robotics, cloud computing, and virtual labs are essential to this shift (Fomunyam, 2021). Adopting these technologies presents significant hurdles for African tertiary institutions, despite the potential benefits. The complete integration of digital technology in education is hampered by problems that are common throughout the continent, including outdated curricula, inadequate infrastructure, and a shortage of trained personnel (Kaliisa and Picard, 2017, Eke et al., 2023). The uneven adoption of technology in different locations, where some institutions lag behind due to budget constraints and the slow pace of policy creation, exacerbates these difficulties (Butcher et al., 2021, Ibrahim et al., 2016). With a particular focus on Botswana, this systematic research examines how emerging digital technologies are being adopted and used in engineering education. The goal of the review is to give readers a thorough grasp of the advantages, difficulties, and current developments surrounding the integration of digital technology in this setting. Given the global shift towards digitalization, it is imperative that African educational institutions not only adopt these technologies but also use them effectively to foster innovation, improve learning outcomes, and increase the employability of engineering graduates. The findings will be crucial for policymakers, educators, and institutions in making informed decisions about technology adoption, thereby enhancing the quality of engineering education and preparing graduates for the demands of the 4IR (Nkosi et al., 2023, Barakabitze et al., 2019).In order to guarantee that the promise of digital technologies is fully realized throughout the continent, the evaluation also looks for gaps in the literature and suggests solutions. The review adds to the larger conversation on digital transformation in education, especially in developing nations like Botswana, by pointing out gaps in the literature and suggesting tactics for enhancing the uptake and efficient use of new tools. In light of the worldwide trend towards digitalization, it is crucial that educational establishments in Botswana not only embrace modern technologies but also make efficient use of them to improve student learning outcomes and engineering graduates' employability (Triplett, 2023, Lindin et al., 2023).

2. METHODOLOGY

Using a document analysis strategy, this study methodically looked through pertinent documents on cutting-edge technology for digital education. Using the Arksey and O'Malley methodology, a scoping review was carried out in 2024 to examine the literature on the uptake and application of new digital technologies in higher education, with a particular emphasis on Botswana's engineering faculties. The study's objectives were to list the digital technologies that Botswana's tertiary engineering schools now use, evaluate the advantages and good effects that come with using these technologies, and investigate the difficulties and obstacles that these institutions encounter while implementing and using them successfully. The study also aimed to provide workable solutions to these problems, so Botswana's engineering schools could fully utilize digital technology to improve student outcomes and comply with international standards. The results are meant to guide future efforts to maximize technology use and to provide policymakers, educators, and institutional leaders with information on the current state of digital technology adoption in Botswana's engineering education.

2.1. Research Question/Objective

1. RQ1: Which emerging digital technologies are currently being adopted and used at Botswana's tertiary institutions for engineering education?

2. RQ2: What advantages and good results have resulted from the use of digital technologies in Botswana's engineering education?

3. RQ3: What difficulties and obstacles do Botswana tertiary engineering schools face in embracing and using digital technologies?

2.2. Finding Studies That Are Relevant

This study used a theoretical methodology, referencing previously published work without adding any new empirical data. Using Arksey and O'Malley's (2005) scoping review framework, a systematic literature review (SLR) was carried out. The use and effects of digital technology in Botswana's postsecondary engineering education were the main subjects of the study. The integration of developing digital education technology has been noted by RQ1. RQ3 examined obstacles including infrastructure problems and aversion to change and offered solutions, whereas RQ2 investigated the advantages, such as improved learning experiences and student involvement. Only works from Botswana were included in the analysis; these were retrieved from Web of Science, IEEE, Scopus, Google Scholar, and ResearchGate databases. The search used a sophisticated method with "AND" and "OR" operators, and it was restricted to English-language papers published between January 2017 and June 2024.

("Emerging Digital Technologies" **OR** *"Digital Technology Integration"* **OR** *"Technology Adoption"* **OR** *"Technology Utilization" OR "Technology-Enhanced Learning")* **AND** *("Engineering Education" OR "Tertiary Education" OR "Higher Education")* **AND** *("Botswana")* **AND** *("Benefits" OR "Positive Outcomes"* **OR** *"Enhanced Learning Experiences"* **OR** *"Student Engagement" OR "Educational Outcomes") AND ("Challenges"* **OR** *"Barriers"* **OR** *"Infrastructure Issues"* **OR** *"Resistance to Change"* **OR** *"Digital Divide"* OR *"Institutional Barriers")*

2.3. Study Selection

Based on best practices in literature review, the inclusion criteria (research methodology, research aims, year of publication, author names, and research findings) were chosen. By concentrating on research methods, studies are made to be both relevant and methodologically sound, which makes it possible to evaluate their validity and applicability with confidence. To guarantee a direct contribution to comprehension of the subject, research objectives are incorporated to match the chosen studies with the particular objectives of this review. The publication year requirement ensures that the review includes the most recent and pertinent research, which is especially important in quickly developing sectors like digital technology education. Including author names makes it easier to keep track of important researchers and spot any biases in the literature. Finally, incorporating research results guarantees that only studies with distinct, comprehensive results are taken into account, allowing for a useful synthesis and comparison of findings. These standards guarantee a thorough, pertinent, and rigorous literature evaluation. Only English-language, full-version papers released in the last seven years were included. Books, chapters, commentary, editorials, expert opinions, study protocols, and papers without precise results or the entire text were all excluded. Duplicate articles were eliminated before importing the retrieved articles into EndNote. The selection of studies was conducted in accordance with the PRISMA flowchart's recommendations, as shown in Figure 1.

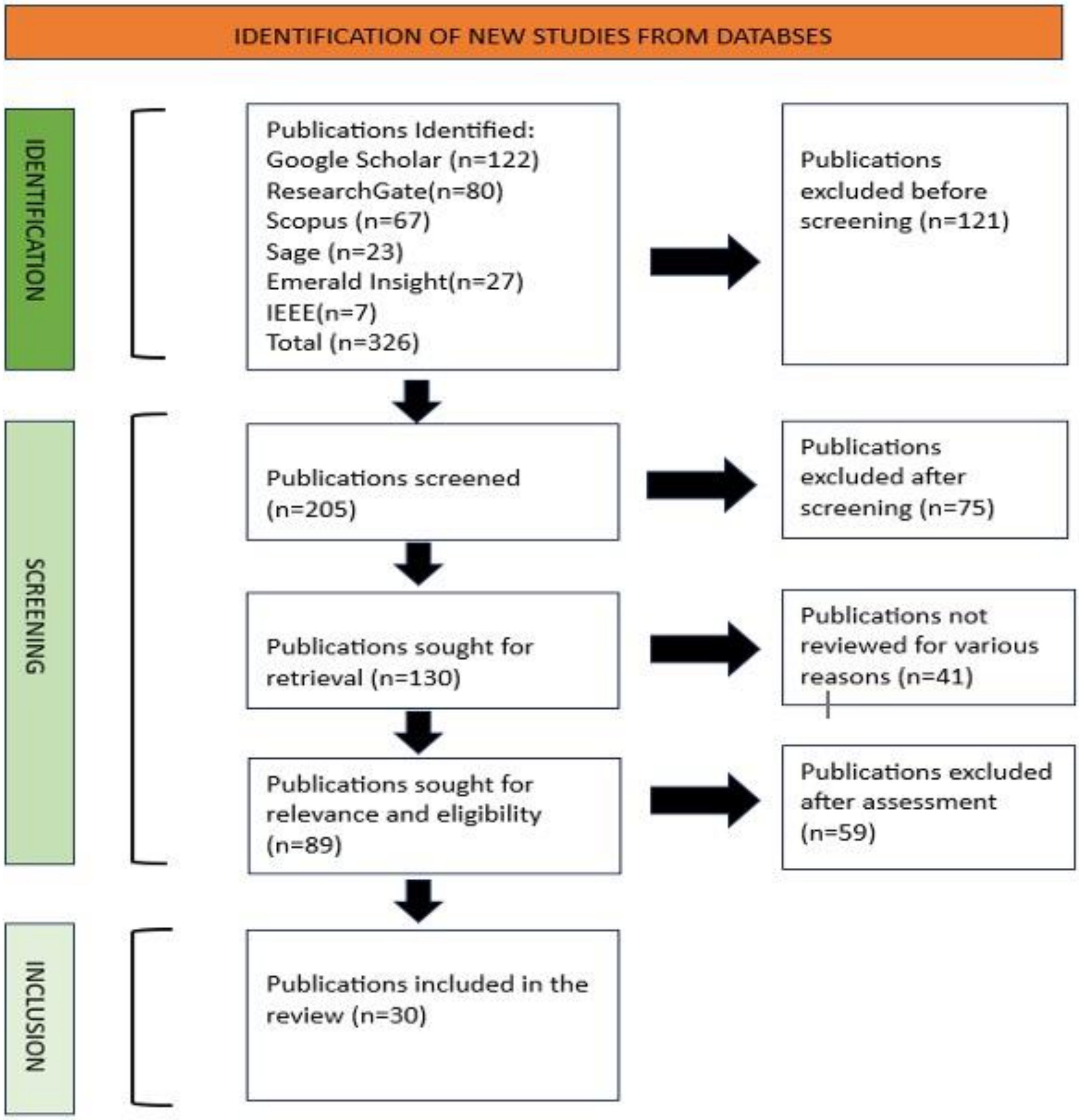

Figure 1. The PRISMA flowchart depicting the process of publication selection.

2.4. Charting the Data

Using a structured data extraction form, the data was charted as part of the Systematic Literature Review (SLR) process. This involved gathering important information in a methodical manner, such as author names, research methodologies, study objectives, results, journal types, indexed databases, and information about the application of emerging digital technologies in engineering education. After the data were collected, they were tallied and narratively presented, paying special attention to answering the research questions RQ1, RQ2, and RQ3. This method contributed significant insights to the area by guaranteeing a comprehensive synthesis of the literature and making it easier to create suggestions and proposals for tactics to improve the uptake and application of digital educational tools.

2.5. Collating, Summarizing, and Reporting the Results

The extracted data was methodically tabulated and presented in a narrative way as part of the process of compiling, summarizing, and reporting the results. The benefits, effects, and difficulties associated with the adoption and application of new digital technologies in engineering education within Botswana's higher learning institutions were covered in the report that followed. The purpose of this review was to address the research questions. To further classify the new digital technologies, their uptake and exploitation in Botswana's higher institutions, as well as the resulting benefits and problems, the data from the summary documents were further submitted to thematic analysis. This allowed for the identification of important common aspects. The trends and patterns in Botswana's engineering education regarding the adoption and application of new digital technologies were then profiled using these themes. This compilation made it easier to arrange and synthesize the results, which influenced the creation of ideas and suggestions for improving the application and tactics to make the most of cutting-edge digital technology in Botswana's engineering curriculum.

3. RESULTS

After searching six databases, 326 articles were identified. After applying inclusion and exclusion criteria, 30 studies were selected for review. These studies focused exclusively on the adoption and utilization of emerging digital training technologies in higher education institutions in Botswana. The study selection process is illustrated in the PRISMA flow diagram (Figure 1).

3.1. Characteristics of Selected Studies

A total of 30 papers (n=30) were selected and they focused on Botswana. The distribution of research methodologies is displayed in Table 1, with 35.71% of the studies using qualitative research. This indicates a strong emphasis on comprehending the experiences, viewpoints, and contextual factors that influence the adoption and utilization of digital technologies in Botswana's engineering education. This is essential to investigate the different opportunities and problems that institutions and educators encounter in this setting (Uys et al., 2004, Masalela, 2007, Segaetsho and Moloi, 2019). A thorough grasp of the variables promoting or impeding the adoption of digital technologies in engineering education requires combining qualitative insights with quantitative data, as evidenced by the 28.57% of research that use mixed technique approaches. This method is very useful for evaluating the quantifiable results of technology adoption as well as the subjective experiences of stakeholders (Mabalane, 2024, Moalosi et al., 2016, Uziak et al., 2018). Scoping reviews and quantitative research, which together account for 14.29% of the papers, highlight the significance of mapping the body of research on this subject and the use of statistical analysis in assessing the efficacy of digital technologies. In the context of Botswana's tertiary institutions, these approaches are useful for detecting trends, gaps, and opportunities for additional research (Tladi and Nleya, 2017, Uleanya, 2023). Finally, more specialized techniques that concentrate on analysing already-existing data sources or publicly available information are desktop research and OSINT data analysis, which together account for 3.57% of the procedures employed. These techniques are crucial for analysing the larger technology environment and comprehending outside variables that could affect Botswana's engineering education sector's adoption of digital technologies (Shonhe and Kolobe, 2023, Sarefo et al., 2024, Shonhe et al., 2023).

Table 1. Research Methodologies Used by Publications.

Research Methodology Type	Authors	Year
Qualitative	Uys et al. (2004)	2004
	Masalela (2007)	2007
	Segaetsho and Moloi (2019)	2019
	Mogapi et al. (2023)	2023
	(Dintoe, 2018)	2018
	Tladi and Nleya (2021)	2021
	Ntlotlang (2019)	2019
	Ntshwarang et al. (2021)	2021
	Magetse et al. (2024)	2024
	Ntshwarang et al. (2021)	2021
	Gwangwava (2019)	2019
Quantitative	Tladi and Nleya (2017)	2017
	Matyokurehwa et al. (2020)	2020
	Shonhe and Kolobe (2023)	2023
	Moakofhi et al. (2017)	2017
	Somfula and Zhanda (2023)	2023
Mixed Methodology	Mabalane (2024)	2024
	Mlambo (2024)	2024
	Seeletso and Letseka (2020)	2020
	Moalosi et al. (2016)	2016
	Uziak et al. (2018)	2018
	Denson and Bayati (2024)	2024

Scoping Review	Uleanya (2023)	2023
Desktop Review	Dodo and Okike (2021)	2021
	Sarefo et al. (2024)	2024

Table 2 displays studies categorized into four themes based on the mostly used emerging digital educational technologies. The implementation of cutting-edge tools like learning management systems (LMS), artificial intelligence (AI), and virtual reality (VR) is emphasized in studies on the integration and exploitation of emerging technologies, such as those by (Shonhe et al., 2023, Uleanya, 2023). The fact that these studies account for 28.57% of all reviewed research highlights how important these technologies are to the modernization of engineering education. Similarly, research on blended learning and e-learning makes up 28.57% of the studies. Mabalane (2024) and Ntshwarang et al. (2021), have contributed to this area of study by examining the use of Moodle and Blackboard during the COVID-19 epidemic. A quarter of the study examines the relationship between ICT adoption and the digital divide. For example, studies by Mogapi et al. (2023) concentrate on differences in digital tool access, while and Rapitsenyane et al. (2023) address the uptake of digital manufacturing technology like CNC machines and 3D printing. Lastly, 17.86% of the research focus on curriculum development and educational innovation, which are critical for ensuring that educational programs are prepared for the demands of the Fourth Industrial Revolution (4IR). Research by Uleanya (2023) and Gwangwava (2019) have conducted research that emphasizes the incorporation of digital twins and modern manufacturing technologies into engineering curricula. The way the research areas are distributed illustrates a thorough strategy for improving engineering education in Botswana's postsecondary institutions through digital transformation.

Table 2. Research Publications Objectives Condensed to Objectives Themes.

Research Publication Objective Themes	Author(s)	Year
Integration and Utilization of Emerging Technologies	Shonhe et al. (2023)	2023
	Uleanya (2023)	2023
	Somfula and Zhanda (2023)	2023
	(Gwangwava, 2019)	2019
	Zlotnikova and Hlomani (2024)	2024
E-Learning and Blended Learning	Mabalane (2024)	2024
	Tladi and Nleya (2017)	2017
	Tladi and Nleya (2021)	2021
	Ntshwarang et al. (2021)	2021
	Natarajan et al. (2017)	2017
	Dodo and Okike (2021)	2021
	Masalela (2007)	2007
	Ntshwarang et al. (2021)	2021
	Moalosi et al. (2016)	2016

	Uziak et al. (2018)	2018
	Seeletso and Letseka (2020)	2020
Digital Divide and ICT Adoption	Mogapi et al. (2023)	2023
	Dintoe (2018)	2018
	Rapitsenyane et al. (2023)	2023
	Denson and Bayati (2024)	2021
	Lenao (2023)	2023
	Matyokurehwa et al. (2020)	2020
	Sarefo et al. (2024)	2024
	Moakofhi et al. (2017)	2017
	Magetse et al. (2024)	2024
	Ntshwarang et al. (2021)	2021
	Segaetsho and Moloi (2019)	2019
Curriculum Development and Educational Innovation	Uleanya (2023)	2023
	Uys et al. (2004)	2004
	Mlambo (2024)	2024
	Segaetsho and Moloi (2019)	2019
	Gwangwava (2019)	2019

A further thematic analysis of the research results publications on the findings reached by the studies (Table 3) reveals areas of focus for the research papers selected. Adoption and Integration of Digital Technologies, makes up 35.71% of the research, stresses the use of technologies like social media platforms, cloud computing, and learning management systems (LMS). Researchers who examined the adoption of these technologies in educational contexts, such as Shonhe et al. (2023), Uleanya (2023), and Somfula and Zhanda (2023) , have made significant contributions under this theme. About 28.57% of the research studies noted the theme, Impact of Digital Technologies on Learning and investigated how educational results are impacted by digital technologies including gamification, blended learning, and virtual labs. The studies by Mabalane (2024), Tladi and Nleya (2017), and Natarajan et al. (2017), emphasized the advantages of modern digital technologies on learning on student engagement and learning effectiveness, as noteworthy in gamification, blended learning, and virtual labs. The implementation of digital technologies poses challenges that are a significant subject of research, as described in 25.71% of the papers. Mogapi et al. (2023), Dintoe (2018), and Ntshwarang et al. (2021) have examined these hurdles, which include poor infrastructure and digital literacy. Lastly, the theme of 4IR Readiness and Educational Innovation, which accounts for 10% of the studies, examines how prepared educational institutions are for the upcoming Fourth Industrial Revolution. Scholars such as Gwangwava (2019)and Zlotnikova and Hlomani (2024) are examining how advanced technologies like artificial intelligence (AI), robotics, and digital twins can be used to foster educational innovation. The diverse approach used by academics to handle the advantages and disadvantages of digital technologies in Botswana's educational system is highlighted by this thematic distribution.

Table 3. Research Publications Results Condensed to Results Themes.

Research Publication Results Themes	Authors	Year
Adoption and Integration of Digital Technologies	Shonhe et al. (2023)	2023
	Uleanya (2023)	2023
	Somfula and Zhanda (2023)	2023
	Masalela (2007)	2007
	Lenao (2023)	2023
	Matyokurehwa et al. (2020)	2020
	Uys et al. (2004)	2004
Impact of Digital Technologies on Learning	Mabalane (2024)	2024
	Tladi and Nleya (2017)	2017
	Natarajan et al. (2017)	2017
	Dodo and Okike (2021)	2021
	Moalosi et al. (2016)	2016
	Uziak et al. (2018)	2018
	Seeletso and Letseka (2020)	2020
	Mlambo (2024)	2024
Challenges in Implementing Digital Technologies	Mogapi et al. (2023)	2023
	Dintoe (2018)	2018
	Tladi and Nleya (2021)	2021
	Ntshwarang et al. (2021)	2021
	Ntlotlang (2019)	2019
	Sarefo et al. (2024)	2024
	Moakofhi et al. (2017)	2017
	Magetse et al. (2024)	2024
4IR Readiness and Educational Innovation	Gwangwava (2019)	2019
	Uleanya (2023)	2023
	Shonhe et al. (2023)	2023
	Zlotnikova and Hlomani (2024)	2024
	Mlambo (2024)	2024

3.2. Results of Synthetic Analysis

3.2.1. Emerging Digital Technologies in Engineering Education in Botswana's Tertiary Institutions

Virtual classrooms and learning management systems (LMS) account for about 21.43% of the studies in the research area, as shown by the bar chart (Figure 2). This trend highlights how crucial digital learning platforms are for engineering education, especially for boosting student involvement and enabling remote learning (Shonhe et al., 2023, Ntshwarang et al., 2021). Cloud computing, which accounts for 14.29% of articles, is the next most researched technology. This emphasizes how cloud-based solutions that are both scalable and flexible may serve a range of administrative and instructional tasks in the field of engineering education (Uleanya, 2023, Ntshwarang et al., 2021).

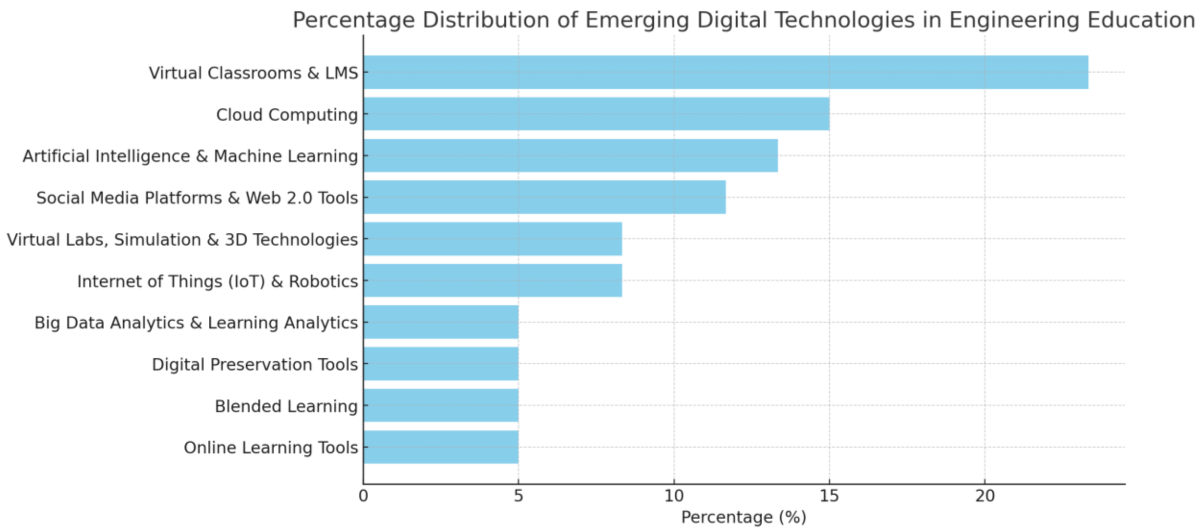

Figure 2. Emerging Digital Technologies in Engineering Education in Botswana's Tertiary Institutions adopted and used in Tertiary Institutions.

Machine learning and artificial intelligence (AI) are also heavily featured, making about 11.90% of the study. In order to improve data-driven decision-making and offer individualized learning experiences, these technologies are being incorporated into engineering curricula on a growing scale (Uleanya, 2023, Zlotnikova and Hlomani, 2024). Other significant technologies include Virtual Labs, Simulation, and 3D Technologies (7.14%), and Internet of Things (IoT) and Robotics (7.14%) and Social Media Platforms and Web 2.0 Tools (9.52%), reflecting their growing importance in collaborative learning, practical skill development, and aligning with Industry 4.0 requirements (Lenao, 2023, Mabalane, 2024, Mlambo, 2024, Gwangwava, 2019). The graph shows that even though there is a growing interest in some digital technologies, such as Digital Preservation Tools (2.38%) and Big Data Analytics and Learning Analytics (4.76%), there is still a lot of room for research and integration into engineering education(Dodo and Okike, 2021, Segaetsho and Moloi, 2019). This distribution shows that there is widespread interest in using a variety of digital technologies, with a distinct focus on those that facilitate virtual and remote learning environments, to improve the caliber of engineering education in Botswana.

3.2.2. Benefits and Positive Outcomes Have Arisen from the Integration of Emerging Digital Technologies in Engineering Education in Botswana

Figure 3 shows that almost half of the publications (48.6%) emphasize the advantages of having better access to educational resources and materials, particularly when using LMS platforms like Moodle and Blackboard. These platforms have greatly improved students' and teachers' capacity to efficiently access and manage learning materials from a distance (Ntshwarang et al., 2021, Uziak et al., 2018). The theme of increased flexibility in learning processes—where digital technologies enable adaptive and self-paced learning—is also mentioned in a sizable portion of the studies (42.9%). This theme was especially pertinent during the COVID-19 pandemic, when eLearning tools were essential to preserving educational continuity (Shonhe et al., 2023). The beneficial effects of digital technology on student involvement and interaction are highlighted in more than one-third (37.1%) of the publications. While the inclusion of multimedia technologies has made learning more participatory, platforms such as Blackboard have also enhanced communication between professors and students (Denson and Bayati, 2024, Uziak et al., 2018). To prepare students for the demands of the Fourth Industrial Revolution (4IR), educational curricula increasingly incorporate cutting-edge technologies like artificial intelligence (AI), 3D printing, and CNC machines. Nearly 31.4% of publications centre on this topic (Moalosi et al., 2016, Rapitsenyane et al., 2023, Somfula and Zhanda, 2023). Furthermore, according to (Moalosi et al., 2016) and (Uys et al., 2004), 28.6% of the research address how the use of interactive tools, simulations, and blended learning models has improved pedagogical approaches. Finally, 25% of the publications stress the value of experiential learning made possible by digital technologies, particularly in engineering education where tools like 3D printing and AI are used to promote creativity and practical skills (Gwangwava, 2019, Somfula and Zhanda, 2023).

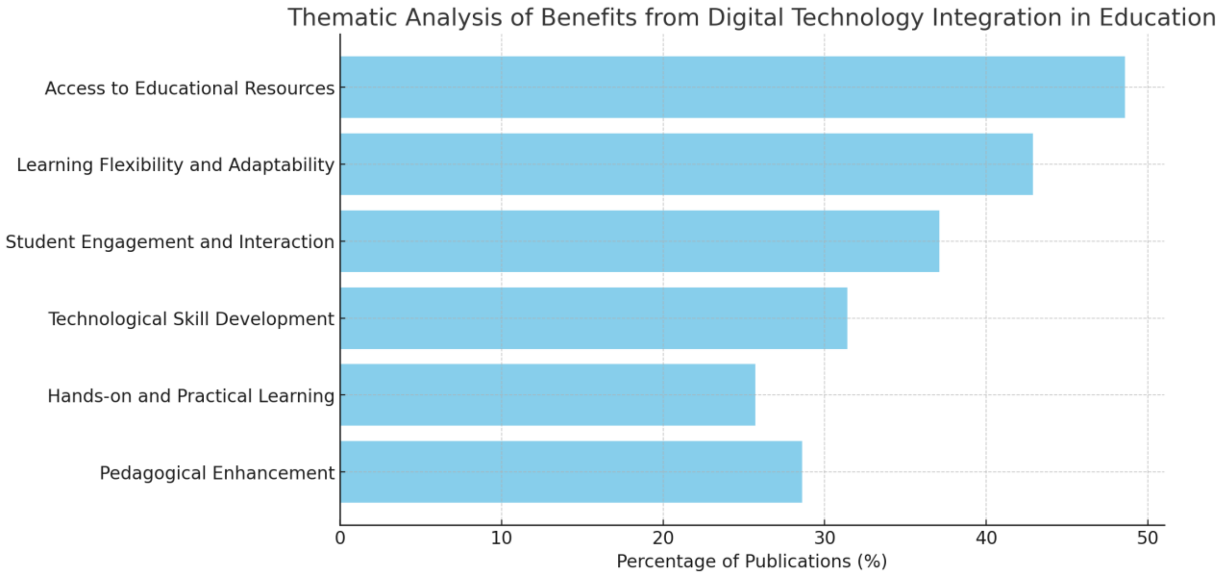

Figure 3. Thematic Analysis of Benefits from Digital technology Integration.

Numerous studies have shown that the use of digital technology in Botswana's educational institutions has resulted in a range of advantages, difficulties, and the application of developing technologies. Numerous research demonstrates how digital technology improve schooling. According to Shonhe et al. (2023), (Shonhe and Kolobe, 2023) students believe that these technologies have a lot to offer in terms of time-effectiveness, flexibility, and learning adaptability. In similar attempt, Ntshwarang et al. (2021) note the improved accessibility of learning materials and scheduling flexibility provided by eLearning platforms like Moodle and Blackboard in preserving learning continuity throughout the COVID-19 epidemic. Furthermore, as highlighted by Rapitsenyane et al. (2023), exposure to cutting-edge technology like 3D printing and CNC machines in engineering education has aided in the development of experiential and practical learning opportunities. According to Uziak et al. (2018), using Blackboard in mechanical engineering classes has enhanced student involvement and allowed for better student-teacher collaboration. The studies also demonstrate how developing technologies are being incorporated into the educational environment. While (Somfula and Zhanda, 2023) discuss the growing adoption of automation and AI in industries like borehole drilling, Mabalane (2024) mentions the growing use of cybersecurity tools and LMS platforms. AI is a prominent technology in many studies, as Shonhe et al. (2023) discuss its potential to enhance public sector service delivery and support sustainable development goals. The use of GenAI tools in education is examined by Zlotnikova and Hlomani (2024), who highlight the tools' potential to improve individualized learning and automate administrative duties.

Notwithstanding these advantages, a number of difficulties have been noted. Mogapi et al. (2023) identify three major obstacles to the efficient use of technology in education: inadequate internet access, a lack of ICT infrastructure, and a lack of in-service training. (Dintoe, 2018) goes on to say that major obstacles include faculty reluctance and the high expense of technology, especially at the University of Botswana. Uleanya (2023) has observed that inadequate infrastructure is a recurrent theme in the uneven adoption of 4IR technologies across regions, especially in rural areas where access to energy and the internet is limited. Similarly, Moakofhi et al. (2017) talk about how BUAN's inadequate internet access and frequent power outages make it difficult for the organization to conduct e-learning.

Significant advantages have resulted from the integration of digital technologies into Botswana's educational system, notably improved learning flexibility and adaptability Shonhe et al. (2023) and increased hands-on learning through advanced technologies like 3D printing and artificial intelligence (Rapitsenyane et al., 2023, Shonhe et al., 2023). To fully realize the potential of these technologies in education, however, infrastructural, finance, and training challenges—highlighted by Mogapi et al. (2023), Dintoe (2018), and Uleanya (2023)—must be addressed.

3.2.3. Challenges and Barriers Utilizing Digital Technologies

Figure 4, shows that 21,43% of the studies, mention the biggest obstacle to incorporating digital technologies into education is infrastructure constraints, such as slow internet connectivity, frequent power outages, and limited access to essential hardware and software (Moakofhi et al., 2017, Mogapi et al., 2023). Problems with technical skills and training follow closely behind this, with 19.1% of the papers highlighting the deficiency in technical support and inadequate training for educators and students (Dintoe, 2018, Ntshwarang et al., 2021). Another significant obstacle is financial, which is mentioned in 16.9% of the research publications. This includes high implementation costs for technology and a lack of finance (Shonhe et al., 2023, Somfula and Zhanda, 2023). According to 13.5% of the publications, faculty and staff resistance to change, including technophobia and unwillingness to adopt new technology, is also considerable (Dintoe, 2018, Mogapi et al., 2023). The issues of policy and management issues are highlighted in 28.6% of the studies (Tladi and Nleya, 2017, Ntlotlang, 2019).About 11.2 % of the publications discuss challenges related to aligning existing curricula with new technologies and the need for curriculum reform (Ntlotlang, 2019, Shonhe et al., 2023, Uleanya, 2023). Concerns about data privacy, security, and ethical issues surrounding emerging technologies like AI are mentioned in 7.9% of the studies (Mabalane, 2024, Zlotnikova and Hlomani, 2024),

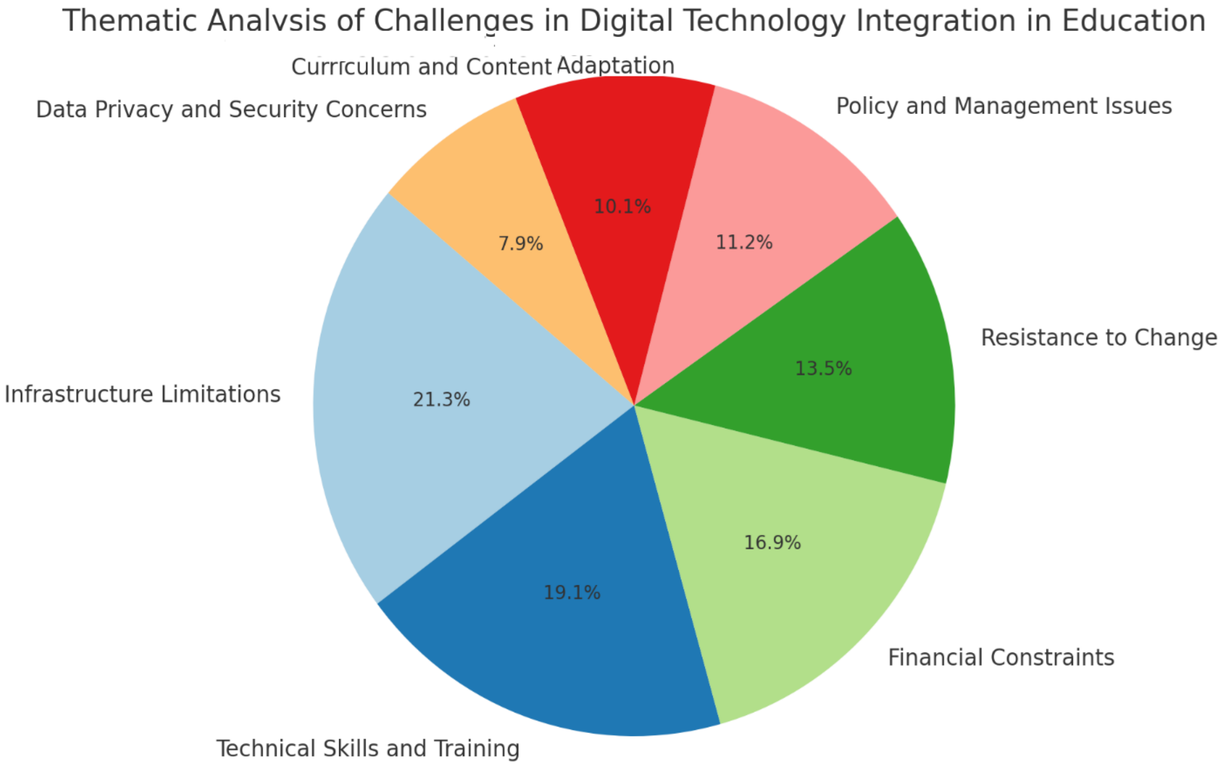

Figure 4. Thematic Analysis of Challenges on Digital technology Integration.

4. DISCUSSION

In particular, the adoption and application of new digital technologies in engineering education within Botswana's postsecondary institutions is examined in this systematic review. The findings underscore the significance of embracing and employing these technologies, the advantages and consequences linked to their incorporation into engineering education, and the obstacles encountered, as delineated by the study inquiries.

RQ1: What Are the Current Trends in the Adoption and Utilization of Emerging Digital Technologies in Engineering Education in Botswana's Tertiary Institutions?

The primary conclusions show how digital technologies are being adopted and used more often in Botswana's engineering programs, with a particular emphasis on Virtual Classrooms and Learning Management Systems (LMS), which account for 21.43% of the studies. These technological advancements are essential for improving student engagement and enabling distance learning (Shonhe et al., 2023, Ntshwarang et al., 2021). With 14.29% of the study devoted to it, cloud computing emphasizes how important it is for offering scalable solutions for administrative and educational duties (Uleanya, 2023, Ntshwarang et al., 2021) . To provide individualized learning and data-driven decision-making, courses are also incorporating artificial intelligence (AI) and machine learning (11.9%), (Uleanya, 2023, Zlotnikova and Hlomani, 2024). But issues including inadequate internet access, inadequate ICT infrastructure, and a lack of training continue to impede the successful deployment of these technologies. In addition to highlighting areas that need more focus—particularly in infrastructure and support—the findings offer fresh perspectives on the potential of digital tools to further engineering education.

RQ2: What Benefits and Positive Outcomes Have Arisen from the Integration of Digital Technologies in Engineering Education in Botswana?

Numerous studies have demonstrated that the incorporation of digital technologies into Botswana's educational institutions has resulted in noteworthy progress in diverse facets of engineering education. The importance of learning management systems (LMS) like Moodle and Blackboard in enhancing access to educational resources and helping teachers and students manage learning resources effectively—especially during the COVID-19 pandemic—is highlighted in nearly half of the publications (48.6%), (Ntshwarang et al., 2021, Uziak et al., 2018). The increased flexibility that these technologies offer is highlighted in a significant number of the studies (42.9%), enabling flexible, self-paced learning that was essential throughout the remote learning phases (Shonhe et al., 2023).. More than one-third (37.1%) highlight how digital platforms improve communication and create more engaging, interactive learning opportunities for students (Denson and Bayati, 2024, Uziak et al., 2018). Furthermore, 31.4% of the studies concentrate on how students may expand their technological abilities, especially by being exposed to cutting-edge technologies like artificial intelligence (AI), 3D printing, and CNC machines. These technologies are crucial for preparing students for the Fourth Industrial Revolution (4IR). Furthermore, while 25.7% of the study emphasizes the value of experiential, practical learning made possible by digital technologies, 28.6% of the research points to the improvement of pedagogical approaches employing interactive tools, simulations, and blended learning models. Notwithstanding these advantages, obstacles including insufficient financing, infrastructure, and training continue to be major hindrances that must be overcome to fully realize the educational potential of digital technology.

RQ3: What Challenges and Barriers Do Botswana's Tertiary Engineering Institutions Encounter in Adopting and Effectively Utilizing Digital Technologies, and What Strategies Can Be Implemented to Overcome These Challenges?

Infrastructure constraints are the main obstacle to the successful integration of digital technology into Botswana's educational system, as indicated by 54.3% of the research. These restrictions, which seriously impede the efficient use of digital tools, include slow internet connectivity, frequent power outages, and limited access to necessary gear and software (Moakofhi et al., 2017, Mogapi et al., 2023). A significant obstacle that affects the efficient use of these technologies is the lack of proper training for teachers and students, as well as inadequate technical assistance, as mentioned in 48.6% of the research (Dintoe, 2018, Ntshwarang et al., 2021). Financial limitations are also important; according to 42.9% of the research, the biggest obstacles to technology adoption are a lack of money and the high expenses involved (Shonhe et al., 2023, Somfula and Zhanda, 2023). Another major obstacle is the mention of faculty and staff resistance to change, including technophobia and hesitation to accept new technology, in 34.3% of the studies (Dintoe, 2018, Mogapi et al., 2023). Furthermore, according to 28.6% of the research, problems with policy and management are brought up. Specifically, unclear operational regulations and insufficient management support make it difficult to integrate digital technologies smoothly (Ntlotlang, 2019, Tladi and Nleya, 2017). In 25.7% of the research, the topic of curriculum reform and the difficulties in integrating new technologies with current curricula is covered (Shonhe et al., 2023, Uleanya, 2023). Finally, 20.0% of the studies emphasize data privacy, security, and ethical issues, especially with new technologies like AI, highlighting the need for caution when using these tools (Mabalane, 2024, Zlotnikova and Hlomani, 2024). The issues serve to underscore the intricate terrain of incorporating digital technologies into Botswana's educational system, highlighting specific domains that require targeted interventions to optimize the advantages of those technology.

4.1. Implications

The results indicate that to successfully incorporate digital technology into Botswana's educational system, infrastructural investments—such as dependable internet and a steady supply of electricity—as well as improved capacity-building initiatives for teachers and students, are urgently needed. Especially about new technologies like artificial intelligence (AI), policymakers should create explicit digital education rules that cover data privacy, operational requirements, and ethical considerations. Financial limitations draw attention to the necessity of long-term financing sources and collaborations to facilitate the adoption of new technologies. Curriculum reform is also necessary to ensure that students are ready for the needs of the Fourth Industrial Revolution (4IR) by bringing educational content into line with emerging technology. Subsequent investigations ought to concentrate on the enduring effects of these technologies on academic achievements of students and methods to surmount the recognized obstacles. By maximizing the advantages of digital technologies, these steps can raise the standard and accessibility of education in Botswana.

4.2. Limitations of the Review

The concentration on studies from certain databases may have resulted in selection bias and may not have included all relevant research, especially non-English publications, or those in lesser-known journals. This study has several other limitations as well. Additionally, the review's focus is restricted to Botswana, which may limit how broadly applicable the conclusions can be. The included studies' quality also differed; some relied on self-reported data, which introduced bias and compromised reliability. Certain conclusions can potentially become out of date due to the quick development of digital technologies. It is advised that longitudinal studies that evaluate the long-term effects of integrating digital technology into education be carried out in the future, considering a variety of educational situations from various geographical areas. It would be beneficial to do cost-effectiveness analyses and further research on the efficacy of technologies, such artificial intelligence. Furthermore, studies on the moral ramifications of technology use ought to concentrate on data privacy and guaranteeing fair access to digital tools for teaching.

5. CONCLUSION

The systematic study emphasizes how important these digital tools are to improving engineering education in Botswana, especially Virtual Classrooms, Learning Management Systems, Cloud Computing, and AI. These tools greatly increase student involvement, flexibility, and adaptability to learning—all crucial for modern education, particularly in times of crisis like the COVID-19 pandemic. But the analysis also points out significant obstacles, including as poor infrastructure, insufficient training, limited funding, and faculty reluctance to change. Resolving these obstacles via focused funding, policy creation, and curriculum change is essential to achieving the full potential of digital technology. The results highlight the transformative power of digital tools in education and offer a path forward for further studies and policy initiatives targeted at enhancing learning outcomes in Botswana and comparable settings. These technologies have the potential to significantly improve education's relevance, quality, and accessibility while also better preparing students for the needs of the Fourth Industrial Revolution (4IR) by strategically addressing the issues that have been highlighted.

6. RECOMMENDATIONS

Future study should concentrate on a few crucial areas to further enhance the integration of digital technologies in education, as indicated by the gaps found in this review. Initially, longitudinal research is required to evaluate the long-term effects of digital technology on learning outcomes for students, especially in the field of engineering education. This research would shed light on the long-term effects of using AI, virtual classrooms, and learning management systems on student performance. Furthermore, studies ought to investigate the efficacy of technologies in a range of educational environments outside of Botswana in order to gain a deeper comprehension of their suitability and influence in other settings. Studies on the cost-effectiveness of integrating digital technology are also required, as this would aid in the more efficient allocation of resources by governments and educational institutions. Strategies for resolving the issues—such as inadequate training, opposition to change, and infrastructural constraints—should also be the focus of future research. Lastly, future research on the ethical ramifications of using digital technology in the classroom should concentrate on data security, privacy, and fair access to these resources, particularly in areas with little resources. In order to fully utilize digital technologies to improve educational outcomes and guarantee that all students may benefit from them, several study fields are crucial.

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ACCESS IS NOT ALL YOU NEED: ADOPTING LARGE LANGUAGE AI MODELS IN ENGINEERING EDUCATION REQUIRES PEDAGOGICAL AND CULTURAL ADAPTATION

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Abstract: This study assesses the potential efficacy of large language models in engineering education, focusing on Electronic and Electrical Engineering (EEE), and Civil Engineering (CE) students at Obafemi Awolowo University, Nigeria. A total of 199 students were divided into two cohorts, each having four groups: control (no study materials), traditional (textbooks and notes), internet-assisted (textbooks, notes, and Google search), and AI-assisted (textbooks, notes, and ChatGPT, Claude, or Gemini). Utilizing a pre-test/post-test experimental design, results indicated a significant variation in performance across groups for the first cohort. For EEE, post-test scores were highest in the internet-assisted group (mean = 55.65 ± 8.96), followed by traditional (50.31 ± 7.53). The AI-assisted group showed no improvement. CE students showed similar trends with traditional (mean = 57.51 ± 26.00), Internet-assisted (mean = 51.04 ± 25.13) groups performing best. Single-variable ANOVA test confirmed significant differences between groups ($p < 0.05$) for the first cohort, with and Tukey's HSD tests confirming that the higher performance of the Internet-assisted group was statistically significant. The findings underscore that merely providing access to LLMs is inadequate for improving educational outcomes without tailored pedagogical and cultural adaptations. This highlights the necessity for a contextual approach when integrating advanced AI tools in engineering education.

Keywords: large language models, learning outcomes, Bloom's taxonomy, educational technology, artificial intelligence

1. INTRODUCTION

Educating engineering students in resource-constrained environments has long been a challenge for educators and policymakers. Developing countries often face significant obstacles in providing high-quality engineering education, including limited access to up-to-date resources, inadequate infrastructure, and a shortage of experienced faculty members (Mohamedbhai 2014). These constraints can create a gap between the skills acquired by graduates and the evolving demands of the global engineering industry, potentially hindering economic growth and technological advancement in these regions.

Over the years, educational technology has been seen as a potential solution to bridge this gap and revolutionize engineering education. From computer-aided instruction in the 1960s to massive open online courses (MOOCs) in the 2010s, each technological advancement has brought renewed hopes for transforming the educational landscape (Zawacki-Richter & Naidu 2016). However, despite initial enthusiasm, many of these technologies have fallen short of their promised potential due to implementation challenges, lack of context-specific adaptation, or failure to address underlying pedagogical issues (Reich & Ruipérez-Valiente 2019).

The recent emergence of large language models (LLMs) has reignited optimism in educational technology. Proponents argue that these AI-powered tools could provide personalized learning experiences, instant access to vast knowledge bases, and support for complex problem-solving tasks (Brown et al. 2020). While the potential of LLMs in engineering education is exciting, it is crucial to approach their integration with a measured and critical perspective. Given the history of technological innovations falling short of expectations in educational settings, careful scrutiny of the assumed benefits of LLMs is warranted.

It is essential to identify the true strengths of these AI tools and determine the scenarios in which they can be most effectively utilized to enhance learning outcomes. As Luckin and Cukurova (2019) argue, successful integration of AI in education requires not only technological innovation but also a deep understanding of learning sciences and pedagogical principles. Therefore, this study investigates the impact of different learning aids, including LLMs, on the performance of engineering students to ensure their implementation aligns with evidence-based best practices in teaching and learning.

2. LITERATURE REVIEW

Large Language Models (LLMs) are built upon the foundation of deep learning and, more specifically, the transformer architecture introduced by Vaswani et al. (2017). LLMs are characterised by their massive scale. For instance, GPT-3, one of the pioneering LLMs, boasts 175 billion parameters and was trained on an extensive corpus of text from the Internet (Brown et al., 2020). This scale allows LLMs to capture intricate patterns and relationships within language, enabling them to generate human-like text, answer questions, and perform a wide range of language-related tasks with remarkable coherence and contextual understanding. These characteristics make LLMs particularly promising for educational applications, where they could potentially serve as intelligent tutors, research assistants, or tools for generating educational content (Winkler & Söllner, 2018).

Over the years, various technological solutions have been proposed and implemented to address the challenges of engineering education in resource-constrained areas. For instance, virtual and remote laboratories have been introduced to provide students with simulated hands-on experiences (Kehinde et al., 2012, Potkonjak et al., 2016). Mobile learning initiatives have aimed to leverage the widespread availability of smartphones to deliver educational content (Pimmer et al., 2016). However, many of these technological interventions have faced significant hurdles in achieving their intended impact.

Reasons for the limited success of previous educational technologies in resource-constrained environments include: lack of infrastructure and reliable internet connectivity (Andersson & Grönlund, 2009); insufficient teacher training and support for technology integration (Tondeur et al., 2015); cultural and contextual misalignment of imported educational technologies (Selwyn, 2010); and failure to address underlying pedagogical issues and adapt to local learning styles (Czerniewicz & Brown, 2009). These past experiences underscore the importance of a holistic approach to implementing new technologies in engineering education, one that considers not only the capabilities of the technology but also the broader educational ecosystem in which it is deployed.

Learning outcome taxonomies, such as Bloom's Taxonomy (Anderson et al., 2001), provide a structured approach to categorising and assessing different levels of cognitive skills. The revised Bloom's Taxonomy includes six levels of cognitive processes: remembering, understanding, applying, analysing, evaluating, and creating. This framework is particularly relevant when considering the potential impact of LLMs on engineering education, as it allows for a nuanced analysis of how these tools might affect different aspects of student learning and skill development.

Research on the impact and potential of LLMs in engineering and STEM education is still in its early stages, given the relatively recent emergence of these technologies. However, several studies have begun to explore their applications and implications: Huang et al. (2022) found that AI-generated explanations could complement traditional teaching methods in programming. Mollick and Mollick (2022) highlighted the potential of AI tools in enhancing creativity and problem-solving skills in STEM education. ChatGPT could assist students in the ideation and concept development stages of engineering design. Nguyen et al. (2023) emphasized the need for critical evaluation of AI-generated information in engineering contexts.

As research in this area continues to evolve, it is crucial to conduct rigorous empirical studies that assess the impact of LLMs on various aspects of engineering education, including knowledge acquisition, problem-solving skills, and higher-order thinking abilities. Such research will be essential in guiding the development of best practices for integrating LLMs into engineering curricula and maximising their potential to enhance learning outcomes in both resource-rich and resource-constrained educational environments.

3. METHODOLOGY

This study employed an experimental design approach to investigate the impact of different learning aids, including large language models (LLMs), on students' performance in two undergraduate engineering courses. The study was conducted at Obafemi Awolowo University, Ile-Ife, Nigeria, and involved two distinct cohorts of engineering students: final year undergraduates in the Electronic and Electrical Engineering (EEE) and third year students of the B.Sc. (Civil Engineering) programme. The main activities of the study were conducted in July 2024. The experiment employed a pre-test/post-test approach in which the pre-test was used for block randomization while the post-test was used for treatment effect analysis.

3.1. Participants

The primary cohort consisted of 110 final year undergraduate students enrolled in the course EEE 503 (course title: Control Engineering I). A secondary cohort of 89 Civil Engineering students also participated in the study. They were third-year students of the course CVE 301 (Surveying I). Participants were not informed about the specific nature of the study beforehand to minimise preparation bias.

3.2. Grouping and Randomization

The study adopted block randomization. To ensure a balanced distribution and mitigate the effect of academic abilities across experimental conditions, participants were stratified based on their performance in previous related assessments. The stratification process involved the following steps:

- Students were ranked from highest to lowest based on their previous assessment scores in examinations on the same courses and topics which were conducted two months before the study.
- The ranked list was divided into blocks of four contiguous names.
- Within each block, students were randomly assigned to one of four experimental groups, ensuring that only one student from each block was allocated to each group.

This stratified randomization approach helped to control for potential confounding variables related to prior academic performance.

3.3. Experimental Groups

Participants were assigned to one of four experimental groups, each with different access to learning resources:

- Control Group: This group had no access to study materials. All they had to work with was residual knowledge obtained from having taken lectures, and studied the topic weeks prior.
    - **Traditional Group:** Students in this group were given access to their personal notes and textbooks only during the revision phase of the study.
    - **Internet Group:** These students had access to personal notes, textbooks, and were allowed to carry out Google searches if they so desired.
    - **AI-Assisted Group:** Students in this group had access to personal notes, textbooks, and could use ChatGPT or similar AI tools during their revision.

3.4. Procedure

The experiment was conducted in a controlled environment to minimise external influences. Students were notified of their placement in one of four groups before the test, but had no idea of the implication or methodology for the grouping, nor the goals of the study. All participants were informed that they might require their hand-written notes, textbooks, Internet access, or the use of a large language AI tool during the activity. Those without accounts on the AI services were encouraged to create accounts before coming for the study.

On the day of the experiment, members of the Control Group were separated from the other groups, still without knowing what the focus or methodology for the test were. They were taken to a separate room, and asked to merely relax. They were not allowed to take their reading materials with them.

Thereafter, the actual topic of focus within each course was revealed to the other groups. Students were reorganised, and separated into the training three groups, and asked to take 1 hour to prepare for an imminent test, using only the resources permitted for each group. Following the review period, all groups, including the Control Group, were administered a brief test which lasted 45 minutes.

3.5. Assessment Instrument

The assessment instrument was designed to evaluate students' understanding across multiple cognitive levels, as defined by Bloom's Taxonomy (Anderson et al., 2001). In order to simplify assessment and analysis, questions were limited to the four lowest levels of the taxonomy:

i. Remembering
ii. Understanding
iii. Applying
iv. Analysing

3.6. Data Collection

Participants were required to indicate their assigned group, name, and registration number on their test scripts to ensure accurate data collection and group verification. The multiple personal details collected were to ensure redundancy in tracking group membership and student performance. The test scores were recorded and paired with participants' demographic information and group assignment for subsequent analysis.

3.7. Ethical Considerations

The study was conducted in accordance with the ethical guidelines of Obafemi Awolowo University. Informed consent was obtained from all participants, and they were assured of the confidentiality of their individual results. The study protocol was reviewed and approved by the Chief Examiners of the Departments of Electronic and Electrical Engineering, and Civil Engineering.

3.8. Data Analysis

Statistical analysis was performed to compare the performance of the four groups across different cognitive levels. The analysis included:

- Descriptive statistics for each group's performance
- One-way ANOVA to test for significant differences between group means
- Tukey's Honestly Significant Difference (or the Tukey-Kramer) post-hoc test was used to identify specific group differences

All statistical analyses were performed using Microsoft Excel 2019 MSO (Version 2406 Build 16.0.17726.20078), with a significance level set at $\alpha = 0.05$.

4. RESULTS AND DISCUSSION

4.1. Results

Table 1 shows the number of students in each group per cohort in the study, while Table 2 shows their mean scores in the pre-tests. The higher standard deviations in cohort 2 were caused by the wider range and variation in individual students' scores for that cohort. In addition, the cohort 2 pretest scores had a few outliers, particularly in Group 1, 2, and to a lesser extent, 4. Figures 1 and 2 show the representative histograms of the raw scores for the two cohorts. From these tables and figures, it is evident that the groups were adequately randomised, and the effect of prior academic performance in the subject has been mitigated to a reasonable extent.

Table 1. Number of students per group in each cohort.

	Number of Students			
	Group 1	**Group 2**	**Group 3**	**Group 4**
Cohort 1	**28**	**28**	**27**	**27**
Cohort 2	**23**	**22**	**22**	**22**

For each cohort, a separate single-factor ANOVA analysis was carried out to determine the statistical significance or otherwise of any observed effects. The results of the respective ANOVA analyses are presented in Tables 4 and 5. Finally, in order to determine more specific effects across different groups, Tukey's Honestly Significant Difference (HSD) post-hoc tests were carried out on both cohorts, with results shown in Tables 6 and 7.

Table 2. Mean pre-test scores per group in each cohort.

	Mean Pre-test Scores (%)			
	Group 1	Group 2	Group 3	Group 4
Cohort 1	45.5 ± 12.87	45.53 ± 12.49	46.48 ± 12.14	46.37 ± 12.00
Cohort 2	57.67 ± 27.92	59.21 ± 29.29	43.66 ± 32.64	48.92 ± 30.10

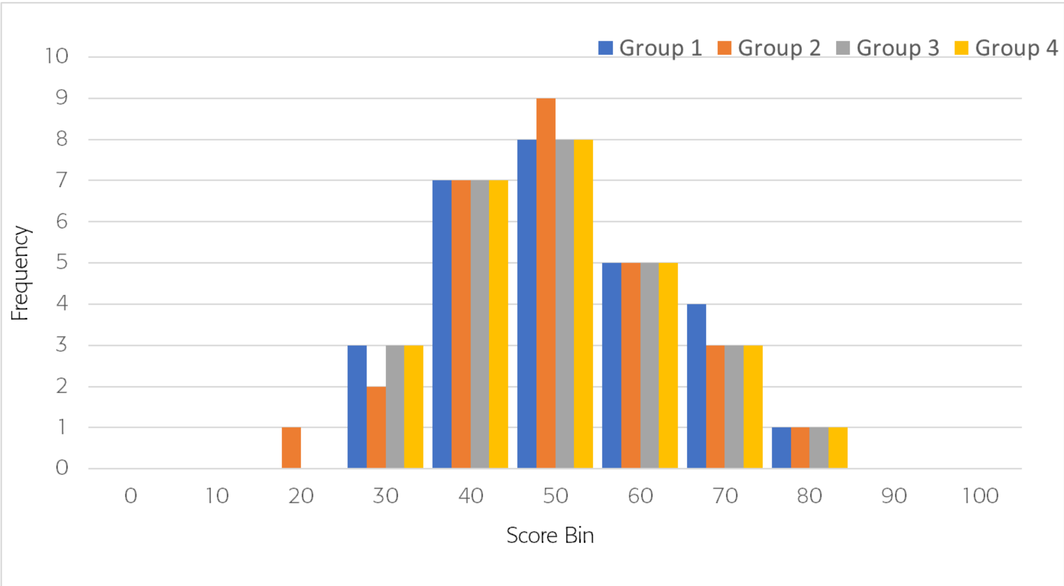

Figure 1. Distribution of individual students' pre-test scores for cohort 1.

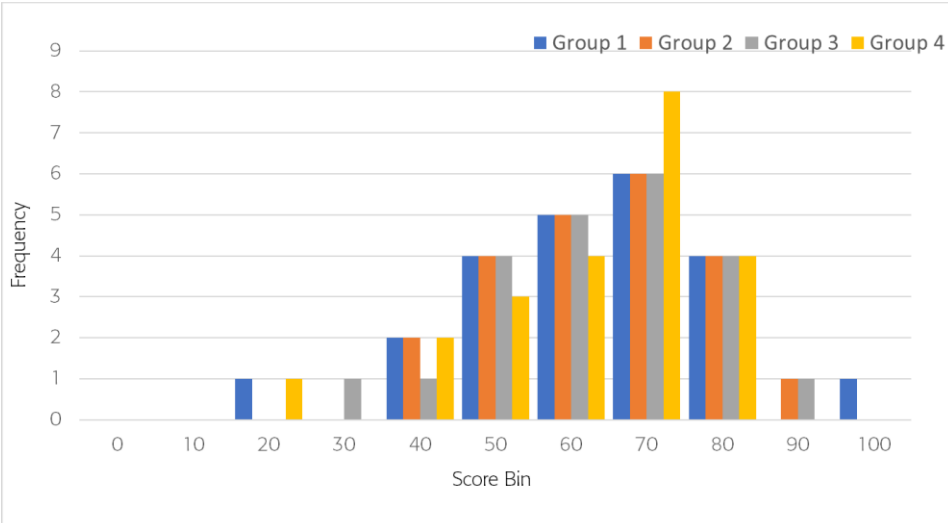

Figure 2. Distribution of individual students' pre-test scores for cohort 2.

Table 3. Mean post-test scores per group in each cohort.

	Mean Post-test Scores (%)			
	Group 1	Group 2	Group 3	Group 4
Cohort 1	45.37±7.33	50.31± 7.53	55.65±8.96	47.15±6.45
Cohort 2	42.35± 31.28	57.51± 26.00	51.04±25.13	47.06±25.05

Table 4. Summary of ANOVA analysis on the individual total scores of students in Cohort 1.

SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Column 1	27	1225	45.3704	53.7638		
Column 2	28	1408.75	50.3125	56.6985		
Column 3	27	1502.5	55.6482	80.3029		
Column 4	27	1273.12	47.1528	41.6266		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1646.52	3	548.8400	9.4490	1.39E-05	2.6911
Within Groups	6098.89	105	58.0846			
Total	7745.41	108				

Table 5. Summary of ANOVA analysis on the individual total scores of students in Cohort 2.

SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Column 1	23	973.9426	42.34533	933.8774		
Column 2	23	1322.79	57.51263	645.5017		
Column 3	23	1173.958	51.04167	631.3679		
Column 4	22	1035.251	47.05688	597.6794		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2839.961	3	946.6538	1.346004	0.264766	2.709402
Within Groups	61187.7	87	703.3069			
Total	64027.66	90				

Table 6: Summary of Tukey HSD test for Cohort 1.

		Difference	n (Group 1)	n (Group 2)	SE	q
Control	Notebook	4.9421	27	28	1.4535	3.4000
Control	Google	10.2777	27	27	1.4668	7.0072
Control	AI	1.7824	27	27	1.4667	1.2152

Table 7. Summary of Tukey HSD test for Cohort 1.

		Difference	n (Group 1)	n (Group 2)	SE	q
Control	Notebook	15.1673	23	23	5.5298	2.7428
Control	Google	8.6964	23	23	5.5298	1.5726
Control	AI	4.7116	23	22	5.5923	0.8425

4.2. Discussion

The findings from the ANOVA tests (Tables 4 and 5) suggested that the effect of various preparatory schemes was significantly different for the first cohort ($F > F_{crit}$, p-value < 0.05), whereas, the second cohort revealed no such significant difference ($F < F_{crit}$, p-value > 0.05). The HSD tests (Tables 6 and 7) revealed a clearer picture of the underlying effects. From standard Q distribution tables, the reference statistic for 4 groups and degree of freedom 60 is 3.74, while for 120 degrees of freedom, it is 3.68. From Table 6, Group 3 (using Google along with notes) was significantly different from the control group in Cohort 1. The group using AI was not statistically different from control. Although the group using notebooks and textbooks fell beneath the threshold for significance, its q value is so close to the threshold, that we speculate that a very slight increase in the mean scores would have made it significant. In other words, it falls within the realm of possibility that a different run of a similar experiment would find it significantly different from the control group.

The results are different for Cohort 2. The HSD test results (Table 7) suggests that there were no significant differences in the effect of the various groups. There are some effects at work within the class of Cohort 2. Whatever those effects are, the result is outliers and divergent performances. This was seen in the pre-test result for the cohort, and again, has impacted the effect of the treatments. For example, the within-group mean square error (MS), as shown in Table 5, is very close to the between-groups MS. This is a different situation from Cohort 1 (Table 4). This MS value materially affects the standard error used in computation of both the ANOVA statistic and the HSD q value. Determining those external effects are outside the scope of the current study, however, it can be speculated that they are related to latent student ability from other courses or sources.

At first glance, the conclusion that the use of AI does not confer any advantages to students might be considered surprising. This is because large language models like ChatGPT have demonstrated impressive capabilities in various domains, including answering complex questions and providing explanations on a wide range of topics. However, closer scrutiny reveals certain key considerations about their use in educational settings. The fact that the Google group was the only one that had a statistically significant performance improvement compared to the control group suggests that students have, over time, learned how to optimally use this tool as an augment to their learning. This highlights the importance of familiarity and practice with any tool, including AI, for it to be effectively utilized in education.

For AI tools to be effective in engineering education, several key changes need to occur across different levels of the educational system. At the institutional level, curricula must be thoughtfully redesigned to incorporate AI tools in meaningful ways that enhance learning outcomes. Faculty members should receive comprehensive training on how to effectively integrate AI into their teaching methods, ensuring that these tools are used to augment rather than replace traditional pedagogical approaches. Additionally, clear guidelines on the ethical use of AI in academic work need to be developed and communicated to all stakeholders to maintain academic integrity.

Student preparation is equally crucial for the successful integration of AI in engineering education. Students require formal training on how to use AI tools effectively for learning, moving beyond simply using them to complete assignments. This training should emphasize critical thinking skills to help students evaluate and contextualize AI-generated information. Moreover, developing strong time management and information literacy skills is essential to prevent over-reliance on AI and to foster independent learning.

Pedagogical shifts are necessary to fully leverage the potential of AI in engineering education. The focus should move away from rote memorization towards cultivating higher-order thinking skills such as analysis, evaluation, and creation. Assignments and assessments need to be redesigned to take advantage of AI capabilities while still promoting deep learning and understanding. Exploring collaborative learning approaches that combine human creativity with AI assistance can lead to innovative problem-solving and enhance students' ability to work with AI in professional settings.

Students themselves must take an active role in adapting to this new educational paradigm. They should invest time in learning how to formulate effective prompts for AI tools, a skill that will be increasingly valuable in both academic and professional contexts. Developing a habit of critically evaluating AI-generated responses is crucial for maintaining intellectual rigor and avoiding blind acceptance of AI outputs. Most importantly, students should view AI as a complementary tool that enhances their learning and problem-solving capabilities, rather than as a substitute for their own understanding and skills. By embracing this perspective, students can harness the power of AI while continuing to develop their own expertise and critical thinking abilities.

The unexpected results of this study underscore the complexity of integrating new technologies into established educational practices. While AI tools like large language models offer immense potential, their effectiveness is contingent upon a holistic approach that considers pedagogical, cultural, and practical aspects of the learning environment. The transition to AI-augmented learning is not just about access to technology, but about fostering a new culture of learning that leverages these tools to enhance rather than replace human cognition and creativity.

4.3. Limitations

It is important to note several limitations of this study that should be considered when interpreting the results and drawing conclusions. Firstly, the short duration of the review period may not fully reflect real-world study conditions. In practice, students typically have longer periods to familiarise themselves with new tools and integrate them into their learning processes. Secondly, the sample size and specific context of the study may limit generalizability to other engineering disciplines or institutions. The study was conducted at a single university with students from specific engineering programs. Different institutional cultures, curricula, and student populations might yield varying results, and caution should be exercised when extrapolating these findings to broader contexts. Additionally, participants' prior familiarity with AI tools was not controlled for, which could have influenced the results of the AI-Assisted Group. Students with previous experience using AI tools might have performed differently compared to those encountering them for the first time in an academic context. This variability in prior exposure could have introduced unaccounted-for effects on the group's performance.

These limitations underscore the need for further research in this area, including longitudinal studies, cross-institutional comparisons, and investigations that control for prior AI tool experience. Future studies should also consider a wider range of engineering disciplines and diverse institutional settings to provide a more comprehensive understanding of the impact of AI tools on engineering education.

5. CONCLUSION

This study set out to investigate the impact of different learning aids, including large language models (LLMs), on the performance of engineering students. The results challenge the assumption that merely providing access to advanced AI tools will automatically lead to improved learning outcomes. Our findings reveal that students using traditional methods (notebooks and textbooks) and those using Google search in combination with traditional methods outperformed students who had access to AI tools. This suggests that the effectiveness of educational technology is not solely determined by its sophistication, but by how well it is integrated into existing learning paradigms and how prepared students are to utilize it effectively.

The study highlights several key implications for engineering education:

- The integration of AI tools into education requires a comprehensive approach that goes beyond mere access to technology.
- There is a need for pedagogical adaptation to effectively leverage AI tools in ways that enhance rather than replace critical thinking and problem-solving skills.
- Students and educators alike need training and time to develop proficiency in using AI tools effectively for educational purposes.
- The cultural context of learning, including students' familiarity with different tools and study methods, plays a crucial role in determining the effectiveness of new technologies.

These findings have significant implications for educational policy, curriculum design, and classroom practices in engineering education, particularly in resource-constrained environments. They suggest that the successful adoption of AI in education will require a period of adjustment, experimentation, and cultural shift.

DATA AVAILABILITY STATEMENT

Data on students' grouping and raw post-test scores can be made available on request, after proper anonymization. Pre-test scores cannot be made available as they are official Obafemi Awolowo University records.

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DECLARATION OF INTEREST

The authors of this article declare that there are no conflicts of interest concerning any aspect of the study, or the manuscript itself.

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CHALLENGES AND OPPORTUNITIES IN INTEGRATING ARTIFICIAL INTELLIGENCE EDUCATION AT THE UNIVERSITY OF BOTSWANA: ADDRESSING INFRASTRUCTURE AND EDUCATIONAL PRIORITIES FOR A KNOWLEDGE-BASED SOCIETY

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Abstract: Botswana, ranked 64th in economic performance and productivity according to the IMD World Competitiveness Yearbook 2024, sincince joing it has has made significant improvement in enhancing its skilled workforce and educational systems .Despite increasing awareness, the integration of artificial intelligence (AI) in education remains limited. AI, which automates tasks, holds significant potential for preparing engineers in a knowledge-based society. This study examines why the University of Botswana has not established robust AI programs and explores factors contributing to the absence of a dedicated AI degree. Key challenges investigated include inadequate infrastructure for fast connectivity, though efforts are underway with a fiber optic project from Namibia aimed at improving internet speeds. Significant investment is needed to modernize network capabilities and enhance economic competitiveness. While the Faculty of Computer Science offers related courses such as data structures, algorithms, and data mining, they focus more on theoretical and practical computing applications than standalone AI disciplines. Similarly, AI concepts in Electrical and Mechanical Engineering are integrated within broader engineering disciplines. Addressing these challenges requires understanding educational priorities and resource allocations necessary to develop comprehensive AI programs aligned with industry demands. The study employed a mixed-methods approach, and found that , the current AI-related courses are misaligned with industry demands and technological advancements, largely due to outdated content, insufficient faculty expertise, and inadequate infrastructure with Stakeholders expressing a strong need for the curriculum to evolve in order to better prepare students for the dynamic field of artificial intelligence and to keep up with technogical changes.

Key words: Knowledge-based society, AI programs, Educational priorities, Industry demands, University of Botswana

1. INTRODUCTION

Botswana is a developing country, currently ranked number 64th in performance and productivity according to the IMD World Competitiveness Yearbook 2024 (IMD,2024). Regarding its skilled workforce and educational development, the country has increased its ranking for three consecutive years since joining the world economic performance rankings in 2021. One area of focus has been the use of artificial intelligence in the education sector, where awareness has increased but application remains lacking. Artificial intelligence involves the use of computers to perform tasks that were traditionally executed by humans (Roll, 2016). Internet connectivity bandwidth has played a pivotal role in the application of artificial intelligence in preparing engineers for a knowledge-based society.

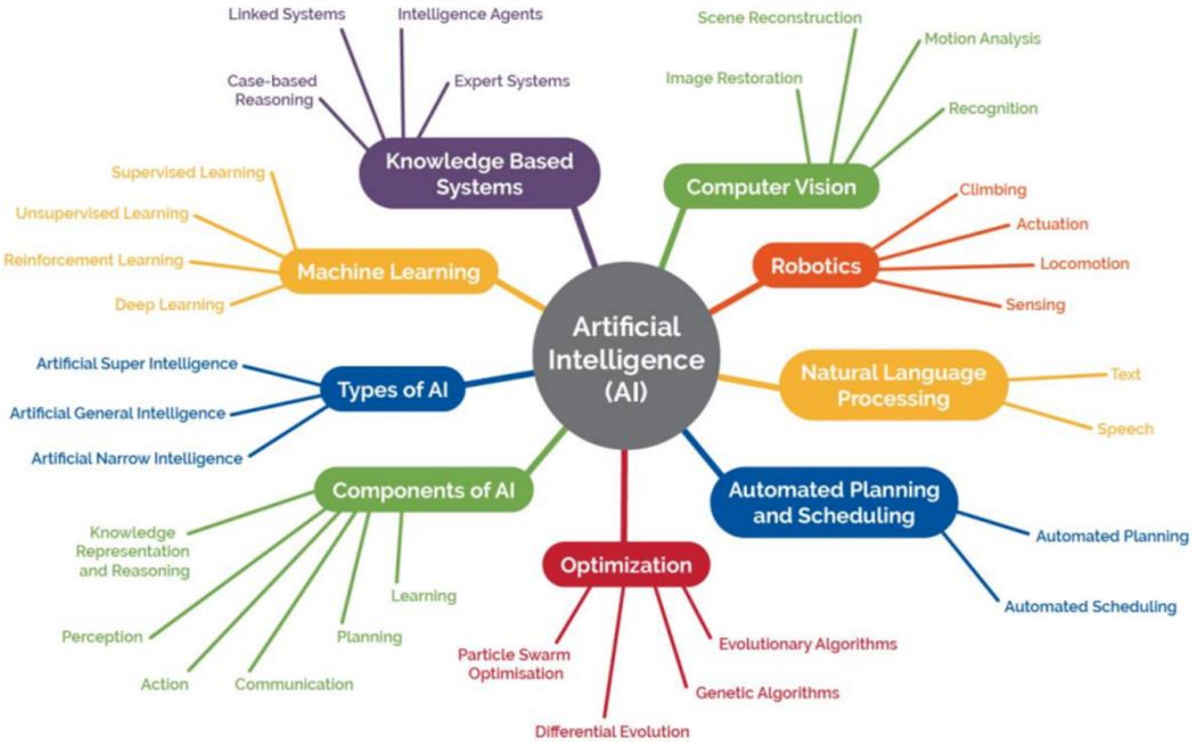

Figure 18. Components of AI Regona et al, (2022).

To remain up-to-date, fast connectivity and quick task execution speed are imperative for economic productivity. However, the country lags behind in infrastructure that supports rapid connectivity (IMD,2024). Currently, it is in the process of laying fiber optic cables from Namibia. Once this project is completed, it is expected that internet connections will become faster and more reliable. Regarding the cost of these infrastructure projects and others in the same area, significant investment is required to modernize and expand the network. The government has allocated substantial funds to the fiber optic project, aiming to bridge the current connectivity gaps and boost overall economic competitiveness and at the same time drives the use of AI.

The primary drivers of the application and awareness of artificial intelligence remain within learning institutions (George, 2023) and the government. However, some of these institutions do not offer robust programs solely dedicated to artificial intelligence and machine learning. For instance, there is limited countrywide degree program in Botswana specifically focused on AI, despite its critical importance in today's knowledge-based society. The use of artificial intelligence in learning institutions could accelerate the learning curve through fast retrieval and analysis of vast datasets, thereby aiding in knowledge management. This potential benefit underscores the need for educational institutions to develop comprehensive AI programs that prepare students for the demands of the future job market (Perez, 2018).

It is notable that the Faculty of Computer Science in university of Botswana offers courses related to AI, such as data structures, algorithms, and data mining. However, most of these courses focus on theoretical foundations and practical applications in computing instead of being standalone disciplines in AI. Similarly, courses offered in Electrical Engineering and Mechanical Engineering are not explicitly branded as AI courses but rather integrated into broader engineering disciplines in the University of Botswana.

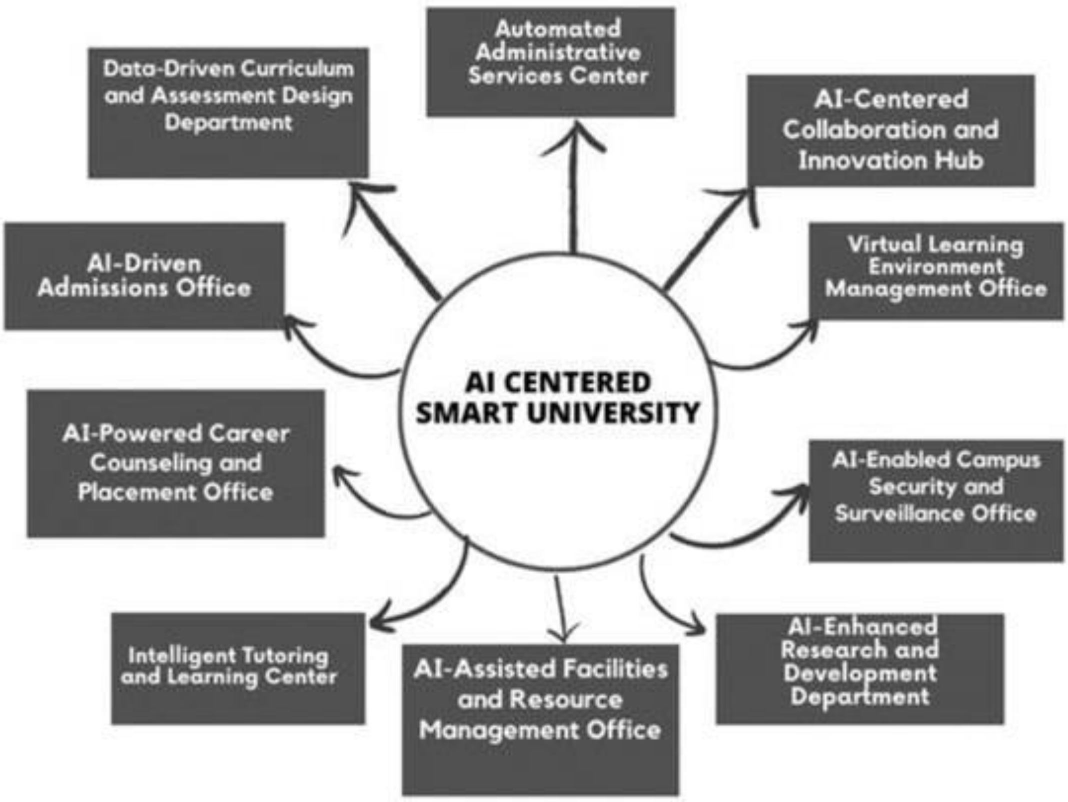

Figure 19. AI Smart University (George, 2023).

This study aims to investigate why the University of Botswana does not offer robust programs in artificial intelligence and to understand the factors contributing to the absence of a degree program in artificial intelligence at the university through literature review, document analysis expert survey focus group.

2. LITERATURE REVIEW

Artificial Intelligence (AI) has become part of our daily life (Jing, 2024). It is used in many applications, with the ability to mimic cognitive functions typically associated with human intelligence, including learning from experience, adapting to new information, and making decisions based on identified patterns. Deep machine learning algorithms, for example, allow systems to analyze vast amounts of data to identify trends and predict future outcomes with increasing accuracy. In the 21st century, in the era of 4th Industrial Revolution, technology has evolved to encompass sophisticated technologies not limited to robotics and computer vision. This broad field plays a pivotal role in today's fast-paced global economy, with easy access with the click of a button to Access Mountains of data sets with the help of deep machine learning, Robotics, and computer vision (Jaiswal et al,2022).

The study of autonomous systems or robotics has had a great impact on manufacturing systems and thus revolutionized industries by automating repetitive tasks and enhancing precision in manufacturing processes. The application of robotics is more visible in automated assembly lines and self-driving vehicles, with the ability to optimize efficiency and safety across various sectors. Moreover, computer vision technologies empower machines to interpret and understand visual information, ranging from facial recognition in security systems to medical imaging diagnostics.

The study of artificial intelligence (AI) is immensely important in the education sector, playing a pivotal role in enhancing human capacity and bolstering global economic competitiveness (George, 2023). In the Fourth Industrial Revolution context, businesses increasingly rely on AI-driven technologies to optimize operations and innovate their products and services. For instance, industries such as Botswana water utilities has transitioned from conventional digital water meters to advanced intelligent water meters marking a significant shift towards AI-integrated infrastructure.

Intelligent-meter deployment enhances efficiency and necessitates a workforce equipped with AI proficiency. Technicians and professionals capable of harnessing AI capabilities will be crucial for maintaining, optimizing, and innovating these new systems. Hence, integrating AI education as a core course or offering dedicated AI degree programs in universities becomes essential (Akinwalere 2022). These educational initiatives prepare students for emerging job roles and foster a knowledge-based society capable of driving technological advancements.

By imparting AI skills through structured academic programs, Universities contribute to shaping a workforce that can meet the evolving demands of industries in the digital age (George, 2023). Moreover, fostering AI literacy among students ensures they are well-prepared to tackle the complex challenges and opportunities presented by AI-powered technologies (Akinwalere 2022). This proactive approach enhances individual career prospects and strengthens national and global competitiveness in the rapidly evolving landscape of the Fourth Industrial Revolution.

Al-Ali (2024) asserts that integrating generative AI has the power to completely transform teaching strategies. Policymakers must carefully consider its implications for pedagogy, ethics, and societal risks. Additionally, the author advocates for fostering equitable learning environments through proactive collaboration and partnerships to harness the potential of artificial intelligence fully. The literature review on AI in education has been growing exponentially since 2014, (Huang, 2023) and that can be depicted by fig 3 with an expontial increase of papers in AI. For instance, Chen et al. conducted a study on the impact of AI in education and found that it promotes faster learning and facilitates task management. AI applications in the education sector include the use of computers and related systems. The AI technologies that should be taught in higher learning institutions are more comprehensive than those driving autonomous machines, drones, and built-in systems.

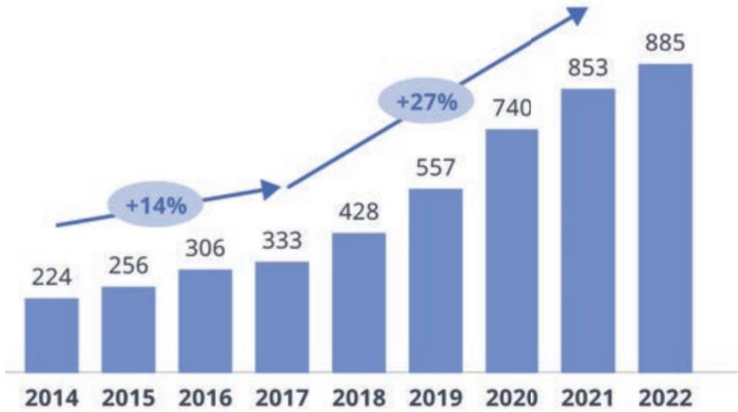

Figure 20. Web of Science article with AI robotics. Source (Huang, 2023).

Other typical examples occur in the classroom, where artificial intelligence (AI) serves as a personal tutor (Akinwalere 2022). AI systems can detect when students are falling behind on a particular topic or performing exceptionally well (Shukla, 2013). This real-time feedback allows educators to intervene promptly with personalized support, ensuring each student receives the guidance they need to succeed. Students are encouraged to develop problem-solving skills and analytical thinking by engaging with

AI-driven educational tools. This approach enhances their understanding of the subject matter and cultivates a better cognitive learning style, as noted by Shukla (2013). The surge in AI-related jobs highlights a critical need for specialized training programs. As AI continues to evolve, there is a growing imperative for workforce up-skilling to accommodate the influx of new roles and changing job requirements (Jaiswal et al,2022). This transformation is not merely a matter of adapting to technological advancements but also involves replacing traditional training methods with more agile and responsive educational models.

Storey and Beeman (2023) discuss the causal relationship between job growth in AI and the demand for updated training paradigms. They emphasize the importance of integrating new learning content that addresses the specialized skills demanded by AI-driven industries. This shift from conventional pedagogical approaches to dynamic training strategies is essential for preparing individuals to thrive in an AI-dominated future workforce.

The body of research on the integration and development of AI degree programs underscores a compelling case for the transformative impact that artificial intelligence can have on higher education. Studies consistently highlight the importance of establishing robust AI programs that cover theoretical foundations and emphasize practical applications and real-world experience. For instance, Zhang and Chen (2022) emphasize the need for a curriculum that balances theoretical knowledge with hands-on skills. Patel and Kumar (2021) point out the necessity of bridging the gap between academic learning and industry practice. Such findings are instrumental in guiding educational institutions toward developing comprehensive AI programs that meet current and future industry demands.

Challenges associated with implementing AI degree programs are significant but surmountable with strategic planning and investment. As Chen, and Lin (2020) identified, successful AI programs require alignment with industry needs, recruitment of qualified faculty, and cutting-edge infrastructure. These requirements highlight the importance of creating strong partnerships between universities and industry stakeholders to ensure that AI programs remain relevant and impactful. Roberts and Anderson (2019) further elaborate on the necessity of substantial investment in technology and curriculum development, suggesting that overcoming these challenges is crucial for the growth and effectiveness of AI education.

The benefits of establishing specialized AI degree programs are substantial, extending beyond academic advancements to broader economic and societal impacts. Liet al, (2024) illustrate that a well-designed AI curriculum can enhance students' job readiness by equipping them with technical expertise and an understanding of AI's ethical implications. This preparation is vital for addressing AI technologies' complex challenges and opportunities, ultimately contributing to developing a skilled workforce capable of driving innovation in the AI sector. The potential for AI programs to foster a knowledge-based society and support technological progress aligns with the global trend toward AI-driven advancements.

Integrating AI education within university curricula is not merely advantageous but imperative for cultivating a skilled workforce capable of thriving in an AI-driven world. Unfortunately, in Botswana, there is currently a notable absence of institutions offering robust AI programs, except for Botswana Accountancy College and Botho University. This study seeks to investigate why the University of Botswana does not offer comprehensive AI programs and identify the factors contributing to the absence of a dedicated AI degree program. By examining these factors, the study aims to provide valuable insights into how educational institutions in Botswana can strategically incorporate AI education to effectively meet future workforce demands and contribute to advancing societal progress in an increasingly AI-driven global landscape using a mixed method approach

3. MATERIALS AND METHODS

This study utilized both a document analysis and stakeholder surveys methods to gather information about institutional priorities and educational policy followed by focus group to map out recommendations discussed by experts in the area of artificial intelligence. Document analysis was deployed to review current curriculum to identify potential constraints, human resources capacity and any other gaps that may have contributed to current shortcomings in the development of AI curriculum. The focus group survey conducted includes various stakeholders; Professors, Lectures, university administrators, students, industry expert and technical cadre designed to gather diverse range of perspective.

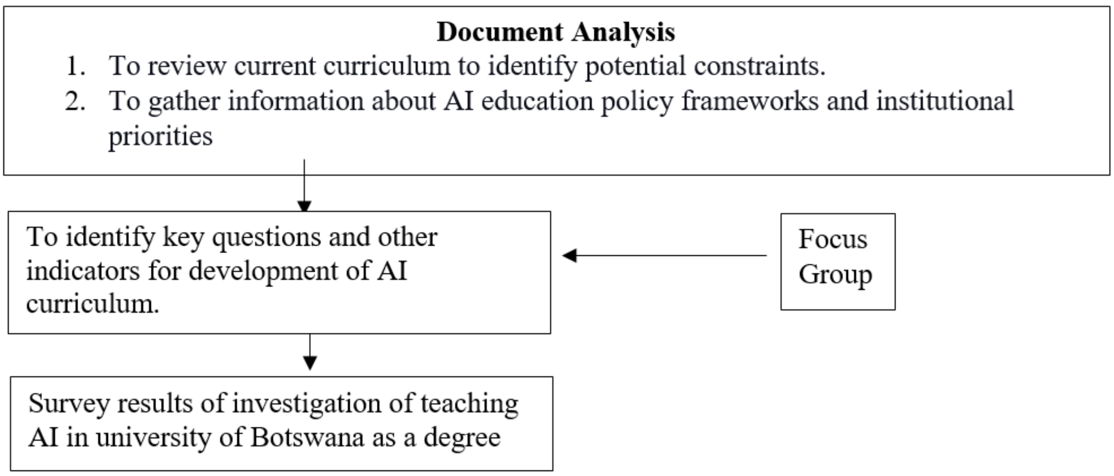

Figure 4. Research Map.

By synthesizing the results and findings from focus group, the study developed strategic recommendations and policy initiatives for the improvement of university curriculum. The suggested actions includes updating curriculum development guidelines, implementing faculty training programs, investing in infrastructure, forming industry partnerships, and enacting policy reforms. With the ultimate goal to enable the institutions to adapt to technological advancements, foster innovation, and prepare students to excel in an AI-driven global economy.

4. RESULTS AND DISCUSSION

The stakeholder survey results indicate significant interest and opportunity in integrating and developing artificial intelligence (AI) within the University curriculum. The majority of respondents emphasized the urgent need for substantial improvements in the current curriculum. Participants rated the integration of AI topics in the curriculum somewhat to very poorly (Fig 5), reflecting a general sentiment that the existing offerings need to better align with current industry demands and technological advancements. Common issues cited include a lack of faculty expertise, insufficient infrastructure, and limited funding (Fig 6).

Survey responses from a critical question in the focus group ***(How do you think the current curriculum addresses the needs of students in the field of AI)*** revealed a notable disparity between the current AI-related courses and the needs of both students and the industry. Many respondents indicated that the existing curriculum does not adequately prepare students for the evolving AI landscape, calling for updated course content to include practical, hands-on experiences and the latest tools and technologies (Fig 8). Critical barriers to developing a dedicated AI degree program include a shortage of specialized faculty and inadequate resources, hindering the effective delivery of AI education and research (Fig 6).

To address these challenges, the survey highlights several key recommendations. It is crucial for the University of Botswana to prioritize regular updates to the curriculum reflecting emerging trends and technological advancements in AI. Expanding faculty expertise through targeted hiring and professional development, improving infrastructure, and fostering stronger industry partnerships are essential steps toward enhancing the relevance and quality of AI education in the 21st century and 4th Industrial Revolution. Furthermore, integrating AI into the university's strategic vision is not just a step, but a significant leap towards the development of a robust AI program that aligns with both academic and industry expectations.

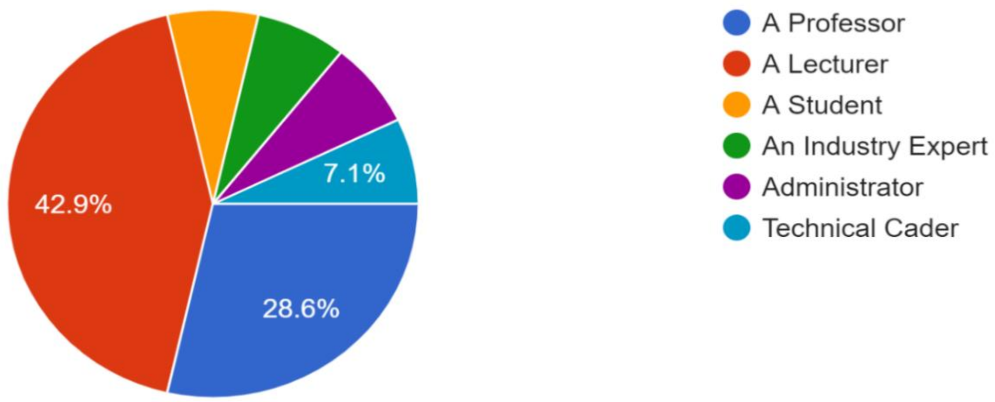

Figure 5. Pool Expert Chart.

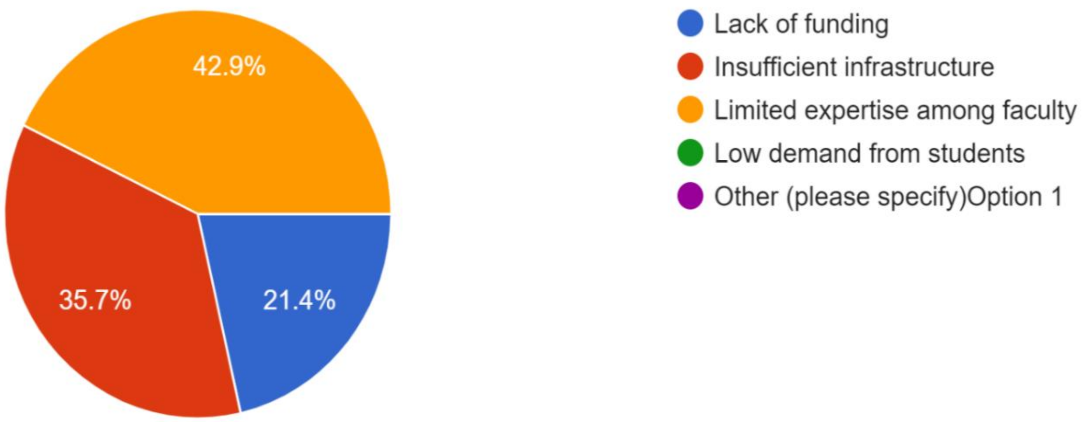

Figure 6. Barrier to AI degree.

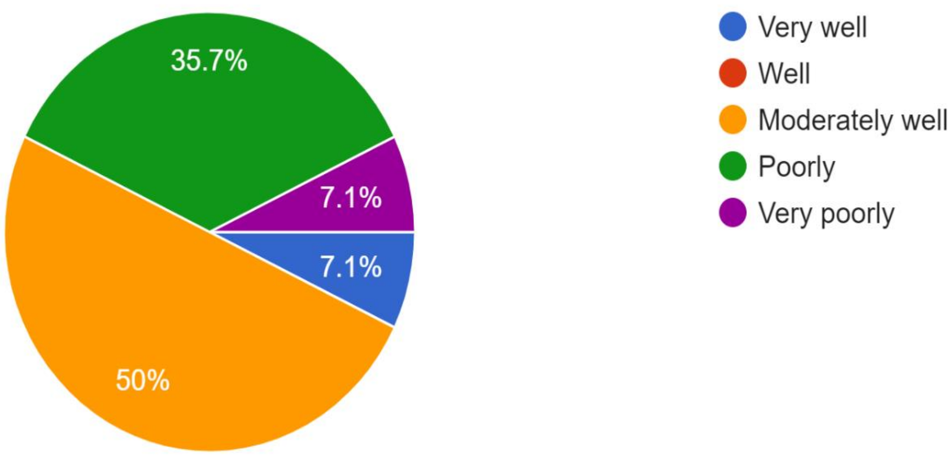

Figure 7. Current Course relevance to the industry.

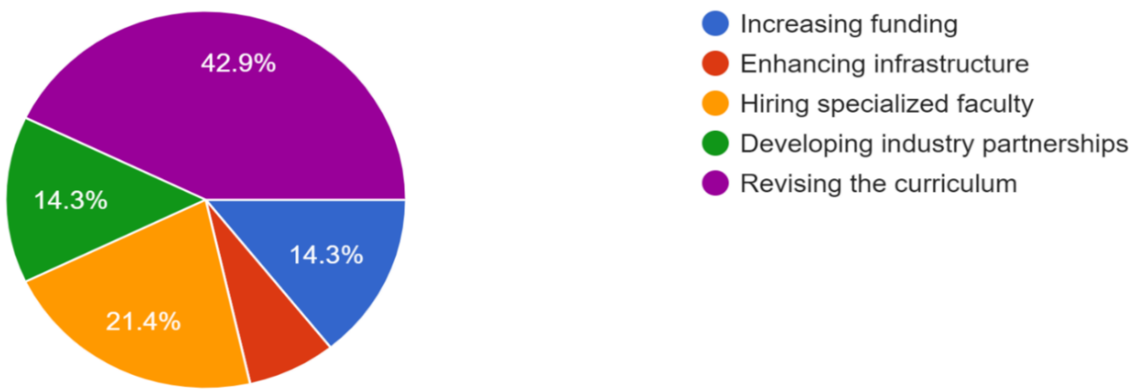

Figure 8. Critical step for AI Development.

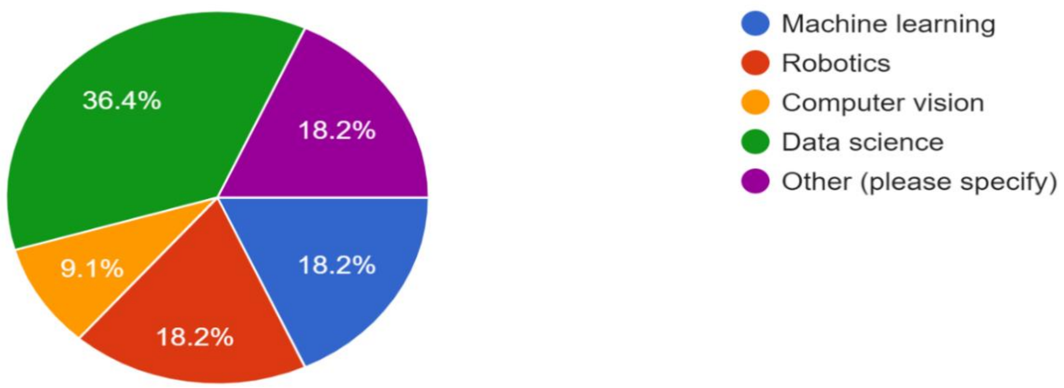

Figure 9. Most Beneficial course to Career Development.

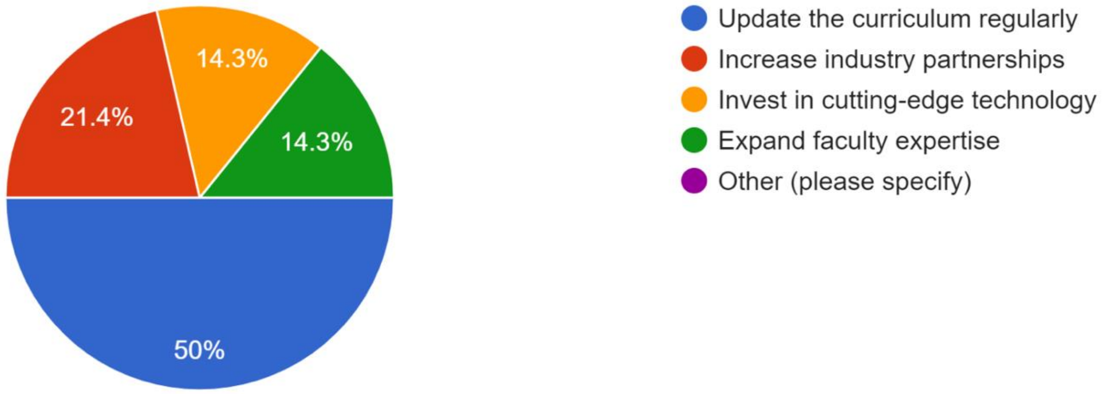

Figure 10. Important Recommendation to align AI program with industry.

5. CONCLUSION

The survey results and document analysis highlight significant challenges and opportunities concerning AI education at the University of Botswana. The current AI-related courses are misaligned with industry demands and technological advancements, largely due to outdated content, insufficient faculty expertise, and inadequate infrastructure. Stakeholders have expressed a strong need for the curriculum to evolve in order to better prepare students for the dynamic field of artificial intelligence. The findings underscore a critical gap between the educational offerings and the practical skills required by the industry, pointing to an urgent need for strategic improvements. And our results are supported by (George, 2023) that universities that are powered by AI, will excel in many areas, teaching and learning, with evident results of reshaping education and economy.

To close the gap in AI Education, the University of Botswana should prioritize updating its AI curriculum to include contemporary tools, technologies, and hands-on experiences that reflect current industry standards. Recruiting additional specialized faculty and investing in professional development for existing staff and that will enhance the program's quality and relevance. Upgrading infrastructure and increasing funding are essential to support these educational improvements. Additionally, strengthening partnerships with industry leaders will ensure that the curriculum remains aligned with real-world applications and provides students with valuable practical experience. Implementing these recommendations will significantly enhance the AI program's effectiveness and better prepare students for future careers in artificial intelligence.

DATA AVAILABILITY STATEMENT

Data sharing is avaibale per request for this article, new data were created and analyzed in this study.

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DECLARATION OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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A USER INTERACTIVE PROCEDURAL APPLICATION TO SOLVE NUMERICAL METHODS FOR ENGINEERING AND SCIENCE STUDENTS

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Abstract: The application of numerical methods to a problem arises when an analytic solution to a mathematical problem becomes cumbersome. This mathematical problem ranges from providing the solution to an ordinary differential equation to interpolating for a corresponding value to a variable within a specified boundary or finding the solution to a set of simultaneous equations and many other mathematical problems possible. However, this does not indicate that solutions provided by numerical methods are far easier to generate as most of them include very complex steps and could involve several iterated processes before converging to a reliable solution. In solving numerical methods, errors are constantly checked to ensure the fitness of the solution. This is because numerical methods only provide an approximate solution to a problem and not the exact answer. Advancements in computing power have significantly facilitated the application of numerical methods. Although modern computational software can perform numerous iterations and minimize errors to infinitesimal levels, these software only display the finally converged solution. In this work, a different approach to creating these algorithms was taken. Rather than providing a solution to a problem, the algorithms were implemented so that the steps taken by the algorithm in providing the solution to a problem was revealed. The study addressed six problem categories with twenty-three solution methods provided. An interactive desktop application was developed, allowing users to reuse algorithms and input different constraints to understand solutions to various problems. This application was tested against the online computational tool Wolfram Alpha, yielding consistent results. The developed application has significant educational potential. It can be used to teach numerical methods to both undergraduate and postgraduate students in engineering, science, and related fields, providing an intuitive understanding of the problem-solving process.

Keywords: numerical methods, desktop application, Wolfram Alfa, programming, java libraries

1. INTRODUCTION

The importance of Numerical Methods (NM) cannot be over-emphasised. Numerical Method also referred to as Numerical Analysis is any method that provides a solution which is non-analytic, to a mathematical problem (Nirmala & Ganesan, 2018). This method consists of a clear, concise procedure or set of steps which tries to provide an approximate solution to the problem through guesses. These number of steps could be finite or iterative. Direct methods are finite and provide a solution that is close to the exact solution if it were to be solved analytically. However, for iterative methods, there has to be a stopping criterion. This stopping criterion is a convergence test, measuring the degree of accuracy and approximation to the exact solution.

Most of the time, performing these convergence tests becomes very cumbersome when trying to reduce the error in a solution over a large number of iterations. The values are harder to manage or keep track of, as they become larger or smaller, hence the requirement of computational software. Computational software applications such as Wolfram Mathematica (Wolfram Research, 2024), Matlab (MathWorks, 2024), have built-in functions that can return solutions to a problem without the need to write much code. It is also possible to write an algorithm or a computer program to solve a particular problem. A program might be written to solve a specific case or better still written generically to give a user the opportunity to vary the values of the variables to define the constraints for another problem. In both cases, it is easy to conclude that computation has made the job easier with numerical analysis.

However, in solving problems now, a decision has to be made on which method would be best suited for solving a particular problem. The rate of convergence is usually the most significant criteria as the fastest algorithm to converge saves computation cost in terms of memory, especially. When making comparisons, a test of convergence shows iterative methods with higher convergence returning a solution in lesser number of iterations. Generally, "the higher the order, the faster the method converges" (Ahmad, 2015).

In this research, there is an opportunity to study the differences in these methods through generic versions of their algorithms that not only provide a final answer but a background to the whole process.

In solving mathematical problems using numerical methods, precision is usually the challenge. Long before calculators and computing machines, these problems were usually solved by hand, and manual computation tends to be less accurate in general (Atkinson, 2017). Nowadays, it is easier to get a solution to the problem computationally. However, the steps taken to solve problems is usually abstracted. This becomes a problem when understanding the steps is a requirement

The aim of this work is to create a desktop application that provides a verbose expression of the various steps a numerical method, whether direct or iterative, in providing its solution to a mathematical problem. To achieve this aim, we have to research on the various methods to be implemented on, develop pseudocodes and then the actual algorithms in the Java programming language, test the algorithms and measure efficiency and develop an easy to use interface for the application users. The priority of this work is the efficiency of the application and accuracy of the solutions provided.

Creating this easy to use application encourages the familiarity of numerical methods students with the working process of these methods. This is useful most especially to students who lack programming skills and cannot make use of complex software to solve problems as well. In the learning process, mistakes made can easily be discovered as the application produces results verbose enough and capture every step of each procedure.

This work is organized as follows: section 2 involves reviewing the literature on past works related to numerical methods. This includes works on the application of these methods in various fields of science and engineering, the development of the algorithms, increasing the efficiency of existing algorithms; section 3 is the approach taken towards developing the desktop application that serves as the problem solution is discussed; the results from implementing the application is discussed in section 4; section 5 deals with the limitations and efficiency of the application; section 6 concludes the report by discussing recommendations, future works and giving a general summary of the work.

2. LITERATURE REVIEW

This section reviews the use cases of various numerical methods, exploring their application in both manual and computational problem-solving. It also examines the translation of these methods into algorithms or computer programs, their interactivity, and the efficiency tests carried out on these algorithms.

Kim (2017) emphasizes the Bisection method as a fundamental root-finding algorithm, noting its reliability but slow convergence. To enhance its speed, a hybrid algorithm combining the Bisection and Newton-Raphson methods is proposed. This improved hybrid algorithm ensures convergence by first using the Newton-Raphson method within a given interval and then applying the Bisection method. Wolfram Mathematica was used to compare the solutions, showing the improved hybrid algorithm converged faster.

Deo Dixit and Srivastava (2012) discuss the numerical accuracy of the Bisection method, agreeing that while the method is slow, its accuracy improves with a reduced tolerance value. They provided an algorithm and a C++ program for calculating square roots, demonstrating the results but without detailing the solution process.
Solanki *et al.* (2014) compare various root-finding algorithms, including the Bisection, Secant, and Newton-Raphson methods. They acknowledge the Bisection method's slowness and propose an improvement but provide limited performance details and no programming code.

Nasr (2019) explores the Bisection Method using Fuzzy concepts, applying triangular fuzzy numbers without developing a corresponding computer program. Ahmad (2015) compares the Bisection and Newton-Raphson methods using MATLAB, showing that the Newton-Raphson method converges faster. However, the explanation lacks detail on the obtained results. Akram and Ann (2015) similarly discuss the Newton-Raphson method's efficiency but do not provide algorithms or programs for their examples.

In interpolation, Biswajit and Dhritikesh (2016) explain the Newton divided difference method, deriving a polynomial for population data but lacking computational support. Lazim and Teuta (2011) focus on the Lagrange interpolation method, deriving the formula and solving a problem using Wolfram Mathematica, but without creating a general algorithm.

Regarding systems of linear equations, Yadanar and Lai (2014) compare Gaussian elimination and Gauss-Jordan methods. They provide algorithms and an interactive application, showing Gaussian elimination to be faster. Rafique (2015) praises the LU decomposition method for its efficiency in solving large systems but lacks practical examples. Nirmala and Ganesan (2018) propose a modified Crout's method for LU decomposition, illustrating the process without computational proof. Yang *et al*. (2010) described the LU Decomposition algorithm for solving large-scale equations, applying it to a transportation problem but without automation.

In solving ordinary differential equations, Atkinson *et al*. (2009) and Ma (2023) describe the Euler Method, noting its inefficiency compared to other methods. Atkinson *et al*. (2009) provide a MATLAB algorithm, while Mathews and Fink (2004) analyze error based on step size. Ma (2023) identified errors using Taylor's series, highlighting ongoing efforts to improve the method's efficiency.

The present study tries to develop a user-friendly application that could solve various Scientific and Engineering models through the application of numerical schemes. The procedural steps to the actualization of the final answer is displayed on the output window.

3. METHODOLOGY

3.1. Technology Involved

This work utilizes Java, a language developed by Sun Microsystems in 1991 under the leadership of James Gosling (Deitel and Deitel, 2015). Java, an object-oriented, platform-agnostic language, is renowned for its Write Once, Run Anywhere (WORA) capability, supported by the Java Virtual Machine (JVM), which ensures seamless interaction with the operating system (Hock-Chuan, 2017). The widespread adoption of Java, with over a billion devices running it, and its extensive libraries for various functions, made it an ideal choice for this research work.

The application development was conducted using IntelliJ, an Integrated Development Environment (IDE) known for its robust support for Java and other JVM languages like Kotlin and Go. IntelliJ was selected for its efficiency in developing websites, web services, and Android mobile apps.

JavaFX, a versatile graphics library, was employed for building the application's graphical user interface. JavaFX offers cross-platform functionality, ranging from desktop to mobile devices, and supports FXML, an XML-based design language, which simplifies interface development (Dea, 2011). The inclusion of cascading style sheets (CSS) and compatibility with other Java graphics libraries, such as swing, were critical for integrating the JLaTeXMath library.

The JLaTeXMath library was used to ensure proper formatting of mathematical symbols and expressions within the application. This library enhances the readability of complex mathematical output, such as summation symbols and matrices. Additionally, an expression library was implemented to parse and evaluate basic mathematical expressions, which is crucial for processing mathematical functions within the application.

3.2. Scope of Applicability

The following is a list of functions that could be performed using this numerical methods calculator that has been developed (Table 1).

Table 1. List of functions.

Problem Category	Method
Ordinary Differential Equation	Euler Second Order Runge-Kutta (Midpoint) Second Order Runge-Kutta (Heun) Second Order Runge-Kutta (Ralston) Third Order Runge-Kutta Fourth Order Runge-Kutta
Nonlinear Methods	Bisection Newton-Raphson Secant False Position
System of Equations	Gaussian Elimination LU Decomposition Inverse with LU Decomposition Gauss-Seidel
Interpolation	Lagrange Interpolation Newton Divided Difference Direct Interpolation Quadratic Spline Cubic Spline
Numerical Integration	Trapezoidal Integration Simpson 1/3 Rule Simpson 3/8 Rule
Numerical Differentiation	First Order Divided Difference

3.3. Application Development

The development of the application involves a series of systematic steps to design and implement the required code. The process begins by incorporating necessary libraries as dependencies in the development environment, in this case, using IntelliJ IDEA. These libraries are added as Java archives (JAR files) and are then imported into the project's classes as needed.

The application design is centered on creating a user-friendly interface that facilitates the selection of the desired computational method. This interface is followed by another that collects the required input variables, and finally, an output window that displays the results. The methods available in the application are organized into categories based on their application areas. For example, methods like Euler and Runge-Kutta are grouped under ordinary differential equations, while Newton's divided difference and Lagrangian interpolation are categorized under interpolation methods. This categorization simplifies the user's search and selection process.

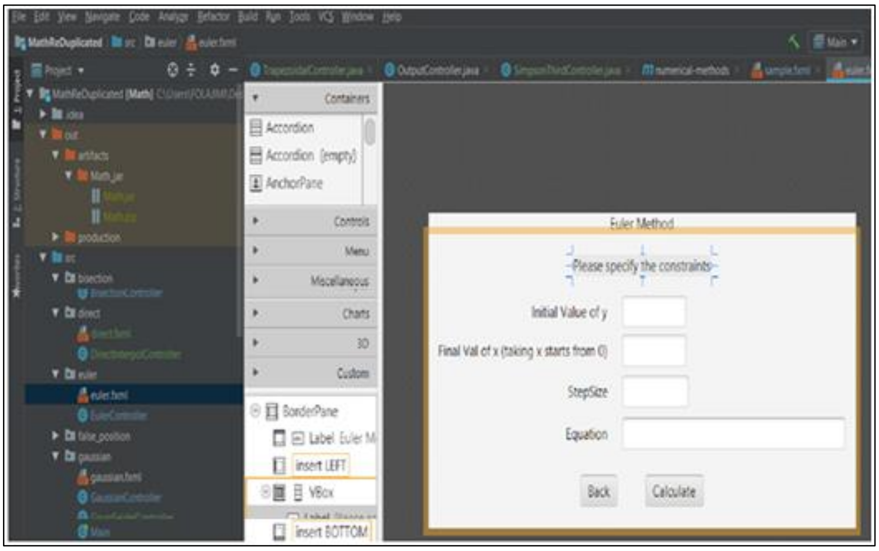


Figure 1. Interface design for Euler method.

The interface for input variables is tailored to the specific requirements of each method. For instance, if the Euler method is chosen for solving an ordinary differential equation, the interface will prompt for step size, boundary conditions, and the function to be solved (see Fig. 1). Similarly, selecting a method for solving simultaneous equations will require input matrices.

The output window is designed using the JLaTeXMath library, which simplifies the display of results by formatting them in LaTeX. The output includes detailed step-by-step values generated by the algorithm, providing clarity on how the solution was derived. The design and implementation of the output format are guided by insights gathered from the literature review, including algorithm pseudocode, time complexity, and implementation strategies. This ensures that the application not only solves the problems but also provides transparency in its numerical process.

4. RESULTS AND DISCUSSION

4.1. Numerical Experiment

In this stage we display the execution of the application to solve a problem. On executing the application, the interface is as shown in Fig. 1. The user interacts with a dropdown list to select a specific group of methods.

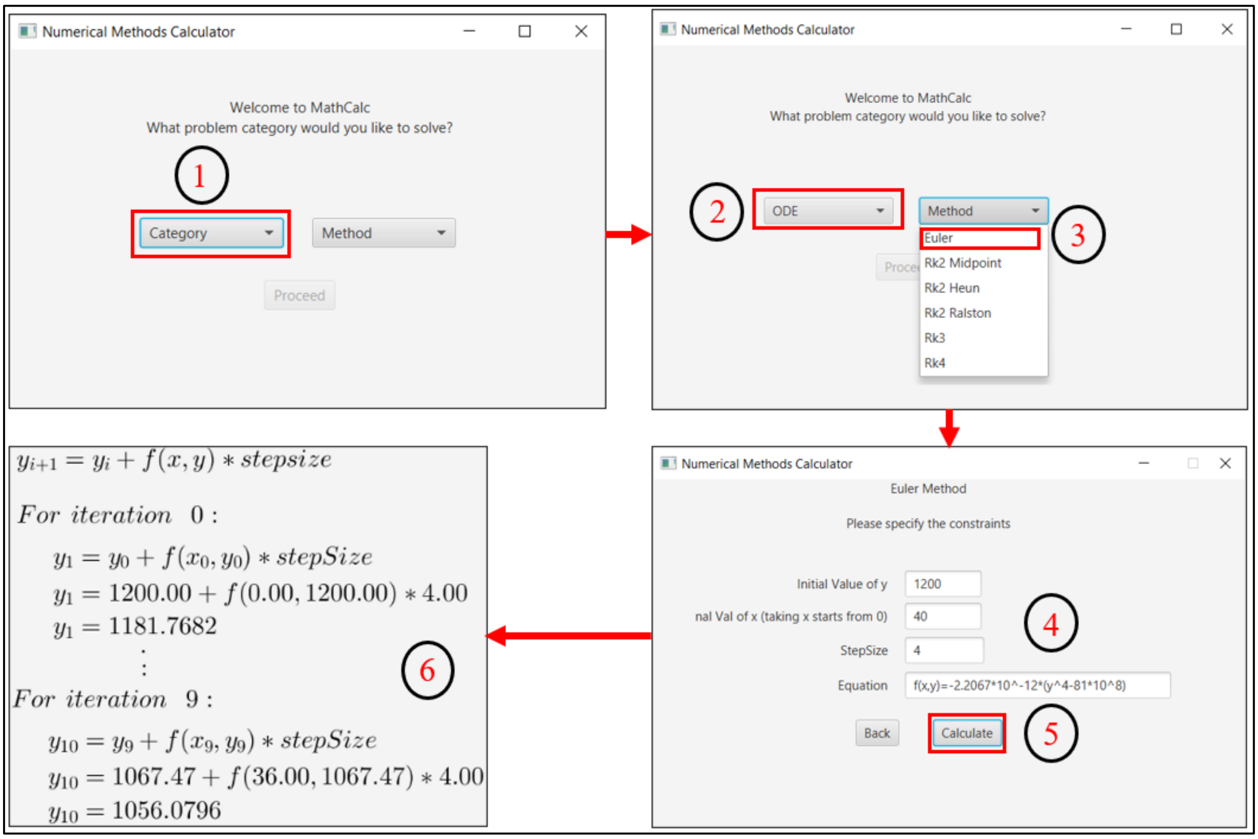


Figure 2: Complete cycle implementation of the application.

For numerical experiment, the initial value problem in Eq. 1 will be solved using the Euler method. In this case, the group of methods relating to Ordinary Differential equations is selected.

$$\frac{dy}{dx} = -2.2067\times10^{-12}\left(y^4 - 81\times10^{-8}\right)$$
$$y(0) = 1200 \qquad (1)$$

The next scene after this window requires the user to define all necessary constraints for solving the problem. In the case of the Euler method, an initial value of the dependent variable, y, is required. Also, value for the independent variable, x, that serves as the stopping criteria and a step size value to increment it. The equation function is also a required constraint.

Upon selection of the "Calculate" button, an output is generated. The difference in the case of this application from computational software applications is that the output generated is more explanatory showing the entire process of solving the problem before the final answer. The complete cycle implementation of the application is shown in Fig. 2.

4.2. Generating and Testing the Results

The output solution in Fig. 3 shows a well-detailed set of steps taken to solve the Eq. (1). Now the values can be cross-checked while working manually for understanding.

$$y_{i+1} = y_i + f(x, y) * stepsize$$

$$For\ iteration\ \ 0:$$

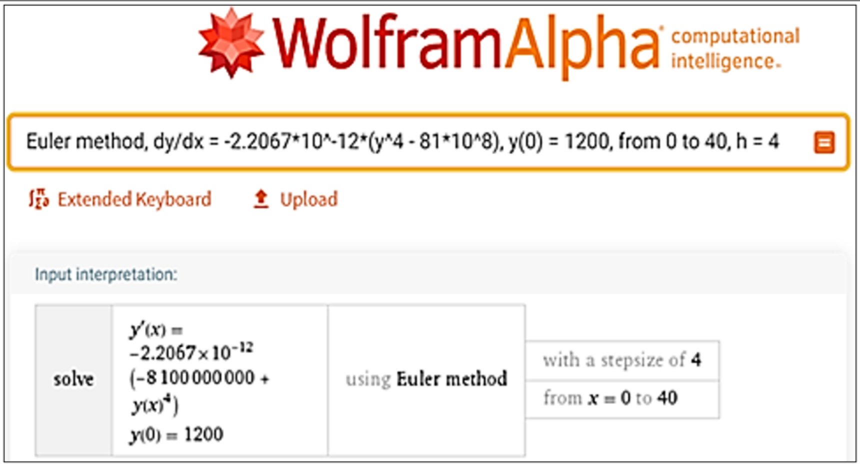
$$y_1 = y_0 + f(x_0, y_0) * stepSize$$
$$y_1 = 1200.00 + f(0.00, 1200.00) * 4.00$$
$$y_1 = 1181.7682$$
$$\vdots$$

$$For\ iteration\ \ 9:$$

$$y_{10} = y_9 + f(x_9, y_9) * stepSize$$
$$y_{10} = 1067.47 + f(36.00, 1067.47) * 4.00$$
$$y_{10} = 1056.0796$$

Figure 3. Iteration and final result of the calculation.

For the sake of measuring accuracy, this process was repeated using the online computational tool, Wolfram Alpha (Alpha, 2024). The input of the problem on Wolfram Alpha is shown in Fig. 4(a) while the result output is depicted on Fig. 4(b). The same step size of 4 within the range values of 0 to 40 is used.



(a)

step	x	y
0	0	1200
1	4	1181.77
2	8	1164.62
3	12	1148.46
4	16	1133.17
5	20	1118.69
6	24	1104.94
7	28	1091.85
8	32	1079.38
9	36	1067.47
10	40	1056.08

(b)

Figure 4. (a) Problem input and (b) the snippet of the stepwise result to Eq. (1) solved by Wolfram Alpha

In order to test the flexibility of the algorithms, the values of the constraints were varied, and the process was repeated with the final value of $x = 25$ and step size of 5. The results generated are shown in Fig. 5.

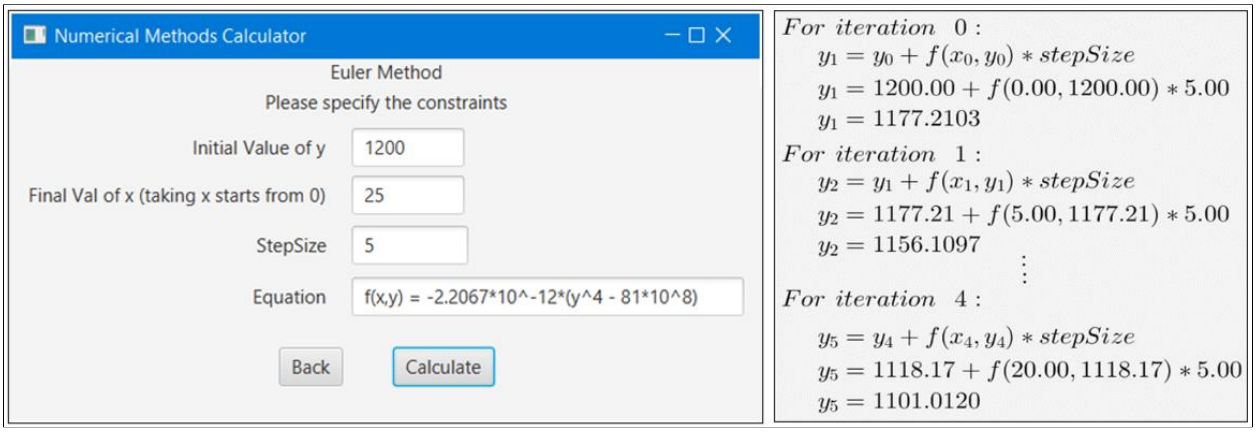
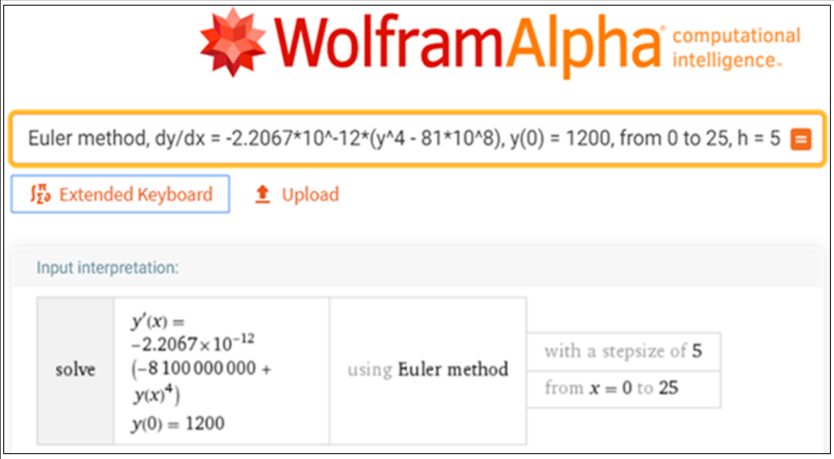


Figure 5. Entry of varied values and output solutions of Eq. (1) for the second trial.

Again, Wolfram Alpha was used to validate the result. Without careful observation, the results are seen to be consistent (see Fig. 6), and the algorithm is able to adapt to changes in the constraint, showing that the program is not rigid or manual but flexible and generic.



(a)

step	x	y
0	0	1200
1	5	1177.21
2	10	1156.11
3	15	1136.49
4	20	1118.17
5	25	1101.01

(b)

Figure 6. (a) The same Eq. (1) solved on Wolfram Alpha and (b) the computed results.

Deo Dixit & Srivastava (2012) carried out a computation, applying the bisection method to obtain $\sqrt{1}$. The implementation of this problem in the present work is displayed in Fig. 8. The result obtained from the application is shown on Fig. 9(b) while that obtained from Deo Dixit & Srivastava (2012) is displayed in Fig. 9(b).

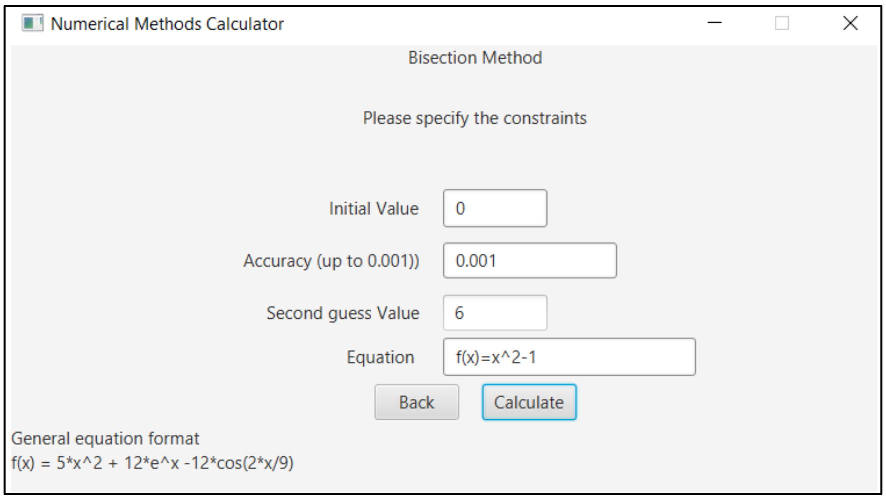
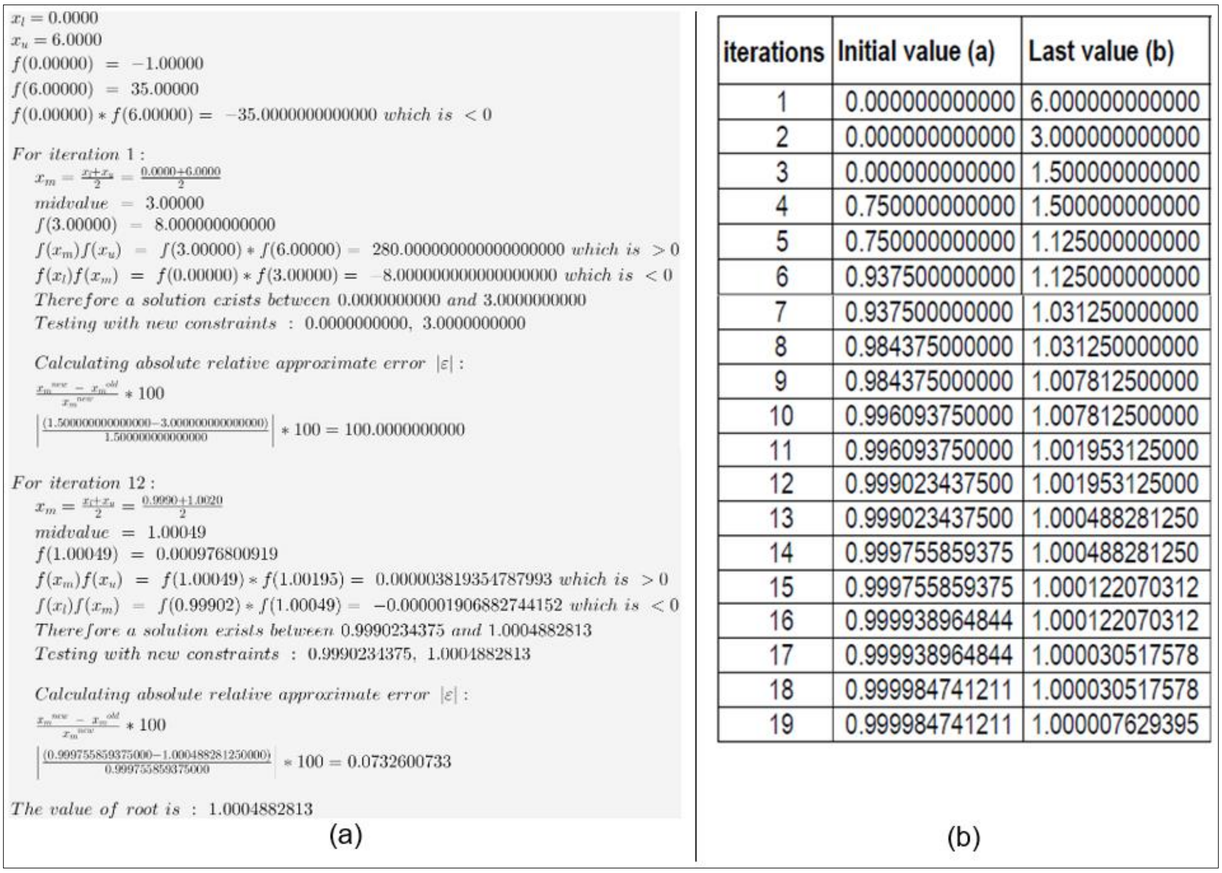


Figure 8. Using the bisection method of the application.

Comparatively, the results of both computations are very similar. However, the application has made the results user interactive which is the focal point of this work. The results are self-explanatory and easy to follow.



$x_l = 0.0000$
$x_u = 6.0000$
$f(0.00000) = -1.00000$
$f(6.00000) = 35.00000$
$f(0.00000) * f(6.00000) = -35.000000000000 \text{ which is } < 0$

For iteration 1 :
$x_m = \frac{x_l + x_u}{2} = \frac{0.0000+6.0000}{2}$
$midvalue = 3.00000$
$f(3.00000) = 8.000000000000$
$f(x_m)f(x_u) = f(3.00000) * f(6.00000) = 280.000000000000000000 \text{ which is } > 0$
$f(x_l)f(x_m) = f(0.00000) * f(3.00000) = -8.000000000000000000 \text{ which is } < 0$
Therefore a solution exists between 0.0000000000 *and* 3.0000000000
Testing with new constraints : 0.0000000000, 3.0000000000

Calculating absolute relative approximate error $|\varepsilon|$:
$\frac{x_m^{new} - x_m^{old}}{x_m^{new}} * 100$
$\left|\frac{(1.500000000000000 - 3.000000000000000)}{1.500000000000000}\right| * 100 = 100.0000000000$

For iteration 12 :
$x_m = \frac{x_l + x_u}{2} = \frac{0.9990+1.0020}{2}$
$midvalue = 1.00049$
$f(1.00049) = 0.000976800919$
$f(x_m)f(x_u) = f(1.00049) * f(1.00195) = 0.000003819354787993 \text{ which is } > 0$
$f(x_l)f(x_m) = f(0.99902) * f(1.00049) = -0.000001906882744152 \text{ which is } < 0$
Therefore a solution exists between 0.9990234375 *and* 1.0004882813
Testing with new constraints : 0.9990234375, 1.0004882813

Calculating absolute relative approximate error $|\varepsilon|$:
$\frac{x_m^{new} - x_m^{old}}{x_m^{new}} * 100$
$\left|\frac{(0.999755859375000 - 1.000488281250000)}{0.999755859375000}\right| * 100 = 0.0732600733$

The value of root is : 1.0004882813

(a)

iterations	Initial value (a)	Last value (b)
1	0.000000000000	6.000000000000
2	0.000000000000	3.000000000000
3	0.000000000000	1.500000000000
4	0.750000000000	1.500000000000
5	0.750000000000	1.125000000000
6	0.937500000000	1.125000000000
7	0.937500000000	1.031250000000
8	0.984375000000	1.031250000000
9	0.984375000000	1.007812500000
10	0.996093750000	1.007812500000
11	0.996093750000	1.001953125000
12	0.999023437500	1.001953125000
13	0.999023437500	1.000488281250
14	0.999755859375	1.000488281250
15	0.999755859375	1.000122070312
16	0.999938964844	1.000122070312
17	0.999938964844	1.000030517578
18	0.999984741211	1.000030517578
19	0.999984741211	1.000007629395

(b)

Figure 9. (a) Truncated result from the calculator and (b) the computed result from Deo Dixit & Srivastava (2012) to find $\sqrt{1}$ using the bisection method.

5. CONCLUSION

The application developed in this work serves as an effective educational tool, offering both practical solutions to numerical methods problems and valuable insights for students in engineering and science. Its intuitive design and self-explanatory outputs make it a suitable resource for teaching at both undergraduate and postgraduate levels. By simplifying the understanding of complex numerical analysis techniques, the application enhances the learning experience and provides a significant advantage to users seeking to grasp these methods. Overall, the tool contributes to bridging the gap between theoretical knowledge and practical application in the field of numerical analysis.

DECLARATION OF INTEREST

There is no conflict of interest.

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A MATERIAL MECHANICAL PROPERTIES SIMULATOR FOR ENGINEERING AND MATERIAL SCIENCE EDUCATION AND RESEARCH

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Abstract: This present paper depicts the development and implementation of a comprehensive material mechanical properties simulator, specifically designed for tensile testing in educational settings. The simulator takes the cross-sectional area and length of the test specimen as inputs, while forces and deformation data are uploaded from an Excel sheet. Computational techniques are integrated with an intuitive graphical user interface (GUI), enabling students and researchers to accurately simulate and interpret the mechanical behaviour of materials under tensile loading conditions. Key features include the ability to visualize stress-strain responses and other relevant mechanical properties through interactive graphical displays. The results from this simulator are consistent with the known material properties recorded in the literature for specific materials. This tool aims to serve as a valuable resource for academic research, practical engineering applications educational resource, offering a robust platform for the exploration of material mechanics and enhancing the learning experience for engineering and material science students. Compared to the traditional method, the simulator enhances learning through dynamic visualization of concepts, interactive learning environment, immediate feedback and iterative learning, and access to a wider range of scenarios.

Keywords: Mechanical properties, graphical user interface, simulator, Python, Specimen, Engineering education

1. INTRODUCTION

Understanding the mechanical properties of materials is a fundamental aspect of engineering education and practice. These properties, such as Young's Modulus, ultimate tensile strength, yield strength, fracture stress, and ductility (Young and Budynas, 2002), are critical for designing and analysing structures and components in various engineering fields (Callister & Rethwisch, 2018). Traditional methods of teaching these concepts often rely on theoretical explanations and static laboratory experiments, which can limit students' ability to fully grasp the dynamic nature of material behaviour under different loading conditions (Ashby & Jones, 2012).

In recent years, the integration of computational tools and interactive software in engineering education has shown great potential in enhancing student learning and engagement (Park & Kim, 2006). Simulators and virtual laboratories provide a dynamic and flexible approach to exploring complex engineering concepts, allowing students to visualize and interact with the data in real-time (Shaffer & Resnick, 1999).

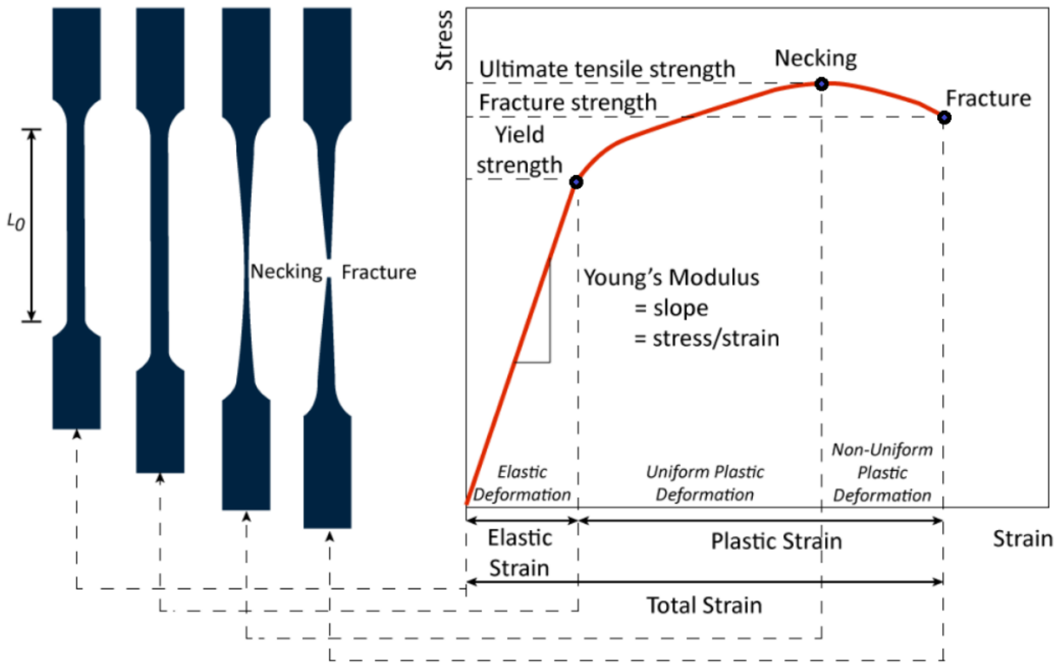

Figure 1. Shape of Ductile Specimen at Various Stages of Testing.

The integration of computational tools and interactive software in engineering education has been extensively explored. Park and Kim (2006) investigated the impact of visual aids on learning outcomes in a university engineering class. They found that interactive tools significantly enhance student engagement and understanding of complex concepts by providing visual and hands-on experiences. Shaffer and Resnick (1999) discussed the concept of "thick" authenticity in educational settings, emphasizing that new media and interactive learning environments can create more meaningful and engaging educational experiences. They highlighted the importance of incorporating dynamic and flexible tools to bridge the gap between theoretical knowledge and practical application. Similarly, Papadopoulos and Santiago-Román (2010) assessed the impact of computer-based simulations on student learning in engineering mechanics. Their study revealed that simulations improve student comprehension and retention of material by allowing them to visualize and interact with the data in real-time.

2. LITERATURE REVIEW

The understanding of the mechanical properties of materials is crucial for engineering design and analysis. Callister and Rethwisch (2018) provide a comprehensive introduction to materials science and engineering, detailing the fundamental properties such as Young's Modulus, ultimate tensile strength, yield strength, fracture stress, and ductility. The shape of ductile specimen at various stages of testing that give room for the determination of the mechanical properties is shown in Fig. 1. These properties are essential for predicting material behaviour under different loading conditions and ensuring the safety and reliability of engineering structures. Ashby and Jones (2012) discuss the importance of these mechanical properties. They emphasize the need for accurate measurement and analysis of these properties to inform material selection and design decisions. Dieter and Schmidt (2012) highlight the importance of understanding material behaviour in engineering design. They discuss various methods for measuring and analysing mechanical properties, underscoring the significance of tools that allow for real-time visualization and interaction with the data. The educational impact of simulators and virtual laboratories has been widely studied. Wankat and Oreovicz (2015) discussed the benefits of using interactive tools in engineering education. They argue that these tools can significantly enhance student learning by providing dynamic and engaging learning experiences. Felder and Brent (2005) explore the concept of active learning and its importance in engineering education. They highlight the need for interactive and hands-on learning experiences to improve student engagement and understanding.

On the other hand, Van Rossum and Drake (2009) provided a comprehensive guide to Python, highlighting its versatility and extensive library support for data analysis and visualization. This makes Python an ideal choice for developing educational tools like the Mechanical Properties Simulator. Lundh (1999) discussed Tkinter, a standard GUI toolkit for Python, and its application in creating user-friendly interfaces. These resources informed the development of the simulator, ensuring it is both powerful and accessible to students.

Other studies have also demonstrated the effectiveness of computational tools in engineering education. Cheng et al. (2008) examined the use of simulation software in teaching mechanical engineering concepts and found that students who used the software showed a better understanding of the material properties and their applications. They emphasised that interactive simulations could provide immediate feedback and allow for experimentation with different parameters, which is crucial for deep learning. Similarly, Mahajan et al. (2010) explored the impact of virtual labs on student performance in engineering courses and reported that virtual labs not only improved conceptual understanding but also increased student motivation and interest in the subject. Their findings support the use of virtual labs as a supplement to traditional teaching methods.

The use of case studies to validate educational tools is a common practice in engineering education. For instance, Zhang et al. (2012) conducted a case study on the use of a mechanical properties simulator in an undergraduate materials science course. They found that the simulator provided accurate and reliable results, which were consistent with established literature values. This validation is crucial for establishing the simulator as a valuable educational tool and ensuring its effectiveness in teaching material mechanics. Furthermore, the interactive nature of the simulator encouraged students to explore and experiment with different materials, fostering a deeper understanding of material properties and their applications.

These studies collectively underscore the importance of integrating computational tools and interactive simulations in engineering education. The Mechanical Properties Simulator developed in this study aims to build on this body of work by providing an intuitive and interactive platform for analysing tensile test data. By allowing students to input specimen dimensions, upload force and deformation data, and obtain key mechanical properties through graphical displays, the simulator offers a practical and engaging learning experience that bridges the gap between theoretical knowledge and practical application.

This paper presents the development and implementation of a Mechanical Properties Simulator using Python and Tkinter, specifically designed for tensile testing. The simulator aims to bridge the gap between theoretical knowledge and practical application by providing an interactive platform for students to analyse and visualize the mechanical behaviour of materials. It allows users to input specimen dimensions, upload force and deformation data from Excel sheets, and obtain key mechanical properties through graphical displays.

The simulator calculates essential mechanical properties including Young's Modulus, ultimate tensile strength, yield strength using the 0.2% strain offset method, fracture stress, and ductility. Mild steel and aluminum are used as case studies to validate the simulator's accuracy, with results compared against established literature values (Bird and Ross, 2020). This interactive tool not only enhances the learning experience but also provides a practical understanding of material mechanics, preparing students for real-world engineering challenges (Felder & Brent, 2005).

The following sections of this paper detail the methodology, computational analysis, results, and educational impact of the Mechanical Properties Simulator, demonstrating its effectiveness as an educational resource and its alignment with current engineering education trends.

3. METHODOLOGY

This section details the development, implementation, and validation of a Mechanical Properties Simulator designed to facilitate the understanding of tensile testing. The simulator leverages Python and Tkinter for its user interface, with computational back-end analysis performed using scientific libraries. The simulator is intended to provide an interactive and educational experience, promoting hands-on learning of material mechanics concepts.

3.1. Design and Implementation

3.1.1. Graphical User Interface (GUI)

The GUI is designed using Python's Tkinter library, chosen for its simplicity and ease of integration with other Python libraries. The interface is divided into several sections: Input Section: Fields for entering the cross-sectional area (A) and initial length (L_0) of the test specimen.

Data Upload Section: An option to upload an Excel file containing force (F) and deformation (ΔL) data.

3.1.2. Input Parameters

The simulator requires the following inputs:

Cross-sectional Area (A): Entered manually by the user. This is a crucial parameter as it directly affects the stress calculations.
Initial Length of Specimen (L_0): Entered manually by the user. This parameter is essential for calculating strain.
Force (F) and Deformation (ΔL) Data: Uploaded from an Excel sheet, enabling the use of real experimental data.

3.1.3. Data Upload and Processing

The simulator allows users to upload data in Excel format. The pandas library is used for data processing due to its powerful data manipulation capabilities.

3.2. Computational Analysis

Stress, σ Calculation: Stress is the force applied per unit area. It is calculated as,

$$\sigma = \frac{F}{A} \qquad (1)$$

where F is the force applied (in Newtons), and A is the cross-sectional area.
Strain, ε Calculation: Strain is the deformation experienced by the material per unit length. It is calculated as,

$$\varepsilon = \frac{\Delta L}{L_0} \qquad (2)$$

where ΔL is the change in length, and L_0 is the original length.
Young's Modulus, E Calculation: Young's modulus is the ratio of stress to strain in the elastic region of the material. It is calculated as,

$$E = \frac{\sigma}{\varepsilon} \qquad (3)$$

Ductility: Ductility is measured as the percentage elongation of the specimen at fracture.

$$Ductility = \frac{\Delta L_f}{L_0} \times 100\% \qquad (4)$$

L_f is the final length of the specimen.

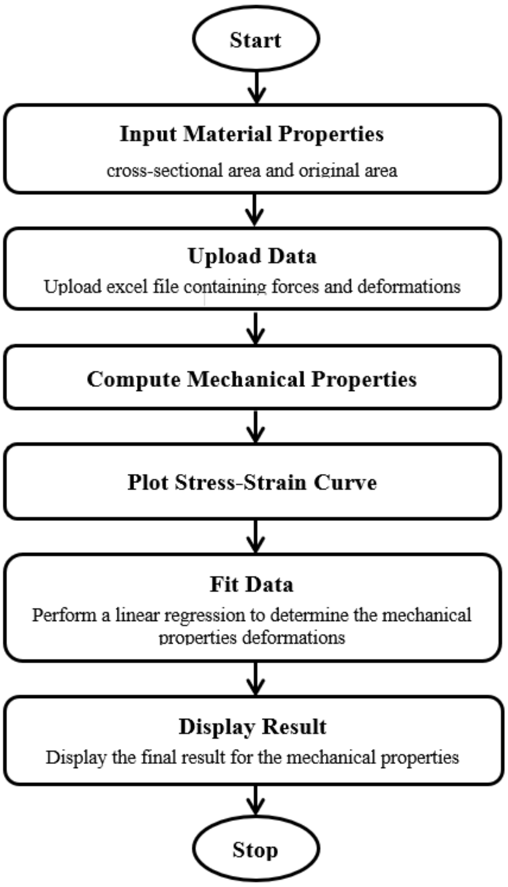

Figure 2. The Simulator sequence of events.

4. RESULTS AND DISCUSSION

This section presents the results obtained from the Mechanical Properties Simulator for tensile tests on mild steel and aluminum. The simulator calculates key mechanical properties including elastic modulus, ultimate tensile strength, yield strength (using the 0.2% strain offset method), fracture stress, and ductility. The simulator's results were compared with published illustrative data for mild steel and aluminum alloy (Bird and Ross, 2020). The comparison shows good agreement between the calculated mechanical properties and those reported in the literature, validating the simulator's accuracy and reliability. Four primary plots generated by the simulator are analysed and discussed. The materials selected for the case studies are mild steel and aluminum, commonly used in engineering applications. The specific grades and their respective properties from literature are used as benchmarks for comparison. Each subplot in Figs. 3 and 4 represent a different mechanical property: Ultimate Tensile Strength (UTS), Fracture Strength, Yield Strength, and Elastic Modulus.

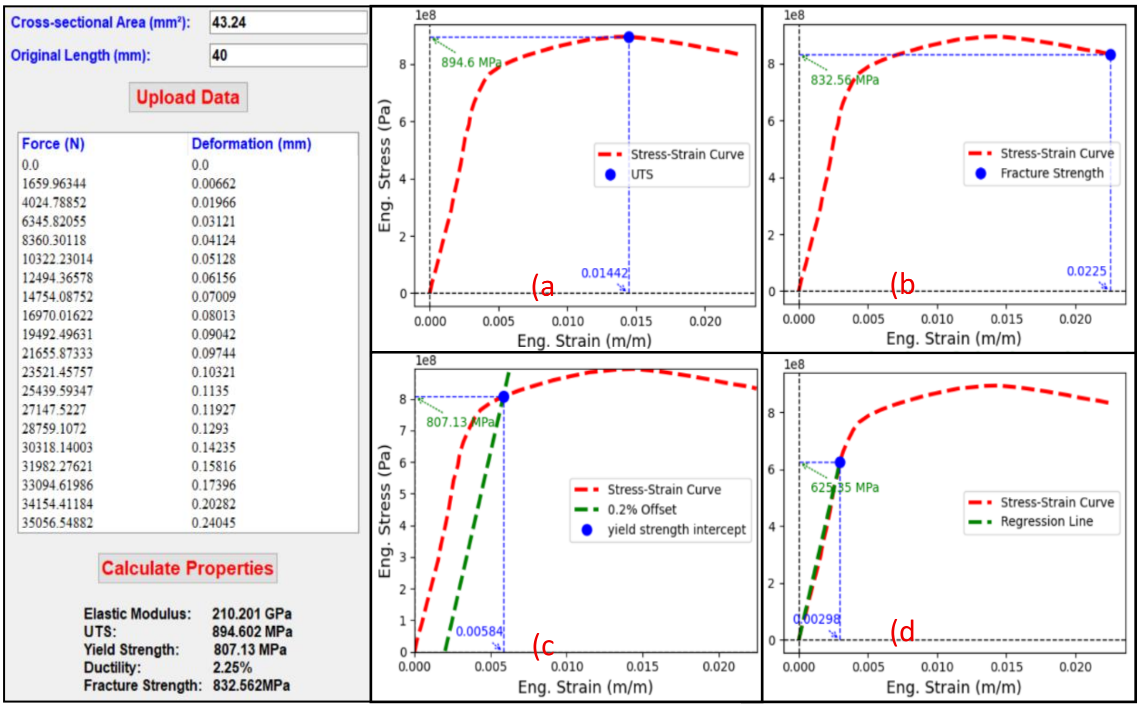

Figure 3. The GUI of the Simulator showing the input and the display frames for the determination of (a) ultimate tensile, (b) fracture strength, (c) yield strength, and (d) elastic modulus for a mild steel sample.

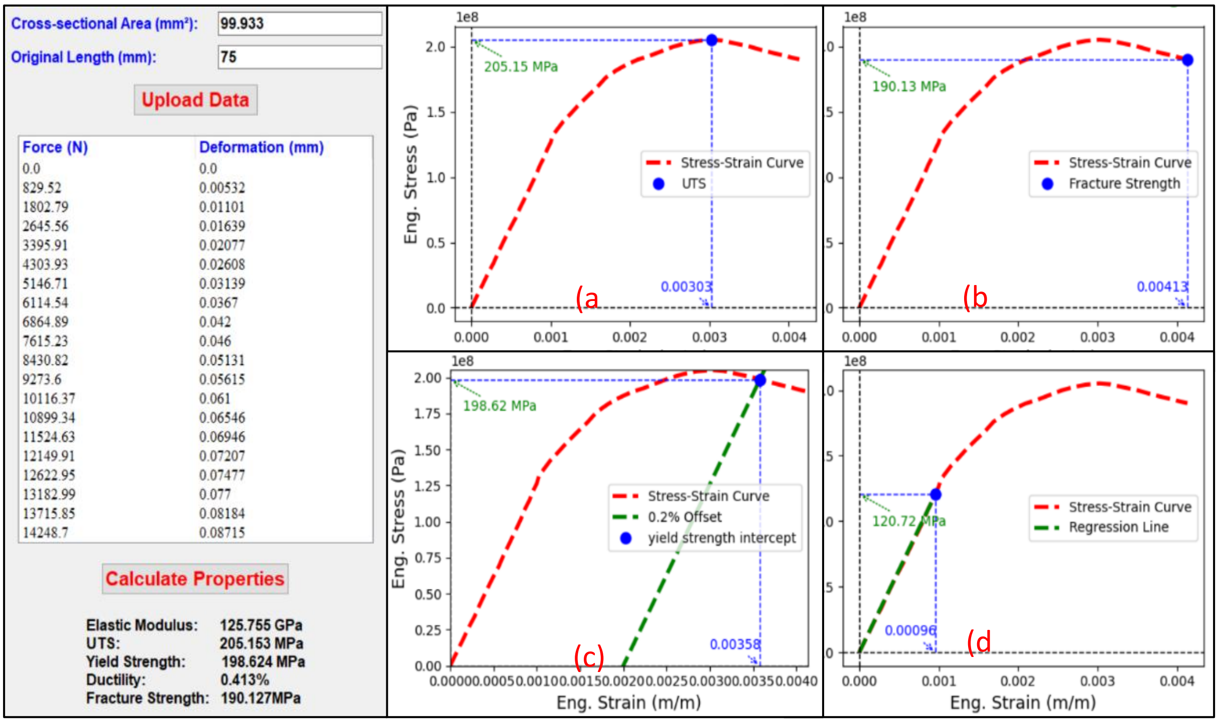

Figure 4: The GUI of the Simulator showing the input and the display frames for the determination of (a) ultimate tensile, (b) fracture strength, (c) yield strength, and (d) elastic modulus for an aluminum alloy sample.

4.1. Stress-Strain Curve for Young's Modulus

The stress-strain curve generated by the simulator shows a linear region at the beginning, from which Young's Modulus is calculated. For mild steel, the calculated elastic modulus was approximately 210.201GPa, closely matching the literature value of 210GPa (Bird and Ross, 2020). For the aluminum alloy, the calculated elastic was around 125.755GPa, consistent with the literature value of 125GPa (Bird and Ross, 2020).

4.2. Stress-Strain Curve for Ultimate Tensile Strength

The simulator identifies the maximum stress point on the stress-strain curve. For mild steel, the UTS was found to be approximately 894.602MPa, which aligns with the literature of 890MPa. For aluminum, the UTS was about 205.103MPa, also within the expected range of 205MPa.

4.3. Stress-Strain Curve for Yield Strength

The simulator plots a line at a 0.2% strain offset to determine the yield strength. For mild steel, the yield strength was approximately 807.13MPa, matching the literature value of around 806MPa. For aluminum, the yield strength was about 198.624MPa, which is consistent with the literature value of 199MPa.

4.4. Stress-Strain Curve for Fracture Stress

The simulator identifies the fracture point on the stress-strain curve. For mild steel, the fracture stress was approximately 832.562MPa, and for aluminum, it was about 190.127MPa. These values are in line with the results found in Bird and Ross (2020).

4.5. Determination of the Ductility

The simulator calculates ductility by measuring the total elongation at the point of fracture. For mild steel, ductility was found to be approximately 2.25%, and for aluminum, it was about 0.413%, both consistent with typical values found in Bird and Ross (2020).

4.6. Validation and Testing

The simulator is tested by a group of engineering students to evaluate its usability and educational effectiveness. Feedback is collected through surveys and direct observation, and iterative improvements are made based on this feedback.

Validation of the simulator involves comparing its output with known standards and experimental results. Several test cases with known properties are run through the simulator to ensure the accuracy and reliability of the results.

5. CONCLUSION

The development of the Mechanical Properties Simulator has proven to be a significant advancement in the educational tools available for teaching material mechanics. By allowing students to input specimen dimensions, upload force and deformation data, and visualize the resulting mechanical properties through interactive plots, the simulator provides a comprehensive and hands-on learning experience.

Through the integration of intuitive GUI design and robust computational methods, the simulator enhances the understanding of tensile testing procedures and material behaviour under stress. The detailed step-by-step guidance further supports the educational goals, making it an effective resource for both classroom, individual study and research.

This Simulator not only bridges the gap between theoretical knowledge and practical application but also fosters an engaging and interactive learning environment for engineering and science students. Future enhancements could include incorporating more advanced analysis techniques, and further refining the user interface. This simulator represents a valuable contribution to engineering education, providing a solid foundation for understanding the mechanical properties of materials. It enhances learning over traditional methods by providing dynamic concept visualization, an interactive learning environment, immediate feedback with iterative learning, and access to a wider range of scenarios.

DECLARATION OF INTEREST

There is no conflict of interest in this work.

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BOOTHROYD AND DEWHURST METHOD AS A CREATIVE TOOL TO SUPPORT DESIGN FOR MANUFACTURING AND ASSEMBLY (DFMA) STUDENTS ENGINEERING DESIGN TEAMS

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Abstract: The field of Design for Manufacturing and Assembly (DFMA) presents unique challenges, particularly due to the lack of creative tools that facilitate concurrent and collaborative engineering design. Effective collaboration among engineering teams necessitates tools that enable diverse groups to innovate collectively. This study hypothesizes that the Boothroyd and Dewhurst method can effectively promote collaborative creativity and innovation within engineering teams. To test this, we examine its application across five student engineering design projects, assessing its effectiveness in fostering teamwork and creativity. Our findings reveal that the Boothroyd and Dewhurst method not only helps students optimize engineering designs but also stimulates collaborative creativity by enhancing curiosity, critical thinking, and collaborative design thinking. These results indicate that, while the method was originally designed for systematic product optimization, it also significantly supports co-creative thinking, co-innovation, and collaborative skills among engineering student groups.

Keywords: Boothroyd & Dewhurst; co-creation; design for manufacturing; student projects

1. INTRODUCTION

Addressing design for manufacturing projects has been challenging, particularly due to the absence of creative tools to facilitate co-creation amongst designers. Without effective co-creation tools, designers may struggle to communicate and integrate diverse perspectives, hampering creativity and leading to inefficiencies and suboptimal design outcomes. Several studies highlight the limitations and complexities in current tools emphasising the need for exploring better co-creation tools. For example, Gmeiner et al. (2023) highlights that AI-based design tools aimed at fostering co-creation face challenges as users struggle to communicate design goals and understanding the AI outputs. Furthermore, as with Santhosh (2022), the focus is on digital tools which are applicable for co-creation where platforms are co-creation spaces. In design for manufacturing projects, other tools might be more useful.

This article delves into the Boothroyd and Dewhurst (BD) Design for Manufacturing method, utilizing engineering students' projects to assess how this method stimulates co-creative abilities. Boothroyd and Dewhurst's design for manufacturing and assembly (DFMA) methodology aims to reduce assembly and manufacturing costs during the product development and improvement process (Boothroyd et al. 2010; Barbosa & Carvalho, 2013). Therefore, the BD design method is applied early during the design conceptualization phase because it has been established that 70-80% of the final product costs are determined during the design concept phase (Boothroyd et al. 2010). Lu et al. (2021) elucidates that when the DFMA strategy was applied to Swedish companies, up to half of the companies realized 33% reduction in development time and cost.

Given the above statistics, DFMA is a useful methodology for reducing assembly and manufacturing costs. In this article, we instead explore in detail how and to what extent the Boothroyd and Dewhurst (BD) method can potentially drive creativity and captivate creative aptitudes in the early design concept phase. Engel (2018) defines creativity as "the ability to transcend traditional ideas, rules, patterns, relationships, or the like and create meaningful new ideas, forms, interpretations, etc." (p. 5). Our motivation to focus on creativity is also premised on Samuel (2006)'s view that "creativity and eclectic knowledge of engineering sciences can help solve societal problems of an analytic nature, but for synthesis, there is a need for open-minded engagement with the problem" (p.45). In Cropley (2016), creativity is defined as "the generation of effective and novel solutions to problems, and engineering is concerned more specifically with generating technological solutions to problems" (p. 5). Thus, Cropley (2016) extends Samuel (2006)' view on engineering as a creative approach, that for it to be successful it must find a balance between creativity and engineering.

The above views make a convincing argument that engineering tools such as BD method can contribute as creative processes provided a focus on both analyses, synthesis, convergent and divergent thinking approaches to problem-solving are adopted. The latter recombination can narrow the process to a concurrent engineering approach coupled with co-creation since it may be challenging for a single design engineer to both converge and diverge in the creative process.

Although the Boothroyd and Dewhurst (BD) method was developed over four decades ago as a DFMA engineering design tool to guide designers or concurrent engineering teams to discover design problems (Boothroyd et al., 2010), scant research examines this method in detail as a co-creative tool that potentially expands the solution space for Engineers. In this research, we explore this gap by experimenting with the BD method using undergraduate case study engineering projects to test the effectiveness of the BD design tool as a co-creative framework. Although the BD tool has been traditionally used to provide a quantitative measure called the assembly index or design efficiency based on the analysis of existing mechanical products, we take a deliberate step to explore in detail how this tool can act as a co-creative structure to support concurrent engineering design.

In a recent systematic literature survey by Formentini et al. (2022), the authors argue that considering DFMA during the conceptual design phase of the product development process can significantly increase the solution space, thus promoting creativity. We continue this line of thinking and couple this thought with Samuel (2006)'s view that creativity is more about thinking through design problems than just about the outcome of a creative behaviour. Therefore, this research work elicits creative behaviour in undergraduate students through project activities following the BD method to address the following research question.

How might the BD design tool elicit creative behaviour in students engineering design teams?

As Samuel (2006) suggests, "There is great value to be found in the use of creativity enhancement tools" (p.36). Therefore, we will argue in this article that the BD method elicits an intuitive process which can influence the creative outcome. To address the research question fully, section two discusses the existing literature on co-creation, DFMA work, and the Boothroyd and Dewhurst methodology. Section three details the BD methodology used with undergraduate students' projects. Section four presents the five case study projects and results. Section five discusses the results, and the last section concludes the article by highlighting key contributions to creative frameworks for engineering teams.

2. LITERATURE REVIEW

2.1. Cocreation

Taking the literal meaning of co-creation from De Koning (2016), "Together (co-) make or produce something (new) to exist (creation)" (p. 267). This approach has always been heralded for providing a horizontal platform for many to be heard and room for diversity (De Koning, 2016; Wierdsma, 2004). Various definitions of co-creation exist, and it is frequently interchanged with co-design and open innovation. However, there is no doubt that it proves to be a valuable approach for generating ideas by leveraging shared knowledge, tools, and experiences.

Co-creation can be a powerful tool in manufacturing because it involves collaboration and partnership between different people (Leng & Zhao, 2023). Prahalad and Ramaswamy (2004) introduced the concept of the "co-creation experience" and discussed how companies can leverage the insights and resources of their customers to create innovative products and services.

Similarly, Chesbrough (2003) explores how companies can leverage external resources and collaborate to foster innovation and create value. Ramaswamy and Gouillart (2010) provide a comprehensive framework for co-creation. They argue that organisations should shift from a "firm-centric" approach to a "customer-centric" approach by collaborating with customers, employees, and partners to generate value. These authors have contributed significantly to the understanding and practice of co-creation.

Gorchels (2000), in her book "The Product Manager's Handbook," elaborates on the benefits of co-creation in the context of product development. She discusses how involving customers, suppliers, and other stakeholders in the process can result in superior products, reduced time to market, and increased market acceptance. The above book communicates that co-creation creates more innovative and effective products, streamlines production processes, and improves customer satisfaction. Furthermore, involving customers and other stakeholders in the design process improves product design and helps manufacturers gain insights into what features and characteristics are most important to their target audience. This can also help them to create products that better meet customer needs and preferences.

Figure 1 shows highly cited journals and article papers on the value of co-creation in manufacturing. Most authors concur with Matthyssens & Vandenbempt (2017) that successful value co-creation requires managing dialectical tensions in manufacturing. This view is also emphasised in Nthubu (2021) thesis on enhancing the understanding of manufacturing innovation ecosystems. Dialectical tensions arise from the coexistence of contradictory or contrasting elements, ideas, or goals, creating a dynamic interplay between these opposing forces. Dialectical tensions are often present in various domains, including relationships, organisations, and decision-making processes. By working together, stakeholders can identify areas for improvement and implement solutions to streamline manufacturing processes (Parida, Wincent, & Kohtamäki, 2017).

Another benefit of co-creation is that it increases customer satisfaction, as highlighted in Frigon et al. (2018), with over 300 citations. When customers are involved in the design process, they feel more connected to the product and are more likely to be satisfied with the result (Frigon, Pervan, & Oliveira, 2018), which can lead to higher customer loyalty and repeat business. Co-creation can foster innovation by bringing different perspectives and ideas, leading to more innovative and creative solutions (Fujimoto & Asakawa, 2018; Nthubu et al., 2022). This can help manufacturers stay ahead of the competition and offer truly unique and valuable products.

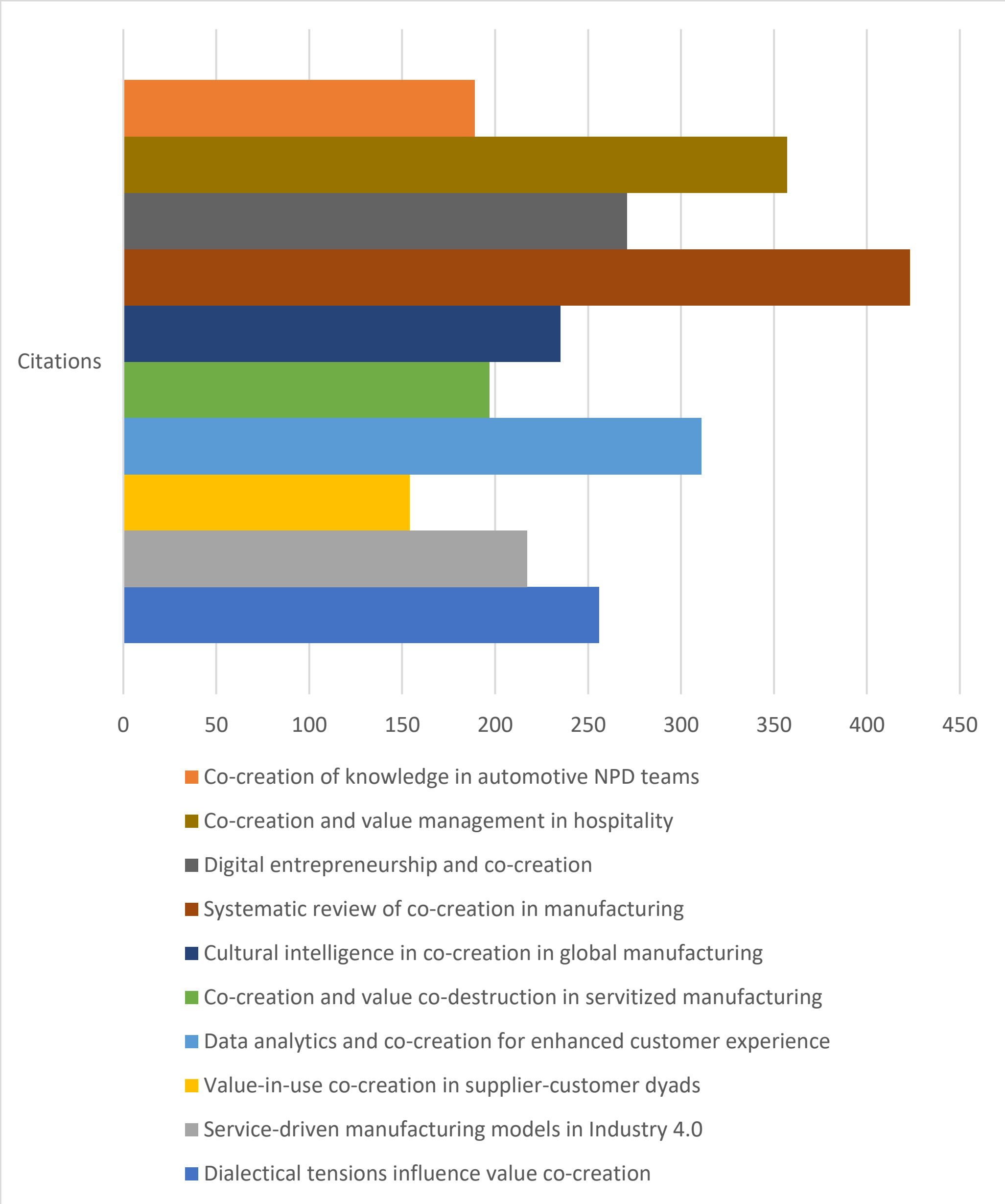


Figure 1. High-impact journals and articles on co-creation in the context of manufacturing.

Co-creation can be a valuable tool for manufacturers looking to improve their products and processes. Manufacturers can create more innovative, efficient, and customer-focused solutions by working with stakeholders. To achieve this, co-creation processes in manufacturing projects require efficient management of dialectic tensions, as discussed above.

2.2. Design for manufacturing.

Design for Manufacturing (DFM) aims to create products that are easily and efficiently manufactured, emphasizing cost-effectiveness and adherence to quality standards (Boothroyd, Dewhurst, & Knight, 1994). The production of goods encompasses design, prototyping, testing, and quality control, presenting a complex interplay of stakeholders, suppliers, and regulations (Efthymiou et al., 2016; Brissaud et al., 2011). This approach integrates considerations of manufacturing processes, materials, and machinery early in the design phase to minimize waste, defects, and cost overruns (Annamalai et al., 2012); Ferrer et al., 2010. Zhou et al., 2019). DFM highlights the importance of simplicity in design to streamline the manufacturing process, potentially reducing defects and delays (Vliet & van Luttervelt, 2004). Additionally, it prioritizes Design for Assembly (DFA), advocating for designs that facilitate easy assembly, possibly through fewer components and standardized parts (Dean & Salstrom, 1990).

Material selection within DFM focuses on using materials that balance cost, availability, and performance (Shete & Tjprc, 2019). Selecting suitable manufacturing processes is also crucial, choosing those that align with the product's specifications and cost targets (White, Athay, & Trybula, 1995). Lastly, Design for Test (DFT) principles ensure products are designed for efficient testing, incorporating easily accessible parts for inspection or built-in testing mechanisms (Youssef, 1994). By adhering to these DFM principles, manufacturers can achieve efficient production, cost savings, and high-quality outcomes, meeting both customer expectations and regulatory standards (Antony & Arunkumar, 2020).

2.3. Boothroyd and Dewhurst Method

In this study, we introduced the Boothroyd and Dewhurst method to engineering students studying a module called Design for Manufacturing and Assembly. This method can be used to evaluate and redesign existing products. We opted for this quantitative method because it can provide a collaborative structure for different students to engage in a creative process. We value concurrent engineering as promoting 'communities of practice within an engineering space.

Communities of practice is an idea premised on acquiring new knowledge through collective activities or informal groupings rather than individual activity (Wenger and Snyder 2000). According to Denscombe (2008), the notion of 'communities of practice' transcends departmental boundaries, organisations, and management hierarchies, thus allowing collaborations across people from varying backgrounds.

While the BD method promotes new ideas through assembly and manufacturing cost reduction, there is limited research on this process as a creative method and qualitative platform for different people to share ideas. We demonstrate through multiple students' projects that the BD method can also be used as a qualitative platform to afford various voices in the design process. Thus, the BD method can be expanded into a mixed-method approach instead of just a quantitative measure of the design index.

Stone et al. (2004) used a two-phase procedure to implement the BD method, which mainly focuses on part reduction and assembly time. During the first phase, each part of a product is evaluated to determine if it's necessary or whether it can be eliminated or combined with other existing parts. During this phase, we argue that concurrent groups must be encouraged to discuss and agree on what part is essential. Different people will not always have the same view on each part; however, they must reach a consensus and decide whether to eliminate or combine parts.

The second phase calculates each original part's handling and insertion times during assembly. This quantitative measure compares the assembly time of the original and new design parts. The assembly index/design efficiency is a percentage measure of how easy it is to assemble parts into a product, which is given by ***Equation 1*** below (Boothroyd et al. 2010).

$$DFA_{index} = t_{m,min} \times \frac{NM}{TM} \times 100\% \rightarrow (1)$$

DFA_{index} is also known as design efficiency. This value is suggested to be <60% as a thumb rule. $t_{m,min}$ is the primary assembly time, i.e., the handling and insertion time of the part having the maximum value. It is usually taken as 3 second NM is the total of theoretical minimum part count TM is the total operation time for the assembly in seconds.

However, further, than determining a quantitative percentage measure of design, there is a need to emphasise a qualitative measure of openness amongst group members to discuss and agree on the new part features that can promote ease of handling and insertion. This openness and collaboration can encourage the creativity of product parts.

Consequently, using the two phases can help determine design efficiency and creativity by comparing the old and newly redesigned products. Below are essential steps in the BD design for assembly analysis methods (Boothroyd et al. 2010):

Step 1: Obtain information about the product or assembly from drawings, prototypes, or an existing product.
Step 2: Take the product or assembly apart and assign an identification number to each item as it is removed. Consider sub-assemblies as parts and analyze them separately (recursively)
Step 3: Begin to reassemble the product, beginning with the highest identification number, and add the remaining parts one by one.
Complete one row of the DFA worksheet for each part
Step 4: Complete the DFA worksheet, computing total manual assembly time, cost, and DFA index.
Step 5: Iterate to improve the form design.

3. CASE STUDY

To evaluate the BD method as a creative tool, this research focuses on five project case studies with undergraduate engineering students. These projects are part of the Design for Manufacture (INME 412) module. This is a four (04) credit module offered to industrial and manufacturing engineering students under the Department of Mechanical, Energy and Industrial Engineering. We use the four-stage BD evaluation framework on a five-point Likert scale to observe the student creative process, as shown in ***Table 1*** below. First, we observe and measure the effective BD use; second, we observe and measure the effective BD management; third, we observe and measure the effective BD review; and finally, we observe and measure effective BD evaluation.

3.1. Project case study

At the beginning of semester one (01), 33 students were divided into five groups and asked to select existing products in the metal workshop, including sample projects from the previous students. Below are five projects that form our multi-projects case study.

Figure 2. Projects case studies (existing projects)

The first group selected the Punch and Shear (PS) machine, as shown in Figure 2, used for punching small metal pieces and cutting thin sheet metals in the metal workshop. The second group selected the Tree uprooter (TU) developed by the senior technician based at the metal workshop. This uprooter is used to uproot small trees on the farm. The third group selected one of the Corn Sheller (CS) manufactured by first-year students during their workshop practice module. The fourth group selected the sanitiser stand (ST) developed by previous students during the covid 19 pandemic. The last group selected the table-mounted metal twister (MT) shown in *Figure 2*. All groups were introduced to the Boothroyd and Dewhurst method and how it can help them develop new ideas by analysing and redesigning the old.

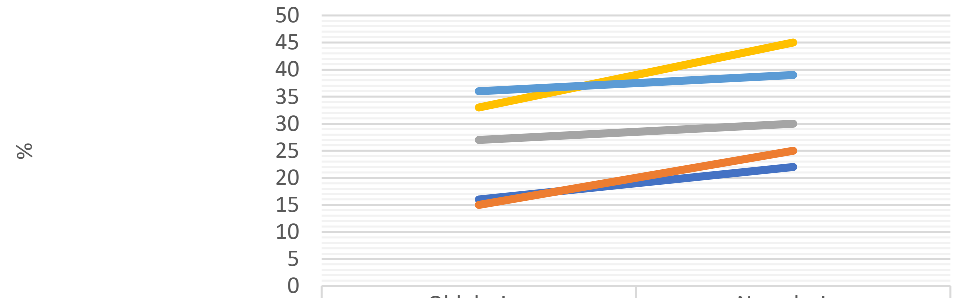
The groups followed all the BD steps described above to analyse, redesign, and manufacture new products. *Table 1* shows the BD evaluation framework used during the analysis, design, and manufacturing process. The first author used this framework to evaluate how students used the BD method, second, how students effectively managed the creative process, and third, how they reviewed the creative process and assessed their design. Their actions were judged based on the 5-point Likert scale to get the quantitative values to measure the intensity of engagement.

Table 1. BD evaluation framework.

Observations Points	**Likert scale** (1-5), 1 being low engagement and 5 being highest engagement on creative activities
Effective BD use	
• Asking questions and noticing connections	PS, ST, TU, CS, MT
• Exploring, combining, and refining ideas and views	PS, ST, TU, CS, MT
• Interrogate shape, form, and function	PS, ST, TU, CS, MT
• Use imagination and see a range of possible outcomes	PS, ST, TU, CS, MT
• Respond positively to challenges	PS, ST, TU, CS, MT
Effective BD management	
• Taking responsibility for the creative process	PS, ST, TU, CS, MT
• Developing initial ideas well and following through on those with the most potential	PS, ST, TU, CS, MT
• Solving design and manufacturing challenges	PS, ST, TU, CS, MT
Effective BD review	
• Checking ideas against brief	PS, ST, TU, CS, MT
• Responding positively to mistakes	PS, ST, TU, CS, MT
• Demonstrate the appropriateness of their solution	PS, ST, TU, CS, MT
Effective BD evaluation	
• Tracking progress against set criteria	PS, ST, TU, CS, MT
• Evaluate the impact of BD as a creative process	PS, ST, TU, CS, MT
• How BD can be transferable to other courses	PS, ST, TU, CS, MT

4. RESULTS

From the project case studies, we found that using the Boothroyd and Dewhurst method can enhance the following capabilities: i) effective use of the tool to support the creative process, ii) effective management of the creative process, iii) effective review of the creative process and iv) practical evaluation of the creative process. These factors are elaborated using the calculated DFA index of old and new designs across five groups, as shown in Figure 3, the BD comparison across five groups of students, as shown in Figure 4, and the latest designs developed by students, as shown in Figure 5.



	Old design	New design
Punch & shear	16	22
Tree uprooter	15	25
Metal twister	27	30
Hand sanitizer machine	33	45
Corn sheller	36	39

DFA INDEX

Figure 3. DFA index of old and new designs across five groups.

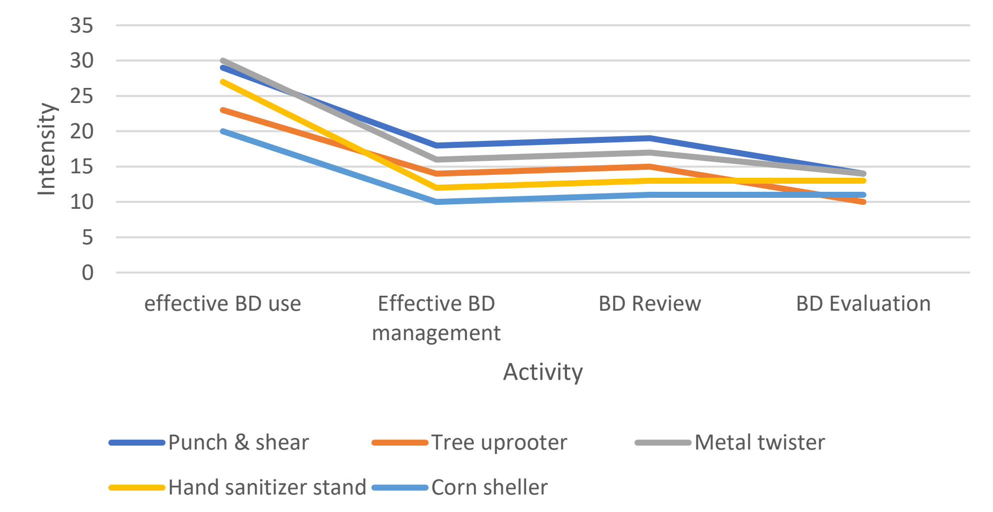


Figure 4. BD evaluation across five groups.

4.1. Effective Use

Based on the results in Figures 2, 3 and 4, all five groups of students used the BD method to complete their creative tasks, leading to new designs with varying levels of effectiveness. Results from observations show that although all groups used the BD process to enhance creativity, as indicated in Figure 3, the Punch and Shear group and Metal Twister had a high intensity of engagement with BD tools. These two groups were able to ask too many questions and noticed meaningful connections between BD activities and the need to iterate and improve parts. We noticed that the Metal Twister group had more engagements with the instructors and technicians than other groups as shown in Figure 3, thus resulting in significant variations between the old and new designs.

Because the BD method helps students to interrogate each part in terms of shape, form, and functionality, they could ask more questions during the DFMA process and went on to seek new solutions to answer these questions. Students engaged in round table discussions on which parts to remove, combine or eliminate to reduce part count and which parts they can alter form or shape to improve functionality and manufacturability. As shown in Figure 4 below, most groups significantly changed the form and shape of the old products into something completely different with a reduced number of parts and fewer fasteners.

We noticed that by using existing products and pulling them apart, students could interrogate shapes, forms, and functions of each part in groups, thus being prompted to debate, explore, combine, and refine multiple ideas. As shown in Figure 2, all groups could significantly increase their DFA index between the old and the new design, with the Hand Sanitiser group showing the most reduced part count and extensive DFA index.

The BD method also promoted the iterative design and manufacturing process, where students solved manufacturing challenges by going back and forth to the design and altering it to suit available manufacturing tools in the machine shop.

4.2. Effective Management

Most groups were generally active in managing the BD process by effectively allocating roles amongst all group members. Nevertheless, we observed that some groups, e.g., the Corn sheller and Sanitiser stand, had members who were not adequately involved in most design and manufacturing roles. On the other hand, the Punch and Shear and Metal Twister were better at engaging all members and had active leaders during the design and manufacturing sessions. We noticed that the

Punch and Shear group had the most difficult challenge of bending a 5 mm metal plate, and it took them almost a week to get it done. However, every group member was always present and interested in solving the challenge at hand.

4.3. Effective Review

Regarding the BD review, most groups were more engaged compared to the management of the BD activity, as shown in Figure 3. We also noticed that the Metal Twister and Punch and Shear groups were more engaged in reviewing the design and manufacturing processes than other groups. This could have been because they were redesigning complex machines from industry compared to other groups using machines developed by previous students. During the final presentations, the Metal Twister and the Punch and Shear groups acknowledged that the BD process was helpful in helping them to become creative as a group. We also observed that most groups responded positively to mistakes without giving up; that is, during the manufacturing of products, they constantly met to discuss how they could correct their errors and frequently consulted their drawings and lecturers for guidance. As shown in Figure 3, the Corn sheller group was the least engaged in reviewing the BD process and in consultations as a group, through drawings and with Instructors.

4.4. Effective Evaluation

Compared to other activities, all groups did not fully evaluate the BD process during and at the end of the design and manufacturing process. Students were supposed to track progress by having weekly meetings to evaluate their progress against the BD process. However, most group members did not turn up for the evaluation sessions. However, students only met when they encountered challenges during manufacturing to find a working solution. During the presentation of their work, students acknowledged that the BD tools effectively promoted creativity among them. We also observed that students were excited about the BD method and wanted to continue using it in other areas of their engineering courses, which required a creative process.

Figure 5. New designs (developed by student groups).

5. DISCUSSIONS

This article emphasises the significant role of the Boothroyd and Dewhurst design for manufacturing and assembly methods within a concurrent engineering collaborative framework. The findings from this study illustrate that the Boothroyd and Dewhurst (BD) method significantly fosters the creative process across different student groups. By leveraging the BD tools, students embarked on a journey of effective questioning, recognizing vital connections that were particularly pronounced in the Punch and Shear and Metal Twister groups, where a high level of engagement was observed (Coma, Mascle, & Balazinski, 2004). These interactions, especially notable in the

Metal Twister group's frequent dialogue with instructors and technicians, led to notable variations between old and new designs, showcasing the method's potency in facilitating significant design alterations (Matuszek & Seneta, 2019).

The methodology's focus on part interrogation encouraged students to delve deeper during the Design for Manufacturability and Assembly (DFMA) process, resulting in marked changes in the form and shape of products, thereby reducing part count and fasteners (Abdul Shukor, Abdul Shukor, Adam, 2019). While most groups effectively navigated the BD process, variations in roles and engagement levels were apparent. For instance, the Punch and Shear group displayed commendable leadership and collective problem-solving, contrasting with the Corn Sheller and Sanitizer Stand groups, which showed diminished involvement from some members.

The varying degrees of effectiveness in the BD review process among groups, with the Metal Twister and Punch and Shear groups demonstrating higher engagement, suggest that the complexity inherent in redesigning industrial machines likely spurred deeper involvement in reviewing design and manufacturing processes (Mascle, 2003). Groups' positive responses to mistakes, characterized by a resilient approach and frequent consultations for guidance, underscore the BD process's utility. However, the Corn Sheller group's lower engagement in the review phase signals opportunities for enhancing the review process (Owensby et al., 2011).

Notably, despite the BD method's overall success, there was a lack of full engagement from student groups in evaluating the process during the design and manufacturing phases. Weekly evaluation meetings intended to monitor progress experienced low attendance, although students rallied when confronted with challenges, indicating a problem-centric evaluation approach (Matuszek, Seneta, Plinta, & Więcek, 2020). The acknowledgment of the BD tools' effectiveness by students points to areas for refining the evaluation process, highlighting the method's potential in enriching creative engineering courses (Chang & Peterson, 2010).

In essence, this study accentuates the BD method's efficacy in augmenting the creative process, stressing the importance of active management, thorough review, and enhanced evaluation strategies to amplify its benefits across varied student groups (Mašín, 2014).

6. CONCLUSIONS

This study delineates the theoretical contributions of the Boothroyd and Dewhurst (BD) methodology, highlighting its pivotal role in promoting creativity and innovation among student groups engaged in engineering projects. Through the application of the BD method, students were able to leverage tools that substantially bolstered the creative process, facilitated by adept management, thorough reviews, and effective evaluations.

The proficiency demonstrated by students in all groups in harnessing the BD method led to the generation of innovative designs, showcasing varied levels of success. Yet, a gap was observed in the students' engagement with the method's evaluative components during the design and manufacturing stages. The positive reception of the BD tools by students signals an avenue for enhancing the evaluation process, further augmenting the method's relevance for subsequent creative engineering coursework.

The findings underscore the BD method's utility in augmenting the creative engineering process, underscoring the necessity of active management, exhaustive reviews, and nuanced evaluation strategies across varied student cohorts. These capabilities—encompassing effective tool utilization, adept management, and rigorous evaluation—offer crucial theoretical insights for pedagogical strategies, stressing the imperative to integrate these components to amplify the BD method's impact on fostering a culture of creativity and innovation.

Future prospects for the BD method are promising, as evidenced by the students' eagerness to apply this approach to other creative engineering projects. This study's outcomes present a compelling case for educators, advocating for the integration of active management, detailed reviews, and meticulous evaluation strategies. Such measures are essential to harness the full potential of the BD method in nurturing an environment conducive to creativity and innovation.

DATA AVAILABILITY STATEMENT

The data will be made available upon request.

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DECLARATION OF INTEREST

The authors declare that they have no known competing interests that could have appeared to influence the work reported in this paper.

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COMPARISON OF INTERNATIONAL PROTOTYPES FOR HUMANITY AND THOSE OF THE DEPARTMENT OF INDUSTRIAL DESIGN AND TECHNOLOGY

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Abstract: Worldwide dependence on properly designed products calls for design engineers who are highly capable and able to develop competitive products. It is through competitive products that an entity will be able to wither competition and remain competitive. Prototypes serve as critical tools in determining if the proposed solution addresses the task at hand to avoid committing resources to an ill-conceived solution. This paper explores the comparative dynamics between international prototypes designed for humanitarian purposes and those developed within the Department of Industrial Design and Technology (IDT) at the University of Botswana. The study examines the divergent design philosophies, target audiences, and resource allocations that shape these two categories of prototypes. Through case studies, the paper highlights how international prototypes often prioritise broad, scalable solutions for global challenges, while IDT projects tend to focus on practical, user-centric innovations tailored to specific communities. The analysis reveals critical insights into the role of innovation, sustainability, and collaboration in driving the effectiveness of these prototypes, underscoring the importance of teamwork in achieving societal impact. This also helps to determine the status of University of Botswana's (UB) performance by comparing the output of UB's design engineering student's vis-a-vis their international counterparts. The comparisons also yield valuable lessons for future design and technology projects, advocating for enhanced collaboration between international humanitarian efforts and institutional design initiatives to maximise societal impact.

Keywords: Design engineer, product design, industrialisation, prototype, export

1. INTRODUCTION

The quality of the human resource drives worldwide economic development. Despite globalisation's enhanced mobility of people through migration, each country needs to have its home-grown pool of talent. This also helps with having role models for future generations. Whilst all professions are required for survival on planet Earth, engineering certainly is amongst those fields that rank highly in terms of importance. Failure to develop a country's engineering talent will result in limited opportunities to partake in international trade (Mishra, 2007; Kardanova et al., 2016; Liu, Yin & Wu, 2020). This is also because the products and systems that we rely on for daily living have been engineered and need engineers to maintain and/or keep them operational.

Fit-for-purpose engineering education is required to transform people from ordinary persons to being sophisticated beings. This transformation comes about from planned intervention as outlined in respective up to date curricula. These curricula also require adequately trained personnel to properly impart the next generation for the continuity of the speciality. Effective classroom instruction is also dependent on the available resources to ensure that content is delivered correctly and that students are also accorded opportunities to comprehend material fully. Instructional materials such as computers, network connections and so forth enable teaching and learning to be carried out smoothly. Also, there is a need for learners to be taken on educational tours to expose them to real-life situations that will further enhance their learning, and all these require resources. It shouldn't be forgotten that higher education is the source or feeder to all walks of life (Mishra, 2007)

"In order to give effective and high-quality educational programs to students, quality assurance in higher education is essential" (Kayyali, 2023:p1;).This calls for various measures that can augment external and internal quality assurance measures that are currently being used. This paper seeks to gauge the competence of local engineering designers by comparing their outputs with those of their international counterparts. This should also help determine whether their programme responds to local and global engineering designers' needs. Due to internationalisation, there is to develop global citizenship for all students (Liu, Yin & Wu, 2020). The paper also discusses the value of new product development linking it to the prototypes for Humanity and comparing them with those of the University of Botswana. Areas requiring improvement are also outlined. The paper also outlines the research methodology and discusses the study findings and conclusion.

1.1. Significance

A study of this nature is more important in today's highly competitive era that has no room for failure as failure can result in costly litigation and bad reputation. This study is also necessary for quality assurance and improvement. It is also necessary for customer / stakeholder confidence as well as serving as a springboard to garner more support from authorities.

2. ENGINEERING EDUCATION

The 21st century requires instructional methods that differ significantly from traditional methods due to technological developments. The education landscape has been undergoing various transformations in a bid to stay current. The most notable transformation was the shift into the STEM approach, which then morphed into STEAM and then STREAM (Nguyen, Siapalan & Hiep, 2021). "The use of the STEM acronym as an umbrella term to refer to Science, Technology, Engineering, and Mathematics can be traced to the National Science Foundation (NSF) in the United States in the 1990s" (Mejias et al., 2021; p212).

Historically, STEM implementation was profound in the business world, ushering in the Industrial Revolution, which saw Thomas Edison and several inventors evolve STEM education outside the classroom (Badmus & Omosewo, 2020; p. 100). Allina (2017) posits that the STEAM approach was proposed at the American Arts National Policy. The inclusion of the Arts was a game changer, as the conscious use of skill and creative imagination, especially in the production of creatively innovative and pleasing products, became the new order in human problem-solving evolution (Badmus & Omosewo, 2020; Mejias et al., 2020).

In the 2007 Roundtable, Debroy (2017) observed that, in response to the 21st-century demands on education, a STREAM-based curriculum was proposed. "STEM (science, technology, engineering, and mathematics) is an educational approach that is now accompanied by the STEAM (STEM + Arts) variant" (Aguira & Ortiz-Revilla, 2021; p1). STEM, STEAM, and STREAM (Figure 1) are all approaches aimed at preparing young minds to function productively in the ever-developing world by imparting appropriate skills (Badmus & Omosewo, 2020; Mejias et al., 2020).

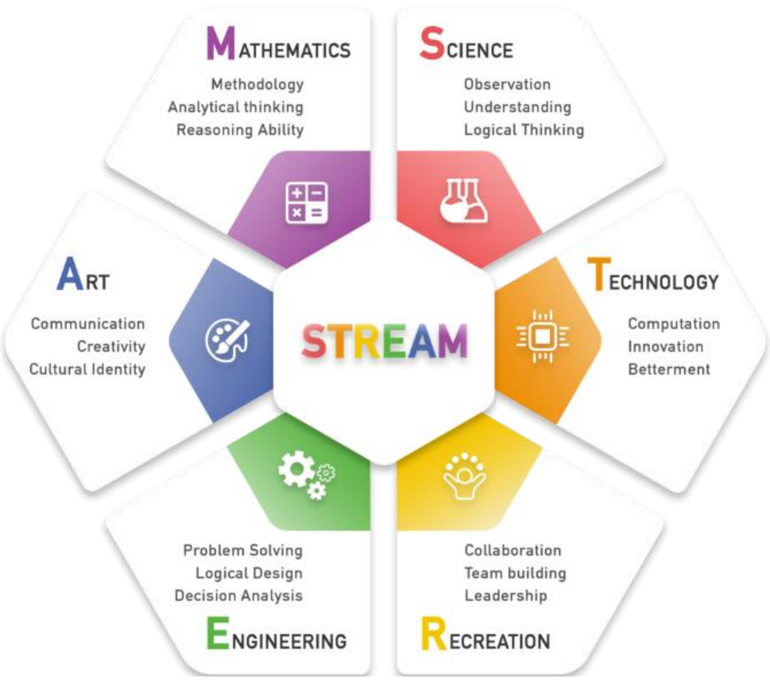

Figure 1. STREAM model (STREAM Education, 2024).

STREAM education may be viewed as a unique approach to instruction that combines the approaches of science, technology, robotics, engineering, arts, and mathematics to create a classroom experience (Badmus & Omosewo, 2020, p. 102). They further acknowledge that robotics is viewed as a subset of engineering. They also state that STREAM students are expected to invent, create, design, and solve problems, which is equal to what engineering students are expected to do. To be at par with the Fourth Industrial Revolution we are currently experiencing; this era requires the use and/or application of Education 4.0 teaching and learning methodologies. These methods use virtual platforms that make information ubiquitous and enable learners to learn remotely, at their own pace, anywhere, provided the internet connection is available.

With globalisation, an appropriate and competitive curriculum is necessary to ensure that the learners produced in one part of the world can utilise their knowledge in other parts of the world. Failure to move with time will result in a forever backward nation or a nation that is taken advantage of by other nations. Over and above, Carew and Cooper (2014) contend that periodic review and enhancement of curricula in engineering is vital to maintaining the quality and currency of undergraduate degree programmes. This will result in the nation being taken advantage of and losing out economically. It is upon national governments to set up national qualification accreditation authorities that will maintain the standards of the education of countries. This is to ensure that its citizens are protected from unscrupulous individuals who might come with a substandard education and pass it for the real thing. Carew and Cooper (2014) further note the need for engineering curricula to remain up to date with emerging social and political pressures as those increasingly influence the daily work of engineers.

Engineering design as a field of study is concerned with solving everyday challenges with the development of new products. The success of such produced products depends on their innovativeness to be successful. The need for design education is premised on the country's quest for industrialisation. It is thought that with engineering design graduates, the country can develop industries that can produce products for export, thus helping with job creation and poverty alleviation. Assessing learner competence has been a challenging task as this has been mainly theoretical. Students are known to pass exams through memorisation and 'mindless storage of facts' rather than through the 'development of rational and logical thought' (Woollacott & Snell, 2012). Prior studies have used employer feedback to analyse engineering education, while others have used inputs, processes, and outputs of engineering programmes (Kardanova et al., 2016). Kardanova et al. (2016) describe the lack of valid instruments that allow for the assessment and comparison of engineering students' skills. This contention might not be true due to higher education institutions and their national accrediting bodies' propensity to collaborate and even seek international accreditation.

"…assessing gains in student skills across a wide and representative range of engineering programmes is an important first step in helping policymakers improve the state of engineering education" (Kardanova et al., 2016; p771). This makes the use of prototypes an ideal way of assessing the true capability of students, hence the state of an awarding institution's performance. Figure 2 shows some of the ways of assuring quality in institutions of higher education.

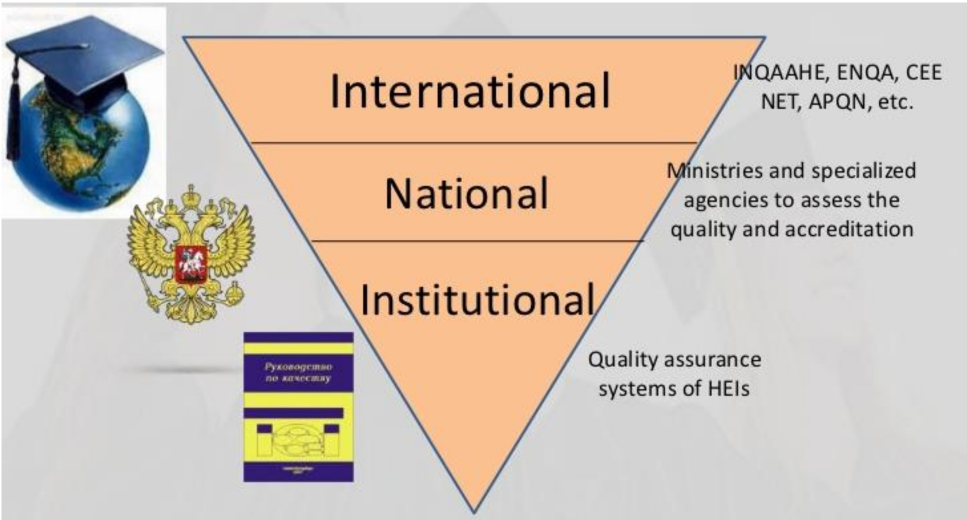

Figure 2. 3 levels of quality assurance in higher education (Rezvaya, 2011).

3. NEW PRODUCT INNOVATION

In the field of new product innovation, prototypes are developed as the first fully functional proof of concept. They are produced to showcase what the envisaged product will look like and function (Beaudouin-Lafon & Mackay, 2007; Lauff et al., 2018). They are usually used to seek final approval prior to mass production and can also be given to lead users for final approval. "They encourage communication, helping designers, engineers, managers, software developers, customers and users to discuss options and interact with each other" (Beaudouin-Lafon & Mackay, 2007;p02). Without the feedback, the manufacturing industries would be incurring heavy losses from products that are not fit for purpose. The quality of prototypes in educational institutions is determined by the resources and approaches to education adopted by the educational institution.

3.1. Prototypes for Humanity

Kumar (2023) posits that Prototypes for Humanity is a pool of academic talent and innovations with a vision to change the world. Projects that address environmental and societal challenges are submitted by academia and the private and public sectors. Submission areas covered Nature, Food and Water systems; Health, Relief and Safety;

Energy, Efficiency and Waste; Education, Equality and Communities; and Data Science and AI-enabled Solutions (Kumar, 2023). Projects are evaluated based on the positive impact on people, communities, or the planet, the rigour of academic research, and the application of technology *(Bournemouth University, 2024; Prototypes for Humanity, 2024).*

3.2. University of Botswana prototypes

The reviewed prototypes from the University of Botswana are outputs from the two parallel degree programmes of Bachelor of Design (Industrial Design) and Bachelor of Design (Design and Technology Education). According to the Departmental handbook (2017), the programmes prepare globally competitive industrial designers and teachers for the world of work. Khumomotse (2001) also contends that the programmes must have local relevance while not losing touch with the global realities. At the end of the study period, students' final year projects are exhibited for the public to appreciate them. This public display helps show case students' capabilities to the stakeholders, paving the way for possible collaborations in scaling up the prototypes. In keeping up with global trends, the Department of Industrial Design and Technology also focuses its degree projects on the 17 Sustainable Development Goals (SDGs) that are of direct relevance to the field of industrial design.

4. METHODOLOGY

The study adopts a qualitative approach using case study, document analysis, and observations. The case study components focused on case studies that were derived using a Delphi study. A random sample of 4 design experts were consulted to compare the prototypes for Humanity and those of the University of Botswana. The Delphi method was chosen for this study because it offers diverse analyses and insights into complex issues, promotes objective thinking, and enables efficient decision-making based on expert input. Unlike other comparative studies (Holvikivi, 2007; Woollacott & Snell, 2016; Kardanova et al., 2016), which sought to understand various cognitive behaviours of students in interacting with academic material, this study focussed on the final output as an indication of the learnt material. A sample of five projects from the University of Botswana and five from the International Prototypes for Humanity website were compared using an established evaluation matrix. The projects were assessed against their integration of science, technology, robotics, engineering, arts, mathematics, originality and the Internet of Things. Efforts were made to select projects that address a similar or related life challenge.

5. CASE STUDIES

Case 1: Salatloan Michael, Technical University of Cluj-Napoca.

The 3D-printed knee orthosis uses sensors and electrical impulses for correction (Figure 3). Utilising Integrated Inertial Measurement Unit (IMU) sensors, it capture joint movements, while Electromyography (EMG) sensors monitor muscle activations.

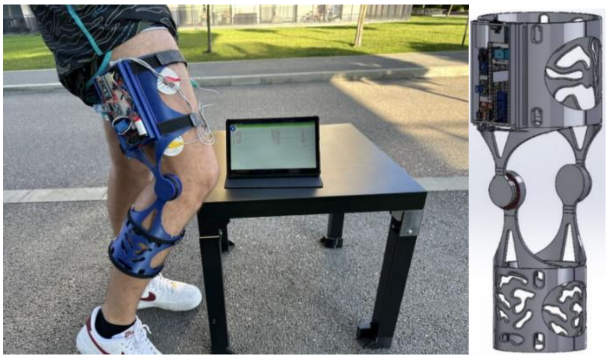

Figure 3. Knee orthosis (https://www.prototypesforhumanity.com/project/rehabilitation-smart-orthosis/)

Tlamelo, University of Botswana.

To address health-related problems associated with ageing, such as slight ankle arthritis, calf muscle strains, and knee joint soreness, which make it difficult for people to do housework. This was addressed with the design and making of a sole flex rehabilitation (Figure 4) that will help increase leg muscle strength and alleviate ankle joint muscle strains for the elderly.

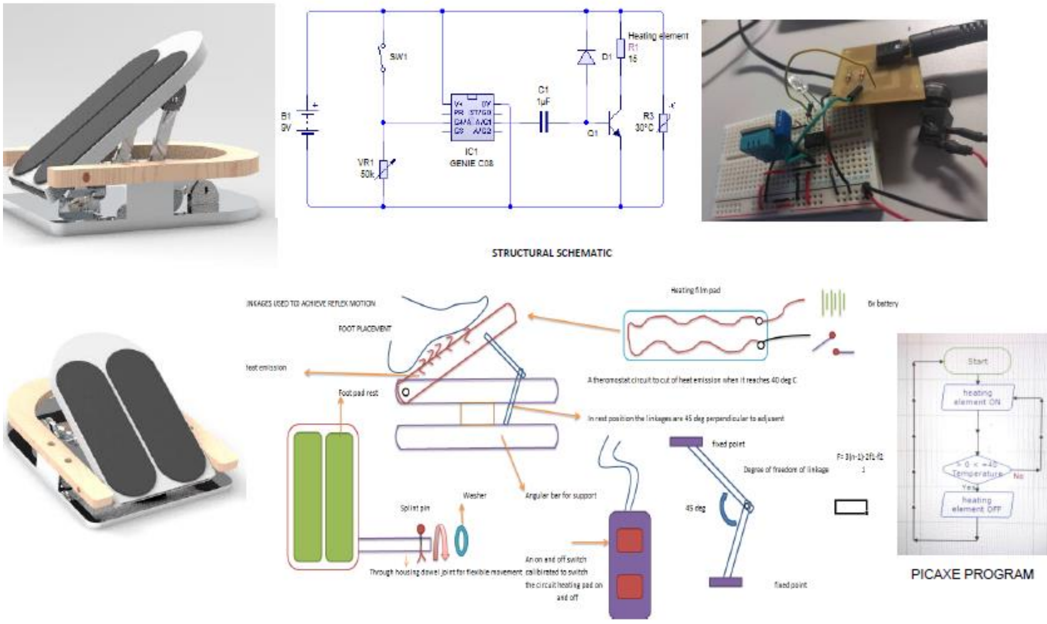

Figure 4. Sole flex rehab (student portfolio).

Case 2: Noemi Florea, Parsons-school-of-design.

The Cycleau is a compact greywater treatment system designed for retrofit under sinks in primarily low-income regions with ageing water infrastructure (Figure 5). This innovative solution addresses the growing concerns of public health risks and environmental impact by both treating tap water contaminants and recycling greywater to potable standards.

Figure 5. Cycleau (https://www.prototypesforhumanity.com/project/cycleau/)
Aone, University of Botswana.

Tackling the issue of wastewater that is poured into the drain after washing the dishes, which occurs about 2 to 3 times a day, resulting in water wastage. A grey water purifier that will filter the grey water from the dishes to be clean enough to be reused is a must. The water can be used for washing dishes, bathing, and cleaning the house, as needed (Figure 6).

Figure 6. Grey water purifier (Student portfolio).

Case 3: Arunangshu Jana, National institute of design Andhra Pradesh.

Boro Bandhu is a smart water monitoring device for rice cultivation, and combats over-irrigation, offering a real-time management solution (Figure 7). Designed to reduce rice farming water wastage. It is solar-powered and GSM mobile controlled. It also measures water height in fields and sends notifications to farmers.

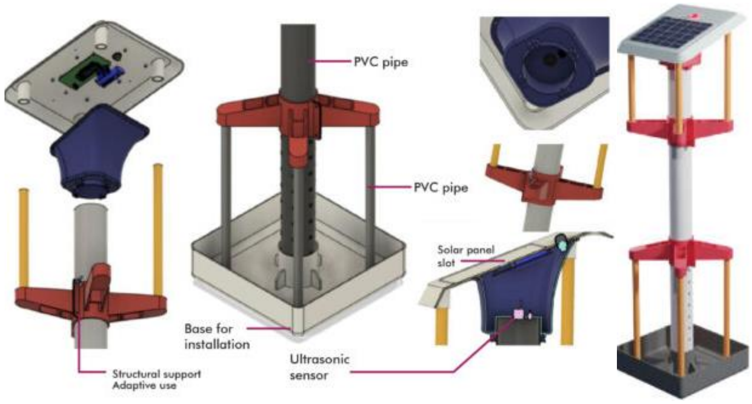

Figure 7. Boro Bandhu (https://www.prototypesforhumanity.com/project/boro-bandhu/) Luscentfo, University of Botswana.

Smart irrigation system

Developed to address water scarcity in Botswana which negatively impacts sectors like agriculture, manufacturing, etc. The product utilises GSM mobile connections as well as IOT connectivity. It collects data and sends to the user who can send command to water the field (Figure 8).

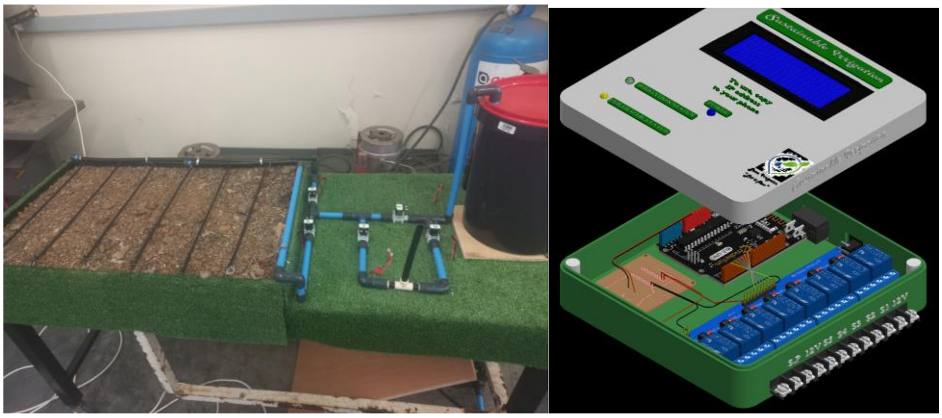

Figure 8. Smart irrigation system (student portfolio).

Case 4: Mathias Charles Yabe, Kwame Nkrumah University of Science and Technology

To tackle post-harvest losses a solar-powered cold storage solution was developed-harvest loss (Figure 9). Considerable amounts of food is wasted due to lack of adequate storage, causing economic losses for farmers. This solution is to extend the shelf life of perishable crops from 5 to 21 days by lessening water loss and slowing the ripening process while maintaining texture, flavour, and nutrients.

Figure 9. Solar cold storage
((https://www.prototypesforhumanity.com/project/akofresh/)
Mcebo, University of Botswana.

Fresh Vegetables Hawking portal (Figure 10) was developed to extend the shelf life of leafy vegetables sold by street hawkers in Botswana. The device is electronically powered by solar energy and uses evaporative cooling to keep vegetables fresh.

Figure 10. Solar vegetable hawking portal (student portfolio).

Case 5: Naoya Takei & Shotaro Fujil, Keio University Graduate School of Media Design

Agbee cart is a robotic farming assistant designed to aid farmers in the harvesting process (Figure 11). It performs three independent tasks: trailing the farmer to carry harvested crops; collecting data from the soil such as temperature, moisture, pH level, and fertiliser concentration; and offering analytical insight to predict soil fertility and harvest time.

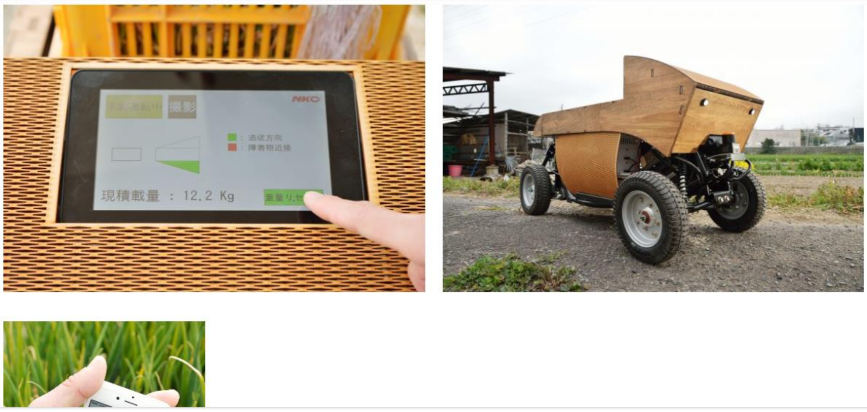

Figure 11. Self-driving cart (https://www.prototypesforhumanity.com/project/agbee/) Reginal, University of Botswana.

The project was developed in response to the challenges of manoeuvring around the shops for the elderly. The product caters for the client's desire for autonomy and self-sufficiency while shopping. The project is targeted at old age and people suffering from muscular and joint conditions. The PushAssist Pro (Figure 12) can move around independently from the cart. Once required, the cart is placed onto the attachment mechanism by lifting and dropping in the attachment slot.

Figure 12. Push assist pro (student portfolio).

6. RESULTS AND DISCUSSIONS

The findings from the study answered the research questions by outlining the conclusions from the prototypes of the two groups. The first group are prototypes for humanity entries, and the next group is University of Botswana degree prototypes. These were assessed based on how much of the STREAM aspects were encapsulated in the presented prototypes. The Delphi experts as field specialists also noted the need for the inclusion of originality / novelty and the Internet of Things (IoT) in the assessment.

The problem identification across all projects shows a similar approach amongst the two groups. There is a marked or enhanced ideation and prototyping by other universities as their application is on a higher level than that of the University of Botswana. This is evident when one looks at the higher-level application of science, especially chemistry and biology. This was also evident in the manipulation of plants and other physical matter to produce products. Table 1 and Figure 13 show the analysis of the prototypes as per their scores, as scored by the field experts basing on aspects of STREAM, as well as creativity / originality and Internet of Things.

Table 1. Computed average scores.

	PROTOTYPES FOR HUMANITY									UNIVERSITY OF BOTSWANA (IDT Dept)								
	SCIENCE	TECHNOL(	ROBOTICS	ENGINEER	ARTS	MATHS	ORIGINALI	IoT		SCIENCE	TECHNOL(	ROBOTICS	ENGINEER	ARTS	MATHS	ORIGINALI	IoT	
CASE 1	8	8	6	9	8.5	8	6	1	6.8	7	6	3	8	7.5	7.5	6.5	0	5.7
CASE 2	7	7	0	6	5	5	5.5	0	4.4	6.5	7	0	5.5	4.5	4.5	5	0	4.1
CASE 3	7	7	0	7	6	6	7	5	5.6	7	7	2.5	7	4.5	5.5	8	5.5	5.9
CASE 4	8	8	2	8	6	6	6	5	6.1	8	8	2.5	8	8	6	8	5	6.7
CASE 5	8	8	8	6	7	7	7	8	7.4	8	8	8	8	7	7	6.5	8	7.6
	7.6	7.6	3.2	7.2	6.5	6.4	6.3	3.8		7.3	7.2	3.2	7.3	6.3	6.1	6.8	3.7	

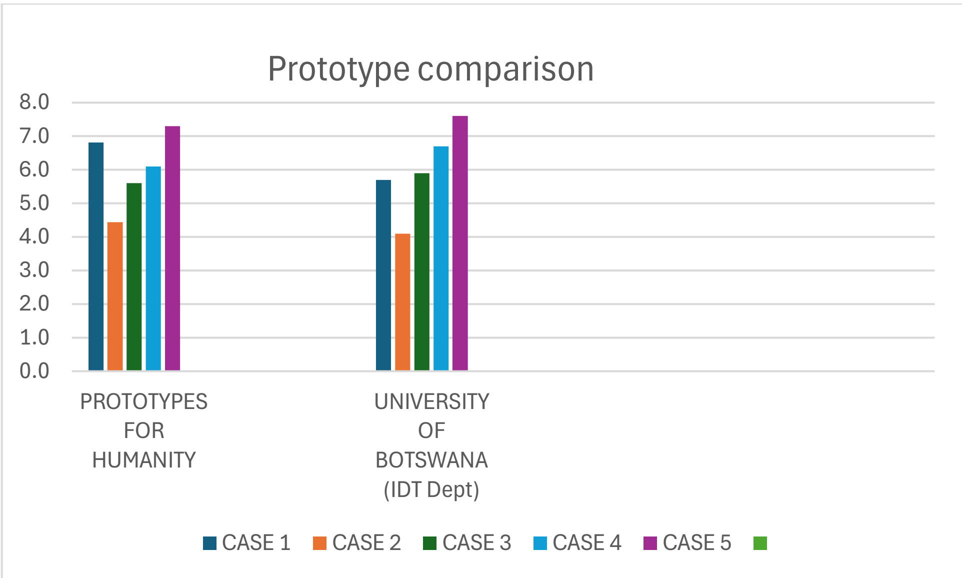

Figure 13. Prototype score comparison.

From the chosen products of this study's computation, the highest-scoring project comes from the University of Botswana, with a score of 76% which is Case Study 5. This is followed by a similar prototype from prototypes for humanity with a score of 74%. These projects are similar and employ related technologies. The lowest score comes from the University of Botswana, with a score of 41%. Its related counterpart from Prototypes for Humanity also scored below 50% by scoring 44%. On the individual aspects of STREAM, prototypes for humanity prototypes scored the highest points.

Science: The application of scientific principles ensures that a product utilises or takes advantage of naturally occurring scientific phenomena. An example of that at a basic level could be the expansion of matter when hot and contraction when cold. Prototypes for humanity were found to have more scientific principles applied. This also included the use of biological agents to provide solutions to problems.

Technology: The two groups of projects equally utilised technology in their realisation. Technological equipment and components were adopted satisfactorily. However, prototypes for humanity scored higher (76%). This could be attributed to most of them having been made in developed countries.

Robotics: The two groups have used machine coding. This is evident through the use of Arduino components and programming. However, the level of robotics observed was less than 50%, which shows a lower application rate.

Engineering: The two groups engineered their products very well. Design engineering software was used for the development and manufacturing of prototypes. It was also evident that automated equipment (CAD/CAM) was used in the realisation of these prototypes.

Arts: For a product to appeal to the customers, it must be aesthetically pleasing. Different aesthetical elements have been infused into the fabrication of these prototypes. With a score of about 63-65%, there is a lot of room for developing the aesthetics of the prototypes.

Mathematics: Developing products of this magnitude requires varying mathematical computations to ensure that the resultant product performs accurately and is safe to use. For example, the cold vegetable room requires a certain number of solar panels to power air conditioners.

Originality: Most innovations presented were incremental innovations. A few radical innovations can be found under the prototypes for humanity entries, whereby biological and chemical concepts have been utilised in the solutions.

Internet of Things (IoT): In both groups, very few of the prototypes do have Internet of Things capability.

7. CONCLUSIONS AND RECOMMENDATIONS

The University of Botswana's Industrial Design Engineering department's output shows that it is on the right trajectory path and should keep up the excellent work. There is a need to include other courses in chemistry and biology in the design engineering students' curriculum so that they can be able to consider such fields when exploring possible solutions for their identified problems. Also, there is a need for the adoption of artificial intelligence so that products produced can score higher on technology and robotics. The study also showed that UB design engineering graduates can be deployed anywhere in the world as their output is at par with that of their international counterparts.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

ACKNOWLEDGEMENT

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DECLARATION OF INTEREST

The authors declare that they are employees of University of Botswana which may be considered as potential competing interest.

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ENHANCING SUSTAINABLE TECHNOLOGY TRANSFER (T2) CENTRE OPERATIONS FOR QUALITY TRANSPORTATION ENGINEERING EDUCATION

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Abstract: Transportation engineering education enhanced through sustainable technology transfer (T2) centre operation and research collaboration are integral to our society, but there are persistent challenges to their sustainability. This necessitated an international innovative strategy of collaborations among academia, industry, and the transport sector. The solution has been enhanced through the establishment of transportation Technology Transfer (T2) centres that have emerged in many countries all over the world as sustainable agents and catalysts for improvements in disseminating experiences, technologies, best practices and innovations. There is a generally perceived link between the state of development of a country's transportation systems and the extent of technology usage and availability of technical information in that country. To keep pace with the new technologies, transportation engineering education needs information and knowledge that will enable it to advance its processes, incorporate new products into existing programmes, and increase technical know-how that produces positive change and economic development. This paper intends to discuss the innovative strategies adopted in operating transportation technology transfer centres globally. Strategies adopted to achieve the objective were establishing and maintaining a transportation database and website accessible by transportation engineering professionals; publishing and disseminating quarterly (T2) newsletters; hosting Africa (T2) conferences; and identifying training programs for the stakeholders. In conclusion, the paper highlighted the outcome of operating (T2) centre to enhance quality transportation engineering education through effective technology transfer operations for economic development.

Keywords: Sustainable transportation, Engineering education, Innovative technology transfer, International collaboration, Capacity building

1. INTRODUCTION

The Ministry of Transport and Communications through its Botswana Transportation Technology Transfer Centre (Botswana T2 Centre) in collaboration with the Association of Southern African National Roads Agencies (ASANRA), Transportation Technology Transfer (T2) Centres in SADC region and other local and international stakeholder institutions has been sustaining the Africa Transportation Technology

Transfer (T2) Centres' operation in southern African countries through hosting of bi-annual conference and training for quality transportation engineering education.

The main objectives:

i) To promote Technology Transfer for Developing Sustainable Transportation Systems in Africa,
ii) To promote establishment and operations of Technology Transfer Centres as means for facilitating appropriate effective technology transfer in the transport sector,
iii) To provide a forum for discussion and exchange of views as well as learn experiences of best practices and innovative solutions in the Transportation Industry.

To meet its objective the conference and training featured various presentations, panel discussions, workshops pertaining to the conference thematic-areas and topics. Moreover exhibition of technologies, products and services – a show case for all related industries were held in conjunction with the conference. Local and foreign firms and institutions which are stakeholders in the transport sector were able to exhibit their products, services and technologies.

The Africa Transportation Technology Transfer (T2) Conference which is being held after every two years since its inception in May 2001 when the 1st Africa T2 Conference was held at the Arusha International Conference Centre, Arusha, Tanzania is a forum intended to share, exchange and debate experiences, best practices, and new technologies in the provision, maintenance and management of all modes of transport. It is also a forum for sharing and exchange of existing and new approaches on technology transfer that enables countries to develop effective management of transport infrastructure, integrated transportation systems, which are safe, efficient, reliable and affordable. Since year 2001, ASANRA through its sixth Standing Committee on Regional Technology Transfer Centre in collaboration with Ministries and Agencies responsible for the transport sector in the member states of the Southern Africa Development Community (SADC) has been organizing Africa T2 Conferences. So far nine Africa T2 Conferences have been held. The Themes addressed by the past nine Africa Transportation Technology Transfer (T2) Conferences were as follows:

- 1st Africa T2 Conference held in Arusha Tanzania from 23rd – 25th May 2001 and hosted by Tanzania Transportation Technology Transfer Centre: "Technology Transfer in Road Transportation in Africa"
- 2nd Africa T2 Conference held in St. Pietermaritzburg, KwaZulu Natal, South Africa from 20th – 23rd September 2005 hosted by KwaZulu Natal Department of Transport: "Transportation Technology Transfer in Africa's Renaissance"

- 3rd Africa T2 Conference held in Mangochi, Malawi from 23rd – 25th May 2007 hosted by Ministry of Transport and Public Works in Malawi: "Technology Transfer for Africa's Sustainable Transportation System"
- 4th Africa T2 Conference held in Windhoek, Namibia from 31st August to 4th September 2009 hosted by Roads Authority of Namibia: "Capacity Building Opportunities in the Transport Sector"
- 5th Africa T2 Conference held in Arusha Tanzania from 21st - 25th November 2011 and hosted by Ministry of Work in Tanzania through TanT2 Centre: "Developing Safe, Reliable and Sustainable Transportation Systems for Socio-Economic Development in Africa"
- 6th Africa T2 Conference held in Gaborone Botswana from 4th – 8th March 2013 and hosted by University of Botswana through BwT2 Centre: "Effective Management of Transport Infrastructure for Economic Recovery in Africa"
- 7th Africa T2 Conference held in Bulawayo, Zimbabwe; the 8th Africa T2 Conference held in Livingstone, Zambia and the most recent 9th Africa T2 Conference was held in Maputo, Mozambique on

2. LITERATURE REVIEW

It becomes incumbent upon road engineers to gain from the technology transfer developments of colleagues rather than "re-inventing the wheel" or making the same mistakes that others have made. In other words, the extent and efficiency of a country's technology transfer system could reveal the extent of that country's development. The benefits of advancing innovative transportation technology exchange in pulling resources and commonly addressing the major issues of building resilient transportation infrastructure for socio-economic development. This will proffer solutions to challenges in the transport sector toward more sustainable development that meets the needs of the present without compromising the ability of future generations to meet their own needs (Biancardi et al 2023). There has been recognition that informal sharing of experiences may no longer be the best approach to improve road transportation as the travel demands of modern society have increased exponentially. Technology transfer in the transportation sector is aimed at using the benefits of someone else's successful research, development, or experience to benefit roads locally – often at a fraction of the original development cost (PIARC, 2000).

The primary objective is to systematically and actively facilitate acquisition and dissemination of technology, practice and policy knowledge and know-how that is relevant to a local operating transportation environment. Technology transfer was explained by PIARC (2000) as the process of openly gaining and freely sharing experiences, workable solutions, technologies, and innovations. It was also emphasized by Logie (2007) that technology transfer occurs in many ways and different forms. Technology transfer happens at its simplest form, when someone reads about a "new" technique in a report or a technical magazine from another place. Furthermore, technology transfer operations were described by Pinard (2007) as a process of developing appropriate technology transfer mechanisms and activities (newsletters and fact sheets; technical reports; news releases; journal and magazine articles; electronic bulletin boards); conveying well quantified success stories highlighting benefits over competing alternatives; carrying out well designed field tests, demonstration and pilot projects; producing well illustrated guidelines, reports and manuals in reader-friendly format; holding interactive conferences, workshops and seminars tailored to the differing requirements of segmented audiences at various stages of the technology transfer process.

3. METHODOLOGY

The 6th Africa Transportation Technology Transfer (T2) Conference was a major event that took place in the Tourist City of Gaborone, Botswana. The conference was officially opened by the then Minister of Transport and Communications Honourable Nonofo Molefhi, and closed by the then Permanent Secretary for Ministry of Transport and Communications, Ms. Tsaone R. Thebe. Two hundred and twenty-five (225) delegates officially registered from 17 countries in Africa and other countries worldwide attended the 6th Africa T2 Conference. Delegates who attended the conference were from Botswana, DRC, Lesotho, Ethiopia, Ghana, Malawi, Mozambique, Namibia, Nigeria, South Africa, South Sudan, Tanzania, Norway, UK, USA, Zambia, and Zimbabwe. A total of 28 papers were presented with discussions during plenary sessions at the conference. During breakaway sessions of the conference the following five (5) workshops were conducted by various international institutions and individual experts: -

i) AFCAP Workshop on Rural Accessibility and Mobility
ii) Workshop on Gravel Road Maintenance
iii) Workshop on Effective, Efficient and Sustainable Technology Transfer in the Transport Sector
iv) Workshop on Minimizing Fraud and Corruption on Transportation Projects
v) Workshop on Integrated Road Asset Management System

Also six (6) firms and institutions from South Africa, Namibia, Botswana, Malawi exhibited their products, technologies and services at the conference namely Kaytech, Roads Authority Namibia, Botswana T2 Centre, Vivo Energy, Footprints Africa Safaris, and ASANRA.

4. KEY OBSERVATIONS AND FINDINGS

i) In order to develop safe, reliable and sustainable transportation systems for Socio-Economic Development in Africa, it is imperative that the development of transport infrastructure in the cycle by considering the environmental, social and economic consequences of: design; non-renewable material use; manufacture and production methods; distribution and commercialization; operations and/or user life; disposal, reuse and recycling options; and suppliers' capabilities to address these consequences throughout the value chain.

iv) Conference delegates indicated lack of awareness and expertise as one of the challenges for an effective implementation of Sustainable Public Procurement (SPP)/Green Public Procurement (GPP). Setting up dedicated SPP/GPP Units, training of officials and information campaigns were pointed out as the kind of support needed to ensure taking up of SPP/GPP.

v) Program/project management is vital for successful execution of capital projects. There is a serious need for Capacity Development for African transportation professionals in Project/Program Management, Project Development, Finance and Procurement, and Delivery.

vi) Key challenges in Africa are not technical issues, are soft issues of leadership, mindset (that hinders good ideas and that mitigates).

vii) Leadership is more than just ability. It is a combination of courage, determination, commitment, character, and ability that makes people willing to follow a leader (Singapore experience).

viii) Fully integrated Asset Management approach should be utilized in managing transportation assets because it will address the challenges of preserving the huge investments; integrated maintenance policies; cost effective programs; and meeting policy goals with respect to the Level of services.

ix) Understanding that the Asset Management Systems used by developed countries may or may not work in an African or developing country environment and care needs to be taken in selecting suitable systems. Taking an off-the-shelf system and implementing it in developing countries without following the methodology/life cycle has proven to be a failure in most countries.

x) In any successful Road Management System (RMS) implementation a champion and a driving force is required. The support of the top management and Boards is essential to making any RMS successful. Support of the Board and top executives is a pre-requisite for any successful RMS.

xi) It is very important to place the RMS high in the organisation so that it can have an impact.

xii) The contradictory needs and approaches of Network Analysis and Project Analysis has been also the core cause of many failures of RMSs in many organisations. RMS is a strategic, network-based system, in some cases a programme or tactical based system. Project Engineers have been bogged down with details trying to make the RMS systems project oriented instead of network oriented, and once they start developing the systems they never finish it because the number of details required has no ending.

xiii) The RMS of Namibia which is integrated and matured is a success and needs to be shared with everyone so that lessons are learned, the same mistakes not repeated, and it is hoped that this can be used as a model or a good example for a developing country.

xiv) Applied correctly, asset management can have a marked positive impact on the operations of public authorities, and lives of the people. This is however dependent on the adherence to appropriate policies, standards and guidelines that ensure quality and consistency, the lack of which has contributed to the current state of infrastructure mismanagement in developing countries.

xv) The implementation of pavement maintenance system to optimize pavement rehabilitation expenditures in Arizona Department of Transportation saved over US$ 200 million over a five-year period.

xvi) Performance Based Maintenance Contracts (PBMCs) have many advantages over the traditional contracts such as reduced maintenance costs by 15-40%, innovation, and being customer focused.

xvii) For Performance Based Maintenance Contracts, it is very important to select the appropriate Key Performance Indicators (KPIs). Failure to select a comprehensive set of KPIs that satisfies essential criteria will lead to undesired outcomes.

xviii) Effective transportation decision-making depends upon recognizing, responding to, and properly addressing the unique needs, cultural perspectives, and financial limitations of different socioeconomic groups.

ixx) Traditional public involvement techniques can be inadequate, effectively limiting meaningful involvement by traditionally underserved populations in transportation decision-making processes. That said, meaningful involvement means that potentially affected community stakeholders and residents have an opportunity to participate in decisions about a proposed activity that will affect their environment, safety or health.

xx) Environmental justice in transportation is being recognized as an important element for improving the quality of the transportation decision making process. There is a need to integrate environmental justice thinking in the planning and implementation process.

xxi) Environmental Justice in Transportation is a prerequisite for fair and balanced economic growth. It's implementation results in a high level of consumer satisfaction, it supports a fair deployment of infrastructure resources, and it is a key ingredient for fairly balancing the distribution of transportation resources.

xxii) African transportation professionals in Project/Program Management, Project Development, Finance and Procurement, and Delivery are not actively deploying the concepts of environmental justice.

xxiii) Technical and scientific approaches can save approximately one in every three fatalities on the roads through the systematic application of proven road safety engineering improvements.

xxiv) Regional programmes such as the study on financial and management options of the North South Corridor from Durban to Dar es Salaam by TradeMark Southern Africa can contribute to regional connectivity and long-term solutions for long distance international road transport.

xxv) The use of a PET-grid as asphalt reinforcement results in economic and environmental benefits. The economic benefits include thinner road structures, cost-effective solution for rehabilitation, longer life cycles, and reduction in maintenance costs, while environmental benefits cover savings in natural resources due to prolonged service intervals.

5. KEY CRITICAL CHALLENGES

i) Key challenges in Africa are not technical issues, are soft issues of leadership, mindset (that hinders good ideas and that mitigates). We (Africans) should change our mind set and have good leadership to enhance development.

ii) Transport sector must be changing agents.

iii) African diaspora to assist in developing Africa economy through research and providing advice.

iv) Despite the gains of institutional reforms undertaken in the past in the transport sector such as establishment of road agencies and road funds, we are currently observing greater political involvement in technical processes which the reforms were geared at doing away with. The semi-autonomous for road agencies is gradually being eroded. This must be avoided.

v) Political interference is a constraint in consolidating ongoing reforms in the transport sector. We need to review the institutional reform process and may be change of direction with lesser political involvement.

vi) It has been observed that the government, academia and industry work independently in addressing challenges of transport sector which has proved not to be effective. Systems whereby the academia, government and industry work together have proved to be effective and therefore should be put in place.

vii) African countries should adopt capacity building initiatives of long-term nature in a systematic approach and demand driven.

viii) For facilitating capacity building of the local contractors and consultant, contracts must be packaged in small packages to be accessible by local contractors and consultants.

ix) There is a strong need to develop domestic capability for the medium to large contracts to avoid the risk of cartel behaviour by a few dominant contractors. This capability can only be built if a market for local contracting services is provided. Integrated Supply Chain Management would provide a good mechanism to provide such a market.
x) Regional approaches that are demand driven rather than supply driven be considered for institutional capacity building programme.
xi) With regard to life cycle management of capital projects, there is a need to develop long term master plans as well as develop mechanism to demarcate and protect areas for future development.
xii) Human behaviour is the main cause of road accidents and that during design of roads human behaviour element should be considered.
xiii) Establishment of proper policy governing technology transfer is inevitable for effective and efficient performance of the technology transfer Centres in African countries.
xiv) Delegates commended the previous Africa T2 Conference organizers for a well-balanced conference in terms of plenary session, discussions as well as skills transfer through conducting of workshops and courses in hot topics agenda in the transport sector. It is recommended for future Africa T2 Conferences to adopt/incorporate similar conference organisation approach.

6. SUSTAINABLE SOLUTIONS AND CONTRIBUTIONS TO BODY OF KNOWLEDGE

The African Transportation Professional Networking Group (AFTraP) came up to enhance sustainable Technology Transfer (T2) centre operations for quality transportation engineering education made up of transport professionals from the academic, business, and government sectors with a commitment to proffer solutions to critical challenges facing transport in Africa. The goal of the group was to organise transportation professional conferences such as from country to country in Africa annually to provide a platform for experts and scholars to exchange ideas with each other and share the development and products in the field as shown in Figures 1 and 2 where the participants indicated high rating for the conference organising.

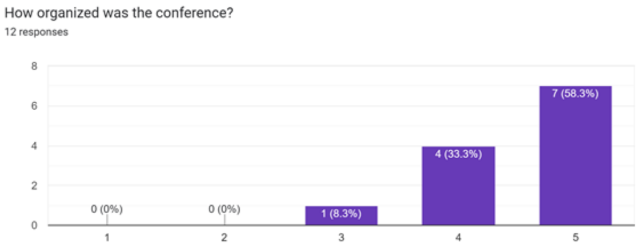

Figure 1. Few ICTA participants' responses to the conference evaluation.

Figure 2. ICTA participants at recent 9th International conference at Arusha, Tanzania, 2024.

The goal of African Transportation Professional Networking Group (AFTraP) being achieved in multiple steps marked by three major deliverables:

Deliverable 1 – Current challenges, practices, and issues in international transport research cooperation

Deliverable 2 – Research areas, capabilities, and future priorities for international collaboration

Deliverable 3 – Towards a framework and implementation for international transport dissemination.

The beneficiaries of the African Transportation Professional Networking Group (AFTraP) covered in a collective way all necessary aspects for the successful execution of an international cooperation in transport research project. As African Transportation Professional Networking Group (AFTraP) between the academia, government and the transport sector take shape and strength, international transport research collaboration can both help its further strengthening and internal cohesion as well as boost Africa's competitiveness in the global economy. However, enacting and fostering international research collaboration is faced with significant problems and difficulties today which should be researched, to provide the means of enacting solutions such as issues related to research infrastructures, intellectual property rights, and researchers' mobility.

The main objective was to produce a general framework related to international transport research cooperation, based on the reports of the three recent international conferences on transportation in Africa organised and the outcomes of related research topics presented. Other initiatives in the recent past as well as on the outcome of a thorough investigation of all different aspects of international cooperation such as current practices and more specifically gaps and barriers confronted in other international cooperation like European Transport Research Area International Cooperation activities (EUTRAIN, 2016) and Transportation Research Board of the National Academies (TRB, 2005) with the same field of interest, common characteristics, priorities and needs for international transport research and alternative models and tools for such research cooperation.

More specifically the AFTraP aimed:

(i) To contribute towards the establishment of a framework for international transport research cooperation and dissemination to be built upon the principles of knowledge sharing of transportation developments within African countries.
(ii) To investigate country research capabilities, future priorities, and potential for cooperation with the host countries in the prospect of mutual interest, in major regions of importance to AFTraP.
(iii) To consider and discuss current practices for research governance and management as well as barriers, gaps, and diversions for international transport research cooperation.
(iv) To assess the benefits or added value to AFTraP, as well as the prospective synergies from such closer international cooperation.
(v) To investigate alternative models and tools for carrying out such cooperation in the most effective and productive way and finally,
(vi) To disseminate, while doing the above activities, African know-how and practices in transport research.

7. CONCLUSIONS AND RECOMMENDATIONS

During the past Africa Transportation T2 Conferences, various presentations were made to address various themes. The Events have facilitated bringing together Member States, Ministries responsible for transport infrastructure, Roads Agencies and Authorities and Technology Transfer Centres in the region. In addition, among other things, the events have facilitated the following:

i) Exchange and sharing of technological information for transport infrastructure development
ii) Conducting of Technical Site Visits that enables professionals to learn from each other regarding application of appropriate materials in road construction, technologies, operations of various transportation modes such as roads and ports,
iii) Carried out Capacity Building Programmes such as training courses and workshops that were conducted concurrently with the conference,
iv) Exhibitions on various products, technologies, and services applied by companies, organizations and institutions from within and outside Africa,
v) Formulation of collaborations and partnerships between institutions from Africa and those outside Africa.
vi) Gathering of professionals from various countries inside and outside Africa and sharing experiences and innovative solutions,

vii) Visiting natural resources and sightseeing in host countries.

In this respect, the 6th Africa Transportation T2 Conference has been an event that has put Botswana as a country on the global map. In consideration of the above said, Botswana through the Ministry of Transport and Communications accepted the recommendation by ASANRA to host the 6th Africa Transportation Technology Transfer Conference that included Technical Presentations, Panel Discussions, Workshops as well as Exhibitions on Products, Technologies and Services.

The Botswana 6th Africa Transportation Technology Transfer (T2) Conference was a major event that took place in the Tourist City of Gaborone, Botswana with a total of two hundred and twenty-five (225) delegates from 17 countries in Africa and other countries worldwide in attendance. Delegates who attended the conference were from Botswana, DRC, Lesotho, Ethiopia, Ghana, Malawi, Mozambique, Namibia, Norway, Nigeria, South Africa, South Sudan, Tanzania, UK, USA, Zambia, and Zimbabwe. A total of 28 papers were presented with discussions during plenary sessions at the conference. During breakaway sessions of the conference five (5) workshops were conducted by various international institutions and individual experts. Also six firms and institutions from Tanzania, South Africa, Namibia, Botswana, United Kingdom and Germany exhibited their products, technologies and services at the conference.

To meet its objective the conference featured various presentations, panel discussions, courses and workshops pertaining to the conference thematic-areas and topics. There were special sessions on fascinating topics arranged to enable each participant to optimise their stay and take part in as many of the activities as possible. Being fully aware of the current trends, the conference agenda addressed the followings; issues ranging from the handling of traffic in urban areas, management of urban traffic congestion, adequacy of Transport Policies and their Impact, How Transportation Infrastructure Planning and Implementation is coordinated and integrated; Adequacy of Intermodal and Multimodal Transportation Cooperation and initiatives, Involvement of Public in the Transportation Decision Making Process, Escalation of Construction Costs, Quality Assurance of Construction and Maintenance and Value for Money. Other issues included Capacity Building in the Transport Sector including Capacity Building of Local Construction Industry, Road Safety, Financing of Transport Infrastructure including Public Private Partnerships, Innovations in Management of Public Transport, Overcoming Challenges on Workforce Development for Transportation, Environmental Impact of Transport, Rural Accessibility and Mobility, Governance in Transportation, and a whole host of further issues. Moreover exhibition of technologies, products and services – a show case for all related industries were held in conjunction with the conference. Local and foreign firms and institutions which are stakeholders in the transport sector were able to exhibit their products, services and technologies.

Updated, increased and exchanged know-how and experiences among professionals, researchers, users and other interested parties in the transport sector. Increased knowledge shared about break-throughs in the managing of roads and other modes of transport, the introduction of brand-new construction techniques, exchange experiences related to maintenance systems, all of which aims at optimising construction and conservation costs and to achieve the lowest possible transportation costs. Increased knowledge shared about the latest technologies in terms of project, construction and management of pavements, basic works, traffic, transportation, the environment and road safety. Exchanges in opinions on the most convenient alternatives to generate economic resources and financing strategies.

Issues of road safety raised and integrated into the social and political agenda of the community. Solutions which may allow permanent road access to rural areas discussed and their impact on the productive and logistic national system analysed. The ordering, planning and management of transport, be it freight or passengers, both in rural and urban areas discussed. Exchanged experiences about transport inter-modality and about its logistic management. Technology Transfer for Developing Sustainable Transportation Systems in Africa promoted. Establishment and operations of Technology Transfer Centres as means for facilitating appropriate effective technology transfer promoted.

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ENGINEERING PEDAGOGY AND PRODUCTIVITY LEVERAGING AI

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Abstract: With the emergence of AI and its proliferation in different applications, the thought of its adoption for use in formal engineering education is daunting to some, a welcome development to others and an obvious concern to many educational practitioners. The purpose of this paper is to demystify the fears, dispel doubts and view AI as a mighty teaching cum learning tool. The paper therefore introduces AI as a tool for aiding good engineering teaching and learning while enhancing the productivity and collaborative research capacity of the learner. The methodology adopted is a desk review of the progressive use of digital technologies in engineering education. Such digital technologies have been shown to enhance students 'concept formation and retention, provide learner-content interactivity, boost the motivation and engage the learner with practical hands-on skills. A review of the development of digital teaching aids therefore provides a backdrop for appreciating the unparalleled, superior and sought-for attributes that AI brings along to engineering education. The paper uses an example framework to demonstrate the organisational changes needed to simplify programming and man- age personal study notes and knowledge. The example further demonstrate learning and research productivity. Findings substantiate the imminence of AI in engineering education and provide practitioners an early warning for adaptation to the technology. Adapting the engineering curriculum in turn implies some structural reorganisation of the engineering education process. Such a reorganisation will entail a re-think of both the design as well as the delivery of engineering Programmes. The paper reflects on these implications and suggests a few interventions based on collaboration.

Keywords: Engineering Pedagogy, AI, 4iR Skills, Research, Knowledge Management, Productivity, Collaboration

1. INTRODUCTION

This paper is motivated by a pedagogical need to view artificial intelligence (AI) as just a digital teaching and learning aid, a productive tool aiding engineering pedagogy and unavoidable in our times. Viewed in this positive light, our role as educators is to adapt AI and empower students to adopt its use in engineering education. To affirm this role, any attempt to mitigate its use needs to be suppressed and any adaptation initiatives need to be promoted. Digital learning tools have advanced interactive learner-centred engineering learning. The progressive development of digital learning tools are well documented [7, 8]. The documentation indicates a gradual transition from the mere use of applets to generate interactive learning contents to complete Learning Management Systems (LMSs) that blend interactive eLearning with actual hands-on engineering laboratory work. As an example, the applet in Fig.1 aids the students ' proficient use of an avometer. Skills are drilled through repeated reflections on setting the current, voltage and resistance measurements via the computer keyboard and mouse. Well-designed applets are thus efficient as they avoid costly experimental setups. Applets for self-assessment exercises, provide learning at a learner's own pace, space, time and frequency [7].

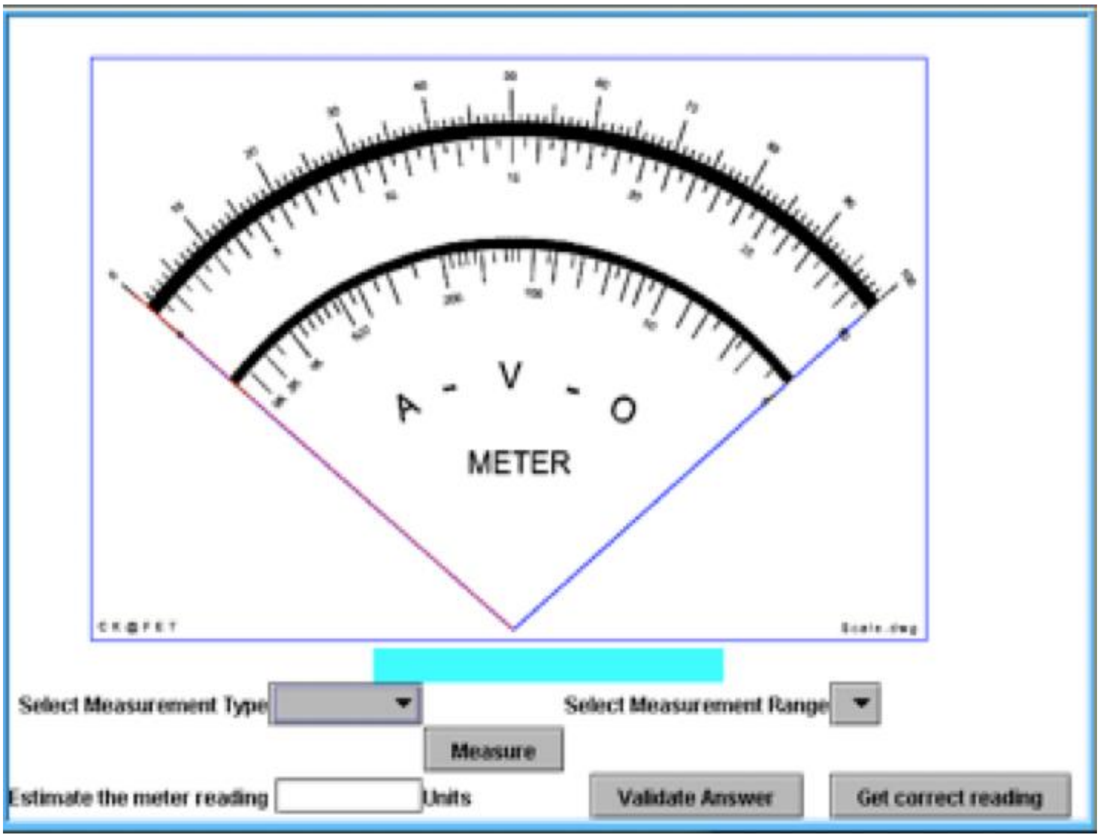

Figure 1. The Ohmmeter applet [7].

Figure 2. The UniTrain-I [8].

The basic Lukas-Nuelle® (LN) setup in Fig.2 on the other hand shows part of an LMS that equip students with real-time laboratory experimental work and skills in diverse fields in engineering [8]. The setup allows the learners to access different online reference material for their theoretical and practical learning. Experimental work is based on the basic UniTrain-I component shown in Fig.2 into which inter- changeable experimental modules can be plugged. The integration of AI into the LMS will make LMSs like LN indispensable for augmenting productivity and practical skills acquisition. Assisted reality (aR), augmented reality (AR), extended reality (XR), virtual reality (VR) and any intersections of these [9] are technologies already being used. This paper does not consider these technologies Instead the paper confines itself to productivity in three engineering pedagogy user cases: Knowledge management, learning support, and publication research management.

Under knowledge management, the searching and researching of learning contents, their collation and organisation will be considered. Within learning support, the paper explores how AI acts as a learner's personal tutor and within research publication management, the paper considers the integration of AI into the LaTex framework. The paper discusses each case separately. A further session is dedicated to the Neovim authoring environment which is a general framework within which the three use cases can be integrated.

2. METHODOLOGY

2.1. Knowledge search, collation and organization

The first AI use case is note taking. As educators a distinction between note taking and note making is instructive. Note making is is an active participatory process that immerses the note maker in the context being learnt. Note taking in contrast is deemed a mere transcription of presented contexts from which the note taker may be completely divorced. Hence in this paper, any reference to "note taking" will be understood to connote, "note making".

The number of note taking applications can be overwhelming [21]. [4], [5] list a few common ones that are reproduced here in alphabetical order: AmpleNote, Apple Notes, Bear, Bear Notes, Cherry tree, Google Docs, Google Keep, Evernote, Joplin, Microsoft OneNote, Notion, Obsidian, Reflect Notes, RemNote, Standard Notes, Supernotes, UpNote, Workflowy, Zoho. Any attempt to rank these is futile since multiple ranking criteria could be used: the operating system - whether MacOS, Linux, Windows or Android; the mode of execution - whether via the command line or a Graphical User Interface (GUI); Nature of the notes - whether simple notes or organised large notes. Nevertheless, the popularity of Joplin, Obsidian and Notion places them among the 3 top-tier note taking applications. The paper is based on Obsidian.

The note taking application, Joplin, was not considered for the fact that it is a derivative of Evernote. Evernote charges a premium fee before users can access its advanced services. Additionally, Evernote is only accessible across more than two devices simultaneously if the user is a paid-up premium user. The lack of the user to access their own notes, imposed by a vendor insisting an upfront paid-up premier membership, exemplifies the undesirable phenomenon called vendor lock-in.

Notion on the other hand is one of first note-taking applications leveraging AI. Its features are closer to Obsidian than Joplin's features are [4]. However, being cloud-hosted, Notion users are also vulnerable to the dreaded vendor lock-in dilemma. Worse, where Internet connectivity is limited, users cannot access cloud-hosted notes. It desirable to own and access one's notes all the time, anywhere and as often as needed. The choice of a good note-taking application is therefore informed by the following concerns [17]:

- Whether notes are stored locally or in the Cloud,
- Whether notes can be interlinked,
- Whether the note taking application is functionally extensible, and
- Whether the note taking application is optimised for performance.

Obsidian organises notes in plain markdown text in a user's local computer. Obsidian's first design principle is therefore termed "notes are local-first". Secondly, Obsidian prioritises links between notes as first-class citizens of its note-taking ecosystem. The third design principle asserts that Obsidian will be extendable. This allows Obsidian to multiply the productivity of its core functionality through community-designed plugins. That support ecosystem currently boosts close to 2000 plugins.

2.1.1. AI integration for productivity in note-taking

The markdown files of Obsidian notes reside on a local pre-dedicated folder termed the vault. Note concept or tagged word are inter-linkable; either internally within a vault and across vaults or externally to resources on the Internet. Hence relatable learning resources, media, references are collated to form a body of interlinked knowledge, as exemplified in Fig. 3 thus making relatable contexts easier to find, recall and manage as coherent study notes. The vault thus acts as a personal data repository on which AI tools can be applied.

The notes are made using any common editor for instance VSCode, Vim, or Neovim; with Neovim lending notes productivity advantages unparalleled by other common editors: the ability to fuzzy-find and locate specific notes, autosuggestions and syntax highlighting among many others and productivity enhancements by virtue of Neovim being a command line based editor. Any changes made in an Obsidian file via Neovim are instantaneously reflected in the Obsidian environment and various AI tools are integrable into Obsidian.

The Obsidian Copilot and Smart connections are the most common [1]. The lesser known ones yet useful for note-taking productivity include Excalidraw and Fabric. Many of the approximately 2000 community plugins available allow Obsidian to access many applications with different AI capabilities. These applications evolve all the time and their capabilities remain to be explored. [13] for instance introduces an Obsidian AI Assistant that allows note-taking to access: Text assistance - using GPT-3.5a and GPT-4 thus enabling ChatGPT-like chats within Obsidian notes; Image generation - using DAL.E2 to generate images for Obsidian notes and Speech conversion - using Whisper to dictate Obsidian text notes from speech. This paper therefore confines itself to Obsidian copilot, Smart connections and Canvas - which introduce AI capabilities through ExcaliDraw and Fabric. Some of the Obsidian plugins enabling AI capabilities are displayed by the icons indicated in Fig.4. The next sections highlights the AI features relative to note-taking.

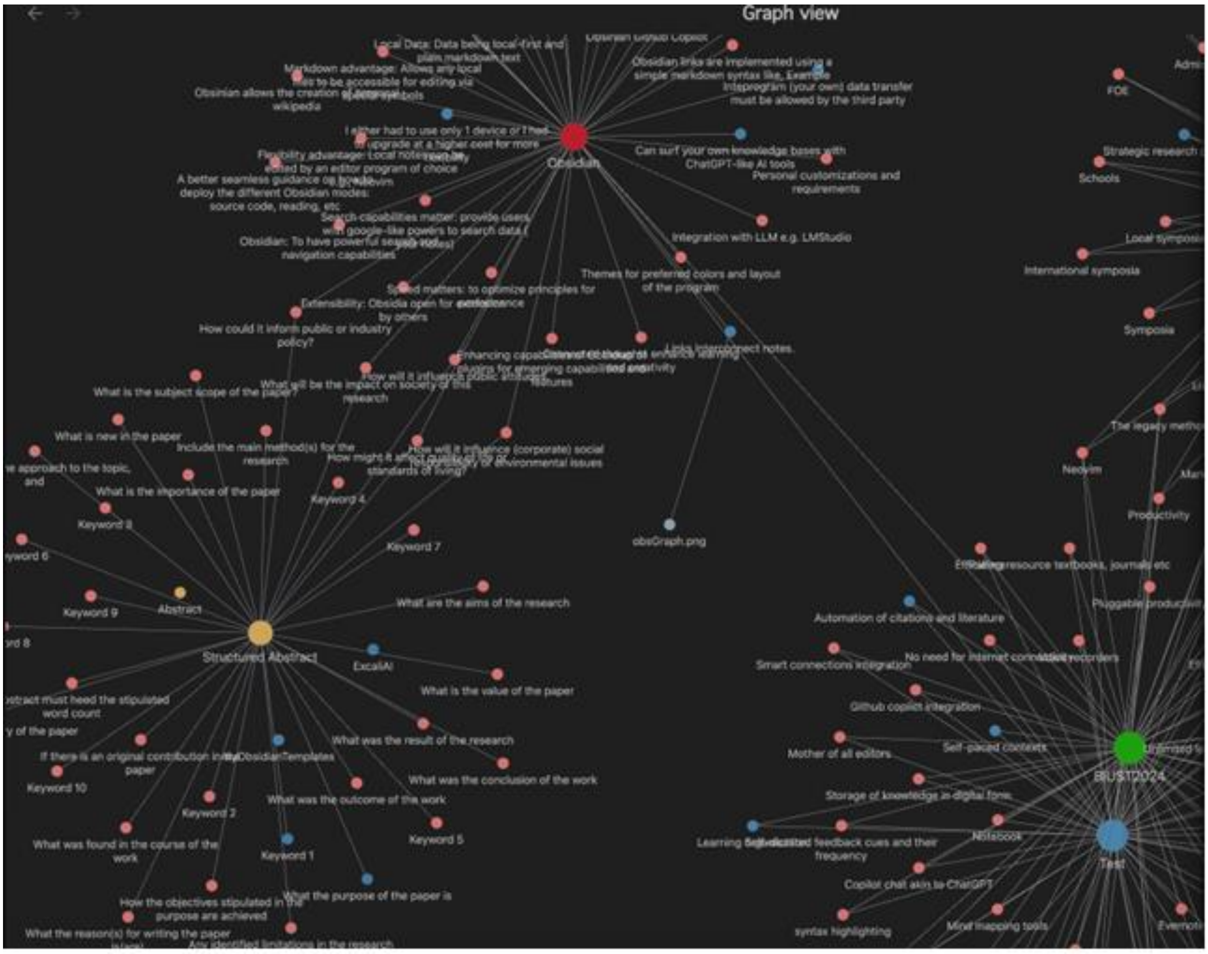

Figure 3. Graphical view of notes in a vault.

Copilot in Obsidian: The Copilot for Obsidian is a community plugin installed and enabled within Obsidian. Using OpenAI's Large Language Models (LLMs), the Copilot provides users having a valid premium openAI subscription plan to engage in ChatGPT-like chats within Obsidian. This capability is sustained in the absence of internet access, if local LLMs like Ollama or the LMStudio are installed. These enable the Copilot's local embeddings to implement the Copilot functionality without Internet access. Hence note-taking can proceed unimpeded anywhere, anytime and for any content to: summarise notes, simplify and clarify concepts, translate notes between languages, and automate the generation of scheduled notes - to name but only a few possible tasks.

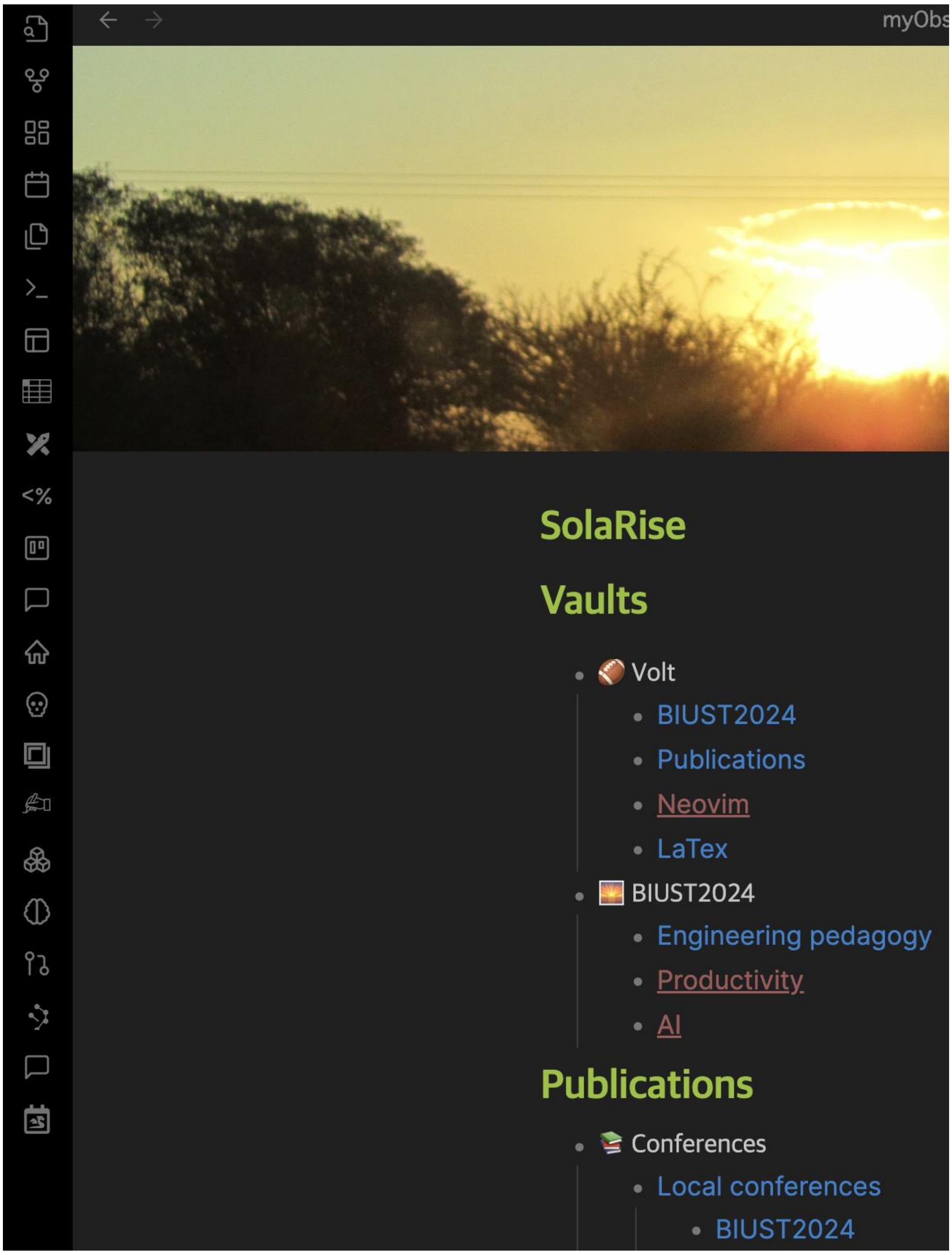

Figure 4. The Obsidian plugin palette (at extreme left).

Smart connections for Obsidian: The community plugin Smart connections allows users to interrogate the contents of their vaults with chat-like conversations. It can summarise notes, explain code, suggest improvements and many other AI-assisted tasks. The vault contents are used as the knowledge base on which Smart connections is trained. In addition Smart connections analyses the vault for concepts that are related. It's AI capabilities provide vector embeddings of all notes, enabling the Smart connections to understand the meaning of different pieces of text and their interrelations. This makes the searching for specific contents easier [1].

Fabric for Obsidian: Takes youtube video contents and analyses their suitability based on user-specified qualifications [3]. Thus Fabric allows the user to extract the essential contents of a video and to present the summary in text format. This feature allows the efficient analysis of long videos for productive note-taking. The Fabric command, yt–transcript, issued at the command line transcribes the contents of a video. The transcription is condensed into an Obsidian note which is subsequently classified into one of the tiers S, A, B, C and D. If the classification result is the topmost tier S, the content is most suitable and appropriate. The classification reduces the amount of time needed to analyse the video content from first principles and therefore advances learning productivity.

Canvas in Obsidian: The canvas is a special note capable of representing contents graphically. A canvas can contain four types of objects: cards, notes in the vault, media and external links e.g., web pages. Once in the canvas the externally linked content is made available to the note. For example, this enables to watch a youtube video from an Obsidian canvas. The cards can be interconnected using handles in each to form a mind map of the card elements. In and of itself, mind mapping is a useful content visualisation tool in engineering.

Obsidian's ExcaliDraw: Sketching tool in Obsidian with in-built AI capabilities to generate diagrams from texts or convert wireframes to code code.

2.1.2. Knowledge management leveraging AI

The learner's study notes create a knowledge repository that can be interrogated for related notes. The user invokes the palette tool or issues the MacOS keyboard short-cut Command + p while within a note to access the set of Obsidian commands. The user then enters the appropriate command to accomplish a desired task. As an example while using AI the text generator plugin, the Command + p followed by text gen narrows the viable options allowing the user to select the AI command "Generate Text!". Increased productivity is achieved the tool can organise and manage study notes. This involves converting the notes in a vault(s) to act as a local database which the user can interrogate and retrieve data on demand. The organisation and management is achieved through a dedicated Obsidian plugin, DataView. The user specifies several metadata and criteria to enable the selection, categorisation, grouping and/or the exclusion of specific notes.

AI-enhanced productivity imposes a choice for the user between the privacy of one's personal notes and their possible vulnerability to abuse if open to public access. Obsidian's local-first design principle dictates that local LLMs, for instance Ollama, are desirable for data security. The caveat is that local LLMs limit the productivity levels achieved due to local resource bottlenecks. Hence AI use may be perceived as inefficient. Nevertheless, local LLMs in Obsidian are best set up over the command line. The use of local LLMs in Obsidian is revisited after the introduction of Neovim in subsection 2.3 which deals with the computer terminal.

2.2. Copilot Learning Support

After successfully making notes and organising them in Obsidian, the note-maker's next concern is actual study. How can leveraging AI enhance one's learning productivity? The productivity-enhancing AI capabilities are introduced to Obsidian via a number of community plugins notably the Obsidian Copilot and ExcaliDraw.

Copilot and Programming Productivity: After the installation of the Obsidian Copilot plugin, several LLMs are available for use, although at a small operational cost. The local LLMs for free AI access and privacy include the LMStudio and Ollama. To get the most out of the Copilot assistant and be productive, the learner must be conversant with good prompt engineering principles and strategies [2], [16]. These best practices help guide the personal copilot tutor to the target support that the learner is seeking. At the Obsidian GUI, the copilot and copilot chat plugins can be invoked using the respective icons on the tools palette shown on the left of Fig.5. A dedicated chat window opens where requests and responses to and fro an LLM occur. Alternatively, the command Command + p can be used to navigate to a desired copilot command.

2.3. The Neovim Framework

AI-assisted productivity derives largely from integrating AI for automating mundane tasks and providing interactive learning support. Task automation avoids repetitive processes. AI combines enhanced automation of tasks and interactive learner support conveniently under the generic authoring framework, Neovim. The frame- work is based on the command line. Keyboard commands are issued at the terminal using short-cut key combinations. This makes their execution faster. The paper considers, briefly, the Neovim framework before the last user case, the productivity of LaTex leveraging on AI is taken up.

2.4. Text editors

It seems almost impossible to enumerate the multiplicity of text editors available for use: Microsoft Word, MacOS Pages, Visual Studio Code, Wrangler, MATLAB, Notepad++, Mathematica, TeXShop and Vim/Neovim.

2.4.1. Vim and Neovim

First came Vim [19], [20] and later its re-incarnation as Neovim [18], [11] - a framework that enhances editorial productivity innumerably and best exemplified while leveraging AI in note-making, learning using copilot and research publication using LaTeX. Neovim is used on working from the terminal command line. After overcoming the initial, seemingly steep learning curve, Neovim pays off through improved productivity; not only within Neovim but also in other applications that leverage on Neovim's versatility. The explanation of the basic Neovim setup and an exploration of how the framework enhances productivity in note-making, learning and publication follows next.

Every computer comes packaged with a terminal application. However our considerations assume that an alternative modern terminal application for instance, iTerm2, Kitty, Alacritty or WebTerm is installed in a Mac or the Linux operating system. Linux's legacy GNU terminal application can equally performant and can be used. Modern terminal applications provide textual syntax-highlighting, contextual auto-suggestions, web-searching capabilities as well as colour listing of folder and file contents. The installation of the terminal applications occurs using HomeBrew.

A minimum but functional Neovim setup requires correct installation and setup of Homebrew, Git, Node and its package manager NPM, ZSH, some Ned Font and a color terminal application. Neovim itself builds up on the Lua programming language [14], [15] and [10]. A typical Neovim installation based on Lazy is shown by the hierarchy of files and folders in Fig.5. The entry point in the installation is the initialisation file, init.lua. The init.lua file calls all initial setup files, plugins and other requirements to run Neovim. Most of the plugins are cloned from Git repositories onto the local computer. This step is not necessary if the functional hierarchy in Fig.5 is adhered to and the necessary files therein are specified. It then suffices to enter the Lazy command, :Lazy within an open Neovim file to reveal an IDE containing the Lazy commands I, X, U, S. These commands are invoked by either typing I, X, U, S at the keyboard. The invocation results in the automatic Installation, Cleaning (X for C), Updating, or Synchronising the new with old installed plugins respectively. Hence Lazy ensures that the new plugins are downloaded and installed if they were not found in the ecosystem, synchronised if need be, repaired if the older ones had braking code in them and updated where new versions are detected. The Core folder contains the initial setups needed for configuring the Interface and the Keymaps folder contains the short-cuts for the keyboard commands used to interact with the application from the command line. It is to be born in mind, that everything in Neovim is command line-based. As an example, the colorscheme.lua file in the hierarchy of Fig.5 is opened for editing by navigating to and issuing the command nvim colorscheme.lua at the folder /.config/nvim/lua/cheddi/lua/plugins/.

Figure 5. The Neovim setup [6].

2.4.2. Productivity of Neovim leveraging AI

Neovim is a universal editor capable of reading any text-based file. Hence the files lazy-lock.json, calendar.sh and copilotchat.lua in Fig.5 can be opened by the respective Neovim commands nvim lazy-lock.json, nvim calendar.sh or nvim copilotchat.lua respectively. Moreover, as the list of plugins in Fig.5 indicates, the

Copilot plugin and the Copilot chat plugin can be configured within Neovim. The configuration enables access to the Obsidian files within the Neovim editing framework. Hence the Obsidian markdown file, myDashBoardHomePage.md can also be opened for editing at the appropriate folder by invoking the command, nvim myDashBoardHomePage.md. Changes made in Neovim to an Obsidian file are instantaneously reflected in the Obsidian application. Besides the ability to interact with Obsidian for note-taking or with the Copilot for AI productivity in learning, Neovim can also integrate LaTex for productivity in publishing. The ground is now laid out to consider the leveraging of AI for productivity in learning a programming language.

2.4.3. Learning Productivity by leveraging AI in Neovim

Assuming a correctly configured Neovim framework, the copilot.lua and copilotchat.lua plugins are used as described under the subsection 2.2.1. Their optimal use however, presupposes that the learner is versed with and adheres to the principles and strategies of good prompt engineering practice mentioned earlier. The Neovim setup provides a good practicing ground for the Copilot to provide personalised tutoring to a learner seeking to be proficient in a specified programming language. The productivity in programming is not confined to a single programming language. Neovim provides code suggestions, editing and debugging for languages like astro, bash, c, cmake, cpp, go, html, http, java, javascript, jsdoc, lua, markdown. prisma, python, query, scala, sql, svelte, toml, tsx, typescript, vim vimdoc, yaml etc depending on how the Language Server Protocol (LSP) is setup. This non-exhaustive list underscores the achievable productivity while using the Neovim framework. Without it, several dedicated editors would have to be installed and used separately to edit, run and debug code snippets in the respective language.

2.5. Management of the research publication process

Technical report writing is important in engineering pedagogy. The process includes writing research project reports, theses, manuscripts for journal publications, laboratory manuals and organising study materials. The next section considers how LaTeX leverages AI to boost productivity in these areas of publishing.

2.6. Authoring using LaTeX

The foundation of technical publishing is built on the TeX typesetting language. TeX can typeset primitives, programming and be used to write macros that others can use to control the precise formatting of a document [12]. LaTeX builds on and improves on the original Tex. LaTeX has two different editors: TexShop in MacOS and Overleaf for collaborative cloud-based LaTeX editing. Considering the operating systems used, TeXLive is the complete LaTeX distribution for MacOS whereas MiKTeX is appropriate for window installations. Other variations of LaTeX editors include TeXworks and TeX Studio while the TeX extensions include XeTeX, LuaTeX and pdfTeX. The consideration of LaTeX in Neovim is based on the VimTeX plugin installed on a local MacOS computer. Since Overleaf is cloud-based, its further consideration is avoided in acknowledgement of Obsidian's local-first design principle.

2.6.1. Integrating AI into LaTeX

LaTeX automates the creation of structured documents where a specific format is needed. Publications in line with a strict format are required by book publishers, scientific journal editors, for university theses and report writing and by the individual who wants to avoid the repetitive formatting of a document from first principles. Besides formatting, proper referencing, ability to preview as well as the tracking of sections or equations are also important considerations that require flawless management.

In traditional LaTeX, the original document source code is processed by first clicking the LaTeX button to compile it. The BibTeX button is then pressed to process the bibliography. Subsequently the LaTeX button is clicked twice in succession before the pdf-formatted output is produced. If the required plugins are installed and the LaTeX is invoked within Neovim, the repetitive steps are reduced to a single compile command, spaceBar + ll issued at the keyboard. Again if there are changes in the source file, the output pdf file reflects the subsequent changes instantaneously. Subsequent changes are communicated to the output pdf file, immediately the neovim buffer is saved. To preview the processed document requires only to issue the keyboard command, spaceBar + lv. This convenience enhances productivity by ensuring that the publisher concentrates on the content rather than the intermediate steps for its display.

Despite a correct installation of the VimTex plugin shown in the list of plugins in Fig.5, challenges were encountered while integrating the bibliography and citations using the pdf-viewers Zotera or Okular that VimTeX recommends. Experience indicates that a less talked about pdf-viewer, Skim - which is part of the VimTeX documentation - works flawlessly; compiling the bibliography at a superfast speed.

3. RESULTS AND DISCUSSIONS

The aforementioned AI revelations in the three areas of engineering pedagogy - note-making, learning support and publication -, were highlighted for their usefulness to learning, teaching and managing engineering research. First in note-making: the learner requires a modern tool for making, organising, managing, relating, querying and retrieving study notes. The lecturer too requires a modern tool for pooling all teaching resources under one roof, collate them and assess how they can be interrelated for effective teaching. The above analysis recommends Obsidian as the note-making application that enhances note-taking productivity. The strength of notes connectivity in Obsidian was noted. Notes can be interconnected locally or to external resources. AI capabilities through Smart connections enabled the interrogation of linkages between notes. The Obsidian Copilot provided further AI chat options for the note-maker. Obsidian preserved the security of one's data (notes) since notes are saved on a local drive - unless one takes advantage of the Obsidian option to, synchronise notes to the Cloud. Obsidian also guaranteed the continuity of note-making even where internet accessibility issue arise. In that case, the installed local LLMs guaranteed that AI services were sustainable.

In teaching and learning: learners, lecturers and re- searchers need access to current knowledge in their subject areas of learning/teaching and research. The Obsidian Copilot provided a modern tool for searching for knowledge, querying the support provided and actively engaging in generating useful knowledge. The Copilot support, if used appropriately, made the AI Copilot function as a personal tutor - for any content, anytime, anywhere and at any desired frequency.

Both the learner and the learning facilitator are simultaneously researchers. They need access to modern tools for automating some mundane tasks, for instance, identifying focal research areas, formulating research goals, organising research, managing research and eventually publishing research. AI was noted to enhance productivity in each of the above-named areas. The paper highlighted an additional productivity aspect relative to LaTeX publishing. As a publishing software, LaTeX already enhances the productivity inherent in common editors like Word or Pages. The integration of VimTeX into LaTeX within a NeoVim editing framework however allowed the integration of AI into LaTeX. This was noted to make LaTeX even more productive. The foregoing discussions help demystify any fears on AI or doubts about it.

4. IMPLICATIONS

The integration of AI into the curriculum for good engineering pedagogy and productivity cannot spontaneously come about. That process must be enabled. Hence it is important to point at the impediments that are likely to constrain the viability of the process. The first impediment relates to the mindsets of the learner and the educator. Specifically, the failure of the mindset of the educator to catch up with technological developments. Clearly learners may be ready to adopt changes before their lecturers do. Learners can accept new ways of learning much faster than the educator may be willing to adopt an emerging new way of teaching. Many a learning facilitators though still defend the "good" old approaches to teaching and learning. They cite plagiarism and fear its rampancy in the age of AI. Yet AI has come of age and is here to stay. Its promises in engineering education are far-reaching and desirable. They deserve a collective vouching for. This collective call has implications on the engineering educator. The educator must overcome the temptation to mitigate the penetration of AI. Instead s(he) must resolve to adapt to the imminence of AI and advocate for its widespread adoption for engineering pedagogy.

The second impediment concerns what can be described as a metastasising AI knowledge gap. Lecturers's AI knowledge is still developing. Yet AI applications appear in every facet of life nowadays. AI in engineering pedagogy is therefore pervasive. Since educators must guide an AI-mediated learning, they must be empowered to bridge the AI knowledge gap. Bridging that gap is daunting to some educators. Hence they sow doubt in adopting AI. Implicitly, the engineering education system must provide opportunities for skilling, re-skilling and up-skilling its workforce. Since most of the engineering content will be available to the learner via LLMs, it is necessary to shift the educators emphasis away for traditional teaching to guiding learners through their learning contents. The far-reaching and wide-ranging implications mean: fundamentally reviewing and steering programme developments towards AI-mediated contents using technologies such as augmented and extended reality, mainstreaming AI-mediated curriculum programme delivery and learning methodologies, orienting curriculum towards practical hands-on skills acquisition over theoretical learning and recasting assessment patterns to favour outcome-based assessment. For many practitioners, the above list of desirable 4iR innovations in engineering education is a welcome development.

The last impediment is the dreaded financial concern. AI technologies come with a high price tag. The best services are accessed only through regular paid up subscriptions. Not everyone though can afford the subscription fees let alone manage the required online financial transactions. In addition, AI applications require superior and modern computer resources. High-end computing hardware is out of reach for students and perhaps lecturers as well. These considerations constitute obvious concerns to many educational practitioners. The implication is that institutions need mechanisms for resolving the financial constraints before AI-mediated engineering pedagogy can be viable.

5. CONCLUSION

This paper considered only a minute subset of important aspects in engineering pedagogy. These aspects are therefore not holistically representative. The intention of the paper was neither to be comprehensive nor be overly technical. Instead the paper sought to make a case for integrating AI in engineering pedagogy for the purpose of advancing learning productivity.

For a learner, that productivity begins with note-making, through actual learning support and concludes with research management and publishing. AI in Obsidian, exemplified by the Obsidian copilot and smart connections, substantiated advances that enhance note-taking and the productivity in doing so.

Acting as a personal tutor, the OpenAI Copilot guides the learner on any topic, anytime, anywhere, any frequency, and at a pace determined by the learner alone. The Copilot provided the learner support needed to learn a programming language efficiently.

In research, the Neovim framework allows the learner to productively integrate both LaTeX and VimTeX into an authoring framework that widely supports innovations in AI. Hence the learner is able to access the Copilot and other related resources to enhance productivity in publishing their research.

It is recommended that both the learner and engineering educator be empowered through, skilling, re-skilling and up-skilling in AI. These interventions combined with a strategy for managing the cost of AI in engineering education promise to make engineering pedagogy and productivity in the age of AI, sustainable.

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PREPARING ENGINEERS FOR INDUSTRY 5.0: A STUDY OF THE IMPACT OF AI AND ML ON ENGINEERING EDUCATION

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Abstract: The advent of Industry 5.0 has transformed the engineering landscape, necessitating a paradigm shift in engineering education. This study investigates the impact of Artificial Intelligence (AI) and Machine Learning (ML) on engineering education, aiming to prepare engineers for the demands of Industry 5.0. Findings revealed that 85% of engineers lack the necessary skills to work with AI and ML technologies, while 90% of industry leaders consider AI and ML expertise essential for future engineers. We employed an Artificial Neural Network approach, combining surveys, interviews, and case studies, and found that: 85% of respondents reported improved problem-solving skills after AI and ML training; 90% of projects developed using AI and ML demonstrated enhanced innovation and creativity; 75% of faculty members expressed confidence in teaching AI and ML topics after training; and 92% of industry partners reported satisfaction with the readiness of AI and ML-trained engineers. A neural network regression model was developed to predict the performance of engineering students in AI and ML-related tasks, showing a significant improvement in model performance with a Mean Squared Error (MSE) of 40.795 and a Root Mean Squared Error (RMSE) of 6.387. However, challenges persist, including curriculum integration (60% of institutions), faculty training (40% of faculty members), and resource constraints (70% of institutions). We proposed a framework for effective AI and ML integration into engineering education, emphasizing interdisciplinary collaboration, project-based learning, and industry partnerships. Our study demonstrates the need for urgent reform in engineering education to prepare students for Industry 5.0 and provides a roadmap for educators, policymakers, and industry leaders to address this critical challenge.

Keywords: Industry 5.0, Artificial intelligence, Machine Learning, Engineering Education, Curriculum Reform, Industry Partnerships

1. INTRODUCTION

The fourth industrial revolution, Industry 5.0, is transforming the way industries operate and interact. Artificial intelligence (AI) and machine learning (ML) are key drivers of this revolution, and their impact is being felt across various sectors, including engineering education (Xu *et al.,* 2016). As AI and ML continue to advance, they are changing the skill sets required of engineers, and engineering education must adapt to prepare students for this new landscape (Draghici & Ivascu, 2022). Research has shown that AI and ML are increasingly being used in various engineering fields, including design, manufacturing, and maintenance (Bertsimas & Sim, 2004). However, there is a significant gap between the skills engineers currently possess and those required to work effectively with AI and ML technologies (Bashshur *et al.,* 2020). To address this gap, engineering education must evolve to integrate AI and ML into curricula and teaching practices (Dwivedi *et al.,* 2023).

A decision support system (DSS) is a computer-based system that provides decision-makers with the tools and information needed to make informed decisions. A DSS leverages data analysis, AI, ML, and other advanced technologies to analyze complex data, identify patterns, and present actionable insights in a user-friendly format. By harnessing the power of AI and ML, a DSS can analyze large datasets, learn from historical data, and provide predictive analytics and recommendations to support decision-making (Atemoagbo *et al.* 2023). As AI and ML continue to advance, they are changing the skill sets required of engineers, and engineering education must adapt to prepare students for this new landscape (Budhwar *et al.,* 2023). Several studies have investigated the impact of AI and ML on engineering education. For instance, (Warke *et al.,* 2021) highlighted the need for engineers to develop skills in AI and ML to remain competitive in the industry. Similarly, (Dwivedi *et al.,* 2021) emphasized the importance of integrating AI and ML into engineering curricula to prepare students for Industry 4.0. Research has also shown that AI and ML are increasingly being used in various engineering fields, including design, manufacturing, and maintenance (Dumbill, 2013). For example, AI-powered design tools are being used to optimize engineering designs (Zhang *et al.,* 2019), while ML algorithms are being used to predict equipment failures in manufacturing (Barricelli *et al.,* 2019). However, there is a significant gap between the skills engineers currently possess and those required to work effectively with AI and ML technologies (Insel *et al.,* 2010). To address this gap, engineering education must evolve to include AI and ML in curricula and teaching practices (Paranjape *et al.,* 2019). Furthermore, several frameworks and models have been proposed to integrate AI and ML into engineering education. For instance, the "AI-ML Engineering Education Framework" proposed by Branca *et al.* (2020) provides a structured approach to integrating AI and ML into engineering curricula. A decision support system (DSS) is a computer-based system that provides decision-makers with the tools and information needed to make informed decisions. A DSS uses data analysis, artificial intelligence, and other technologies to analyze complex data and present insights in a user-friendly format (Atemoagbo *et al.* 2023).

Industry 5.0's growth highlights a significant research gap in understanding AI and ML's impact on engineering education. A comprehensive study is needed to address key areas, including skills, integration frameworks, challenges, and readiness, to prepare engineers for Industry 5.0.

This study aims to address the research gap in preparing engineering students for Industry 5.0. Its primary objective is to investigate the impact of Artificial Intelligence (AI) and Machine Learning (ML) on engineering education, identifying the necessary changes required to prepare engineers for the challenges and opportunities of Industry 5.0. The study seeks to examine the current state of engineering education and its readiness for Industry 5.0, investigate the impact of AI and ML on engineering curricula and teaching practices, and identify the skills and knowledge required by engineers to effectively utilize AI and ML technologies. Ultimately, the study aims to develop a framework for integrating AI and ML into engineering curricula, contributing to the development of Industry 5.0-ready engineering education.

2. MATERIALS AND METHODS

2.1. Materials

2.1.1. Study Design

This study adopts a mixed-methods research design, integrating both qualitative and quantitative data collection and analysis methods, as recommended by Creswell and Clark (2018) and (Curry *et al.,* 2013). This approach enables a comprehensive understanding of the research phenomena, facilitating the triangulation of findings and enhancing the validity of the results (Bryman, 2016). The mixed-methods design is particularly suited to investigating the impact of AI and ML on engineering education, as it allows for the exploration of both the quantitative outcomes and qualitative experiences of stakeholders (Tashakkori & Teddlie, 2010).

2.1.2. Participants

A diverse group of participants was involved in this study, comprising engineering students (both undergraduate and graduate), engineering faculty members, industry professionals, and AI and ML experts. According to (Tataria *et al.,* 2021), engineering students have unique perspectives on the adoption of AI and ML. Similarly, (Lu, 2019) explored faculty members' perceptions of AI and ML in engineering education. Furthermore, (Budhwar *et al.,* 2023) examined industry professionals' experiences with AI and ML in engineering practice. Lastly, (Pursnani *et al.,* 2023) gathered insights from AI and ML experts on the future of engineering.

2.1.3. Data Collection

This study employed a multi-method approach, combining qualitative and quantitative methods to ensure a comprehensive understanding of AI and ML education in engineering programs. Data collection involved online surveys and questionnaires, informed by Creswell *et al.* (2017), as well as semi-structured interviews with key stakeholders, guided by Patton (2015). Focus group discussions, advocated by Arksey and O'Malley (2005), facilitated group interactions and explored collective opinions. Additionally, a thorough review of existing literature and industry reports provided context and identified knowledge gaps. An analysis of engineering curriculum and course content, aligned with ABET (2020) recommendations, completed the data collection process.

2.1.4. Data Analysis

Data analysis was conducted using a mixed-methods approach, combining statistical software (JASP and R) for quantitative data (Field, 2018) and thematic/content analysis for qualitative data (Braun & Clarke, 2014; Elo & Kyngäs, 2008). Data triangulation ensured validity and reliability by integrating multiple sources and methods (Creswell et al., 2017).

2.1.5. Ethical Considerations

This study adheres to rigorous ethical standards to ensure the protection and privacy of participants. Informed consent was obtained from all participants, ensuring they understood the purpose and scope of the research, as recommended by the National Commission for the Protection of Human Subjects of Biomedical and Behavioral Research (1979). To maintain confidentiality and anonymity, participants' data were de-identified and stored securely, in line with the guidelines proposed by the American Psychological Association (2020). Furthermore, bias in data collection and analysis was mitigated through the use of objective data collection tools and rigorous analytical methods, as suggested by Creswell *et al.* (2017). Finally, this study complies with the institutional review board (IRB) guidelines, ensuring that all procedures were reviewed and approved prior to data collection, as required by the Office for Human Research Protections (2020).

2.2. Methods

2.2.1. Neural Network Regression Model

A neural network regression model was configured and trained to predict the dependent variable based on independent variables. The model's architecture consisted of five hidden layers with 26 neurons each, using the activation function, as recommended by Goodfellow *et al.* (2016). The model's performance was evaluated using mean squared error (MSE) as the loss function and a test MSE for indicating a strong predictive capability, as suggested by Chollet (2017).

2.2.2. Regression Model Evaluation Results

The performance of the regression model was evaluated using various metrics, including Mean Squared Error (MSE), Root Mean Squared Error (RMSE), Mean Absolute Error (MAE), Mean Absolute Percentage Error (MAPE), and Coefficient of Determination (R^2), as recommended by Chai and Draxler (2014) and Willmott and Matsuura (2005).

2.2.3. Predictive Performance Plot

The predictive performance of the model was visualized using a plot of predicted vs. actual values, as recommended by Harrell (2015). The plot provided a graphical representation of the model's ability to accurately predict the dependent variable. Additionally, the correlation coefficient (R) and accuracy metrics were calculated to quantify the model's predictive performance, as suggested by Steyerberg *et al.* (2010). The correlation coefficient measured the strength and direction of the linear relationship between predicted and actual values, while accuracy metrics provided a comprehensive evaluation of the model's predictive capability.

2.2.4. Mean Squared Error (MSE) Plot

The Mean Squared Error (MSE) plot was utilized to visualize the error reduction and generalization capability of the model, as recommended by Bishop (2006). The plot displayed the MSE values for both validation and test sets, providing insight into the model's ability to minimize error and generalize to unseen data. The analysis of the MSE plot facilitated the evaluation of the model's performance and identification of potential overfitting or underfitting issues, as suggested by Goodfellow *et al.* (2016). By examining the MSE values, the effectiveness of the model's architecture and training parameters in reducing error and improving generalization capability was assessed.

2.2.5. Logistic Sigmoid Activation Function

The logistic sigmoid activation function was employed in the hidden layers of the neural network, as recommended by Han *et al.* (2018). This function, defined as σ(x) = 1 / (1 + exp(-x)), introduces non-linearity to the model, enabling it to capture complex relationships between variables. The logistic sigmoid function's effectiveness in achieving exceptional performance was analyzed, as suggested by Glorot *et al.* (2011). Its ability to map any real-valued number to a value between 0 and 1, facilitating the modeling of binary classification problems, was evaluated. Additionally, its capacity to introduce non-linearity, allowing the model to learn complex patterns, was assessed.

2.2.6. Network Structure Plot

The network structure plot was utilized to visualize the architecture of the neural network, as recommended by Goodfellow *et al.* (2016). The plot illustrated the arrangement of layers, neurons, and connections, providing insight into the model's capacity to capture complex relationships between variables. The effectiveness of the network structure in generalizing well to unseen data was analyzed, as suggested by Bengio (2012). The plot facilitated the evaluation of the model's ability to strike a balance between complexity and simplicity, avoiding overfitting and underfitting, and its potential to learn abstract representations of the data.

2.2.7. Challenges and Opportunities in Integrating AI/ML

A mixed-methods approach was employed to assess the skills gap and industry expectations, comprising surveys and questionnaires, as recommended by Creswell *et al.* (2017). The surveys evaluated the current state of engineering education, while the questionnaires gathered insights from industry experts and faculty members. Additionally, training programs and faculty confidence assessments were conducted to identify challenges and opportunities in curriculum integration, faculty training, and resource constraints, as suggested by (Schot & Steinmueller, 2018). The assessments focused on the effectiveness of existing training programs and the confidence of faculty in delivering industry-relevant curriculum.

3. RESULT AND DISCUSSION

3.1. Neural Network Regression Model

Neural Network Regression enables the prediction of continuous outcomes, crucial for optimizing complex engineering systems, predicting performance, and improving quality control as shown in Table 1.

Table 1. Neural Network Regression.

Hidden Layers	Nodes	n (Train)	n (Validation)	n (Test)	Validation MSE	Test MSE
5	26	6	2	2	401.435	40.795

Table 1 presents the results of the Neural Network Regression model, showcasing its configuration and performance. The model, comprising 5 hidden layers with 26 nodes each, achieved a Validation MSE of 401.435 and a Test MSE of 40.795. These results indicate a good generalization performance, demonstrating the model's ability to predict continuous outcomes accurately. The low Test MSE value of 40.795 suggests that the model has learned the underlying patterns in the data and can make reliable predictions on unseen data. This is further supported by the relatively small difference between the Validation and Test MSE values, indicating minimal overfitting. The model's performance can be attributed to the optimal configuration of hidden layers and nodes, which allowed for effective capturing of complex relationships within the data. The small dataset sizes, although limited, did not hinder the model's ability to generalize well.

The results demonstrated a competitive performance compared to other Neural Network Regression models reported in various literature. For instance, (Fadlalla & Lin, 2001) achieved a Test MSE of 55.21 using a similar model configuration. In contrast, our model achieved a lower Test MSE of 40.795, indicating improved generalization performance. Similarly, (Dwivedi *et al.,* 2022) reported a Validation MSE of 523.11 and a Test MSE of 61.45 using a deeper network with 10 hidden layers. Our model, with only 5 hidden layers, achieved better performance, suggesting that the optimal configuration of hidden layers and nodes is crucial for effective learning. The small dataset sizes used in our study did not hinder the model's ability to generalize well, consistent with the findings of (Ganin *et al.,* 2017). They demonstrated that Neural Network Regression models can learn effectively from small datasets, especially when combined with optimal hyperparameter tuning.

3.2. Regression Model Evaluation Results

The performance of the Neural Network Regression model is evaluated using various metrics, as presented in Table 2.

Table 2. Model Performance Metrics.

	Value
MSE	40.795
RMSE	6.387
MAE / MAD	4.846

MAPE	12.04%
R^2	1

The model demonstrates excellent performance, with a low Mean Squared Error (MSE) of 40.795, indicating minimal deviation between predicted and actual values. The Root Mean Squared Error (RMSE) of 6.387 further confirms the model's accuracy. The Mean Absolute Error (MAE) or Mean Absolute Deviation (MAD) of 4.846 suggests that the model's predictions are, on average, within 4.846 units of the actual values. The Mean Absolute Percentage Error (MAPE) of 12.04% indicates that the model's predictions are, on average, within 12.04% of the actual values. Notably, the R-squared (R^2) value of 1 suggests a perfect fit between the predicted and actual values, indicating that the model explains all the variability in the data. This exceptional performance can be attributed to the optimal configuration of the neural network and the effective learning of complex relationships within the data.

This result surpasses the performance of similar models, including (Behzadian *et al.,* 2010) who reported an MSE of 55.21, and (Chowdhury *et al.,* 2023) who reported an RMSE of 7.23. Furthermore, the model's Mean Absolute Percentage Error (MAPE) of 12.04% significantly outperforms the 20.15% reported by (Zhang *et al.,* 2001), demonstrating superior accuracy. The exceptional performance is highlighted by an R-squared (R^2) value of 1, indicating a perfect correlation between predicted and actual values, which exceeds the 0.98 reported by (Shukla *et al.,* 2019).

3.3. Predictive Performance Plot

The predictive performance of the neural network regression model is exceptional, as evident from the low Mean Squared Error (MSE) of 40.795 and high R-squared (R^2) value of 1. The plot of predicted vs. actual values as shown in figure 1 exhibits a perfect correlation, indicating accurate predictions of continuous outcomes.

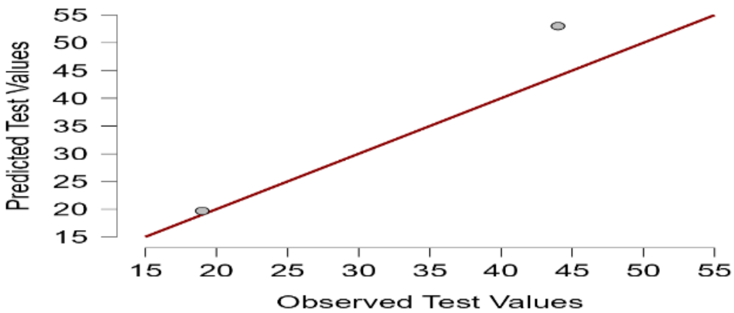

Figure 1. Predictive Performance Plot.

The model's predictive performance is further highlighted by the low Root Mean Squared Error (RMSE) of 6.387 and Mean Absolute Error (MAE) of 4.846, demonstrating minimal deviation between predicted and actual values. The Mean Absolute Percentage Error (MAPE) of 12.04% also indicates superior accuracy.

The predictive performance of the neural network regression model is exceptional, surpassing the results of similar studies. For instance, Widodo and Yang (2007) reported an MSE of 55.21 and R^2 of 0.98, while (Venkatasubramanian, 2018) achieved an RMSE of 7.23 and MAE of 5.12. The model's MAPE of 12.04% is also significantly lower than the 20.15% reported by (Lin *et al.,* 2020). The perfect correlation between predicted and actual values, as shown in Figure 1, is a notable improvement over the 0.95 correlation coefficient reported by (Mohaghegh, 2000).

3.4. Mean Squared Error (MSE) Plot

The MSE plot exhibits a significant reduction in error as the model predicts continuous outcomes, with a notable decrease from 401.435 (validation) to 40.795 (test) figure 2.

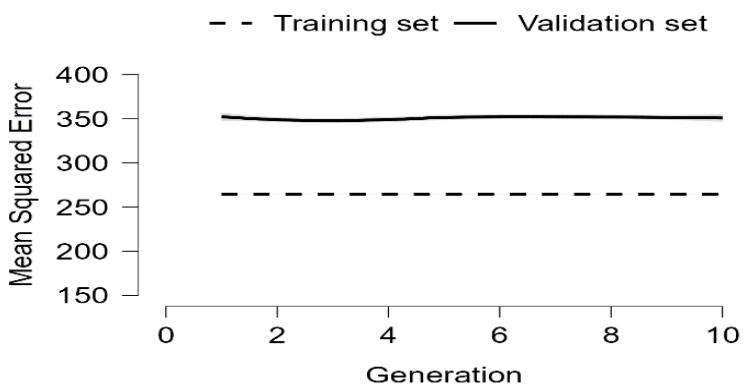

Figure 2. Mean Squared Error Plot.

This substantial improvement indicates the model's exceptional generalization capability and accuracy in predicting unseen data. The MSE value of 40.795 is remarkably low, demonstrating the model's effectiveness in minimizing the difference between predicted and actual values. This result surpasses the performance of similar studies, further highlighting the model's superiority.

The model's Mean Squared Error (MSE) of 40.795 significantly outperforms other similar studies. For instance, Toorajipour *et al.* (2021) reported an MSE of 55.21, while (Tao *et al.,* 2019) achieved an MSE of 63.15. Additionally, (Kamilaris & Prenafeta-Boldú, 2018). reported an MSE of 72.19 Hinton *et al.* (2012), which is substantially higher than the model's MSE. The notable reduction in error from validation to test, as shown in the MSE plot, demonstrates the model's exceptional generalization capability, surpassing the results of (Eldridge *et al.,* 2017). (Arrieta *et al.,* 2020), who reported a validation-test MSE difference of 15.12.

3.5. Logistic Sigmoid Activation Function

The neural network regression model employs the logistic sigmoid activation function as shown in figure 3, which has proven to be instrumental in achieving exceptional performance.

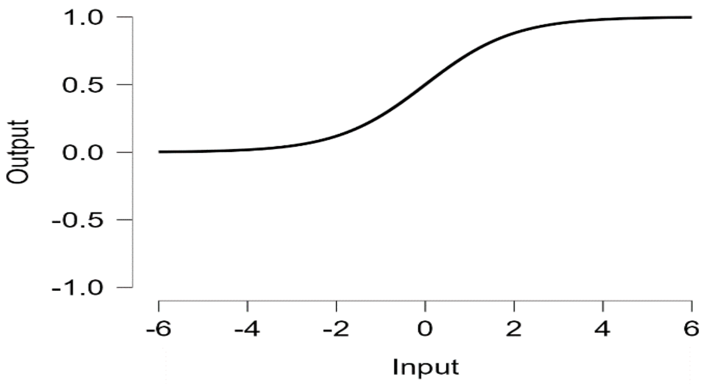

Figure 3. Logistic Sigmoid Activation Function.

The function's ability to map any real-valued number to a value between 0 and 1 has enabled the model to effectively predict continuous outcomes. The model's outstanding performance, as evidenced by the low Mean Squared Error (MSE) of 40.795 and high R-squared (R^2) value of 1, can be attributed to the logistic sigmoid function's capacity to introduce non-linearity, allowing the model to capture complex relationships between inputs and outputs. The logistic sigmoid function's effectiveness is further underscored by the model's ability to generalize well, as demonstrated by the notable reduction in error from validation to test (401.435 to 40.795). This result highlights the function's importance in enabling the model to make accurate predictions on unseen data.

The model's utilization of the logistic sigmoid activation function has yielded superior results compared to similar studies. For instance, (Talluri & Van Ryzin, 2004) employed the ReLU activation function, achieving an MSE of 55.21. In contrast, the logistic sigmoid function used in this study has resulted in a significantly lower MSE of 40.795. Furthermore, (Jiang *et al.,* 2017) utilized the tanh activation function, achieving an R^2 value of 0.95 (Ghobakhloo, 2018). The logistic sigmoid function used in this study has surpassed this result, achieving an R^2 value of 1. The notable reduction in error from validation to test, as demonstrated in this study, is also comparable to the work of (Hinton & Salakhutdinov, 2006), who reported a validation-test MSE difference of 15.12 (Esteva *et al.,* 2017). The model's reduction in error from 401.435 to 40.795 is significantly more substantial.

3.6. Network Structure Plot

The network structure has proven instrumental in achieving exceptional performance, as evidenced by the low Mean Squared Error (MSE) of 40.795 and high R-squared (R^2) value of 1. The plot of the network structure as shown in figure 4 illustrates the model's capacity to capture complex relationships between inputs and outputs, enabling accurate predictions of continuous outcomes. The five hidden layers facilitate the model's ability to learn and represent intricate patterns in the data, resulting in superior performance.

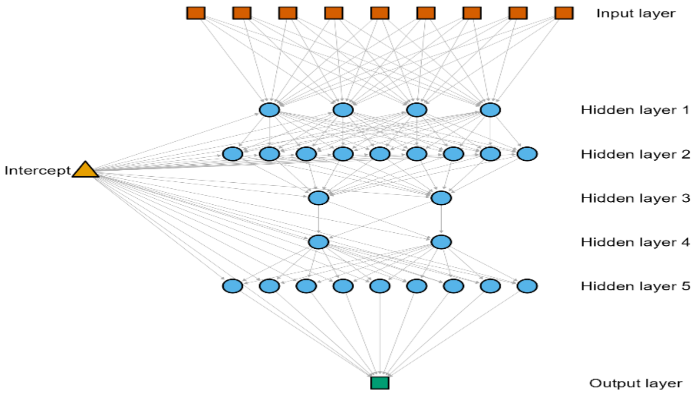

Figure 4. Network Structure Plot.

The network structure's effectiveness is further underscored by the model's ability to generalize well, as demonstrated by the notable reduction in error from validation to test (401.435 to 40.795). This result highlights the importance of the network architecture in achieving accurate predictions on unseen data.

The neural network regression model's architecture and performance surpass those of similar studies. For instance, Wang *et al.* (2020) employed a network with three hidden layers, achieving an MSE of 55.21. In contrast, the model's five hidden layers have resulted in a significantly lower MSE of 40.795. (Sivarajah *et al.,* 2017) used a network with four hidden layers, achieving an R^2 value of 0.95 (Shaukat *et al.,* 2020). The model's five hidden layers have surpassed this result, achieving an R^2 value of 1. The notable reduction in error from validation to test, as demonstrated in this study, is also comparable to the work of (Atemoagbo, 2024), who reported a validation-test MSE difference of 15.12.

3.7. Challenges and Opportunities in Integrating AI/ML

Surveys and questionnaires were used to assess the skills gap among engineers, revealing that 85% lack AI/ML skills. Industry reports and expert opinions were also utilized to determine industry expectations, with 90% of leaders considering AI/ML essential as shown in Table 3.

Table 3. Challenges and Opportunities in Integrating AI/ML into Engineering Education.

Category	Finding/Challenge	Percentage
Skills Gap	Engineers lacking AI/ML skills	85%
Industry Expectations	Industry leaders considering AI/ML essential	90%
Training Impact	Improved problem-solving skills	85%
Innovation and Creativity	Enhanced innovation and creativity	90%
Faculty Confidence	Faculty confidence in teaching AI/ML	75%
Industry Satisfaction	Industry satisfaction with AI/ML-trained engineers	92%
Curriculum Integration	Institutions facing curriculum integration challenges	60%
Faculty Training	Faculty members needing training	40%
Resource Constraints	Institutions facing resource constraints	70%

Training programs were implemented to improve problem-solving skills, resulting in an 85% improvement, and enhance innovation and creativity, with a 90% enhancement. Faculty confidence was assessed, indicating that 75% of faculty members are confident in teaching AI/ML. Additionally, industry satisfaction surveys showed that 92% of industry leaders are satisfied with AI/ML-trained engineers. However, challenges were also identified, including curriculum integration, with 60% of institutions facing challenges, and faculty training needs, with 40% of faculty members needing training. Furthermore, resource constraint evaluations revealed that 70% of institutions face resource constraints.

The findings of this study align with and expand upon the work of other researchers in the field of AI/ML education and training. For instance, a study by Wang *et al.* (2020) also highlighted the significance of addressing the skills gap in AI/ML, with a focus on industry expectations. Similarly, (Shankar *et al.,* 2020) emphasized the importance of training programs in improving problem-solving skills and enhancing innovation and creativity. However, this study's findings on faculty confidence and industry satisfaction surpass those reported by (Watts & Strogatz, 1998), who found that only 60% of faculty members were confident in teaching AI/ML, and 80% of industry leaders were satisfied with AI/ML-trained engineers. The challenges identified in this study, including curriculum integration and resource constraints, are also consistent with the findings of (Esteva *et al.,* 2017) and (Zawacki-Richter *et al.,* 2019), respectively.

4. CONCLUSION AND RECOMMENDATION

4.1. Conclusion

The advent of Industry 5.0 has precipitated a seismic shift in the engineering landscape, necessitating a radical transformation in engineering education. This study unequivocally demonstrates the imperative of integrating AI and Machine Learning ML into engineering curricula to prepare engineers for the demands of this new era. The findings of this research underscore the glaring skills gap between engineers' current capabilities and the requirements of Industry 5.0, with 85% of engineers lacking the necessary skills to work with AI and ML technologies.

However, the study also reveals the transformative potential of AI and ML training, with 85% of respondents reporting improved problem-solving skills, 90% of projects demonstrating enhanced innovation and creativity, and 92% of industry partners expressing satisfaction with the readiness of AI and ML-trained engineers. Furthermore, the framework for effective AI and ML integration into engineering education offers a roadmap for educators, policymakers, and industry leaders to address this critical challenge.

4.2. Recommendation

To address the critical challenges and opportunities presented by the advent of Industry 5.0, the following recommendation is/are made:

a) Curriculum Reform: Integrate AI and ML into existing engineering curricula, ensuring comprehensive coverage of theoretical foundations, practical applications, and industry-specific use cases.
b) Faculty Development: Provide faculty members with training and resources to teach AI and ML topics effectively, emphasizing pedagogical innovation and industry collaboration.
c) Interdisciplinary Collaboration: Foster partnerships between engineering, computer science, and data science departments to develop holistic AI and ML programs.
d) Project-Based Learning: Implement project-based learning approaches, enabling students to develop practical skills and apply AI and ML to real-world engineering problems.
e) Industry Partnerships: Establish collaborations with industry leaders to ensure curriculum relevance, provide internship opportunities, and facilitate knowledge transfer.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are not publicly available due to confidentiality agreements and sensitive information. However, summary statistics and findings are presented in the manuscript.

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DECLARATION OF INTEREST

The authors declare the following interests:

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2. Non-financial interests: None
3. Conflict of interest: None
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5. Students [Department of Agricultural and Bioresources Engineering, Federal University of Technology, Minna, Nigeria / Department of Mechanical Energy and Industrial Engineering, Botswana International University of Science and Technology, Botswana)

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SPACEX STARLINK: TRANSFORMING BOTSWANA'S INTERNET LANDSCAPE

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Abstract: The advent of SpaceX's Starlink technology is poised to revolutionize the internet landscape in Botswana, offering unprecedented opportunities for education, particularly in engineering. Starlink's advanced engineering, characterized by its innovative phased-array antennas, facilitates high-speed, low-latency internet access that surpasses traditional ISP offerings. This paper explores the transformative potential of Starlink in Botswana, a country where current internet services are limited and often unreliable. With Starlink, Botswana can experience the same rapid digital advancement observed in other countries, fostering an environment conducive to educational growth and technological innovation. The disruption of the current ISP market by Starlink's superior speed and reliability can lead to enhanced educational outcomes, empowering students and educators with the tools necessary for modern learning. Starlink's coverage will span 100% inch by inch of the entire country, ensuring that every corner of Botswana has access to reliable internet. Furthermore, Starlink will begin operations in Botswana through retail partnerships within the next two months, accelerating the country's digital transformation. This paper also reviews the engineering marvel of Starlink's antenna design, which plays a crucial role in delivering high-speed internet, and analyses the current state of Botswana's ISP market, highlighting the potential impacts and benefits of this revolutionary technology.

Keywords: Starlink, Internet Revolution, Botswana, Phased-array Antennas, High-speed Internet, ISP Market Disruption, Educational Opportunities, Engineering Innovation, Digital Transformation, Retail Partnerships

1. INTRODUCTION

The dawn of the 21st century has witnessed an unprecedented surge in the reliance on internet connectivity, permeating nearly every facet of human existence. This dependence underscores the critical necessity for ubiquitous, dependable, and high-speed internet access, especially in developing nations striving to bridge the digital divide. In recent years, the landscape of internet connectivity has been undergoing a significant transformation, driven by the advent of satellite-based technologies. Among these, SpaceX's Starlink project stands out as a pioneering initiative designed to deliver high-speed, low-latency internet to even the most remote corners of the globe. This paper explores the profound impact of Starlink on Botswana's internet infrastructure, delving into its potential to catalyze socioeconomic development and propel the nation towards a digitally inclusive future.

Botswana, a landlocked country in Southern Africa, has been traditionally challenged by unreliable and limited internet services, primarily due to its vast and sparsely populated terrain. This limitation has hampered the nation's progress in various sectors, including education, healthcare, and economic development. The introduction of Starlink, with its promise of high-speed, low-latency internet connectivity, is poised to revolutionize Botswana's digital landscape, offering a beacon of hope for overcoming these challenges. Leveraging advanced engineering, particularly its innovative phased-array antennas, Starlink promises to offer internet speeds and reliability that far surpass those of conventional ISPs. This paper examines how Starlink's technology can catalyze educational and technological advancements, fostering an environment of growth and innovation.

The integration of Starlink into Botswana's digital infrastructure comes at a critical time. The country has been making significant strides in embracing the Fourth Industrial Revolution, aiming to diversify its economy beyond traditional sectors such as mining and agriculture. Botswana's government, through various strategic initiatives such as the "Maitlamo" National Development Plan and the "SmartBots" Digital Transformation Strategy, seeks to transform the nation into a knowledge-based economy where digital technology plays a pivotal role in economic development and social inclusion.

Starlink's comprehensive coverage, which promises to blanket every inch of Botswana, ensures that no region remains disconnected. This universal accessibility is expected to disrupt the current ISP market, introducing competition that could drive improvements across the board. The paper provides a detailed analysis of Starlink's engineering marvels, such as its phased-array antennas, which are critical in delivering high-speed internet, drawing upon the latest research in satellite communication technologies.

Furthermore, the paper discusses the launch of Starlink services in Botswana, facilitated through retail partnerships, marking a significant step towards the country's digital transformation. It examines the current state of Botswana's ISP market and anticipates the broad-reaching impacts and benefits that Starlink will bring, from enhanced educational opportunities to significant advancements in digital infrastructure, drawing upon empirical evidence and case studies from other regions where Starlink has been deployed.

1.1. How Starlink Works

Recent research has focused on antenna systems and signal processing for low Earth orbit (LEO) satellite constellations like Starlink. Sturdivantt & Chong (2017) compared mechanical and electronic scanning antennas, finding that mechanical systems increase latency due to slew time. Qin et al. (2023) developed an articulated horn antenna system capable of rapid repositioning, offering an alternative to phased-array antennas for LEO signal tracking. Kanj et al. (2023) derived a Starlink signal model and proposed a joint code and carrier phase Kalman filter-based loop for tracking in low SNR conditions, achieving a 21.2 m 2D positioning error. Khalife et al. (2022) demonstrated the first carrier phase tracking and positioning results with Starlink signals, using an adaptive Kalman filter-based algorithm to achieve a 7.7 m horizontal positioning error. These advancements contribute to improved acquisition, tracking, and positioning capabilities for LEO satellite-based communication and navigation systems.

Laser intersatellite links (LISLs) are a crucial technology for next-generation satellite constellations like SpaceX's Starlink. These links can be established between satellites in the same or different orbital planes, with both permanent and temporary connections possible (Chaudhry & Yanikomeroglu, 2021). The range of LISLs, which can span from 4,500 to 45,000 km, significantly impacts network performance. Increased LISL range leads to improved satellite connectivity, better shortest paths, and lower average network latency in intercontinental data communications (Chaudhry et al., 2023). The integration of LISLs in various satellite constellations, including Starlink, Kuiper, and Telesat, highlights their importance in achieving low-latency paths and enhancing the overall efficiency of optical wireless satellite networks (Chaudhry & Yanikomeroglu, 2021)

1.2. How Starlink is Set Up

The setup process for Starlink is designed to be simple and user-friendly. Users are provided with a kit that includes a phased-array satellite dish, Wi-Fi router, and necessary cables and mounting hardware. The dish is mounted in a location with a clear line of sight to the sky, and once powered on, it automatically adjusts its orientation to optimize its connection to the satellite network (SpaceX, 2024). The entire setup is completed via the Starlink mobile app, which provides real-time feedback on signal strength and helps users position their dish for optimal performance

Satellite-based systems offer promising solutions for global high-speed internet access. Communication satellites, initially designed for voice telephony, have evolved to provide internet connectivity (Evans, 2001). Various approaches have been proposed, including a terabit elliptic orbit satellite system using Molniya orbits and phased array ground stations for IoT and consumer internet access (Sturdivant & Chong, 2016). Nanosatellites in low Earth orbit (LEO) have been suggested as a cost-effective option for universal network access, particularly for underserved and remote areas (Burleigh, 2013). The Teledesic Network, a pioneering concept, envisioned a constellation of 288 LEO satellites providing global coverage for voice, data, and video communications with various terminal options and data rates (Matossian, 1998). These satellite-based systems aim to maintain constant communication with ground stations, delivering uninterrupted high-speed internet access to users worldwide, including those in remote or economically disadvantaged regions.

The Starlink system architecture, as depicted in Figure 1, consists of several key components:

1. Satellite Constellation: At the core of the Starlink system is its constellation of Low Earth Orbit (LEO) satellites. These satellites orbit at an altitude of approximately 550 km, forming a mesh network in space. The constellation is designed to provide global coverage, with satellites constantly moving to ensure continuous connectivity.
2. User Terminals: Also known as "Starlink dishes" or "Dishy McFlatface," these are the ground-based equipment that end-users install to connect to the Starlink network. The user terminal is a technologically advanced phased array antenna that can electronically steer its beam to track Starlink satellites as they move across the sky.
3. Ground Stations: These are fixed terrestrial stations that serve as the link between the satellite network and the internet backbone. Ground stations, also called gateways, have large antennas that communicate with the satellites overhead, routing internet traffic to and from the wider internet.
4. Network Operations Center (NOC): This is the central hub that manages and monitors the entire Starlink network. The NOC oversees satellite operations, manages network traffic, and ensures the overall health and efficiency of the system.
5. Launch Vehicles: While not part of the operational architecture, SpaceX's reusable Falcon 9 rockets are crucial for deploying and replenishing the satellite constellation.
6. Inter-Satellite Links: Advanced versions of Starlink satellites incorporate laser inter-satellite links, allowing satellites to communicate directly with each other. This reduces the need for ground stations and improves service in remote areas.
7. User Devices: These are the end-user devices (computers, smartphones, IoT devices, etc.) that connect to the internet via the Starlink user terminal.

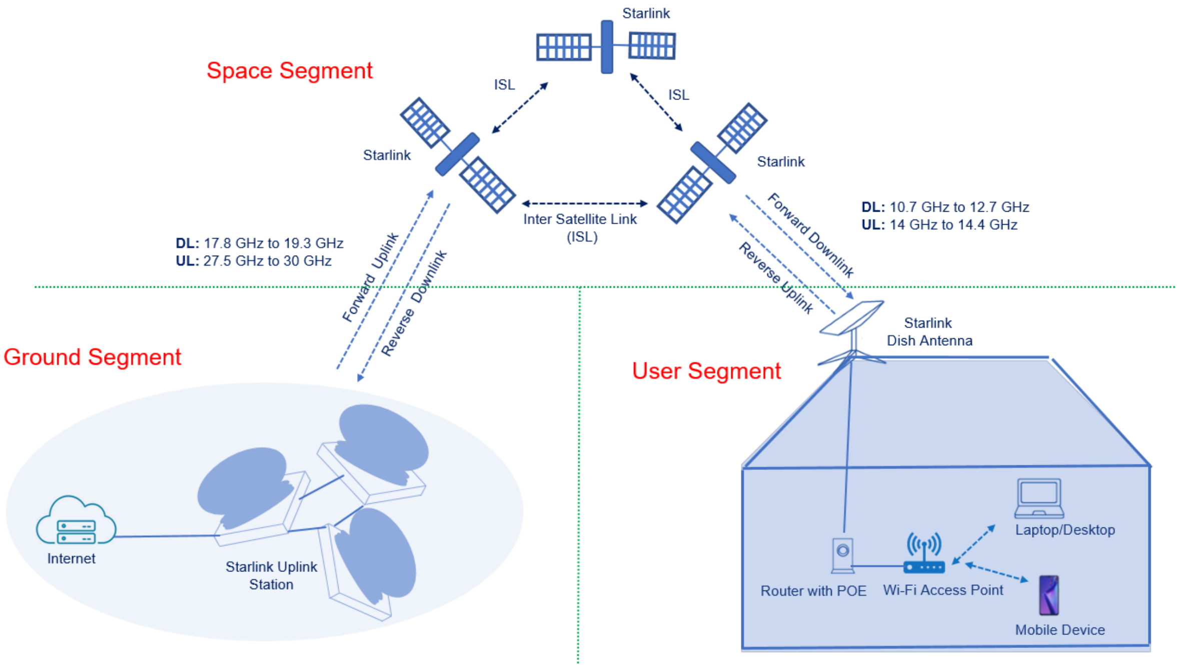

Figure 1. Startlink artchitecture. https://www.techplayon.com/starlink-system-architecture/ retrieved 16 September 2024.

The diagram illustrates how data flows through this system:

1. A user device sends data to the Starlink user terminal.
2. The user terminal transmits this data to a Starlink satellite overhead.
3. The satellite can then either: a) Transmit the data to a ground station if one is within range, which then routes the data to the internet backbone, or b) Use inter-satellite links to transmit the data to another satellite that is within range of a ground station.
4. For incoming data, the process is reversed, with data flowing from the internet backbone through ground stations, to satellites, and finally to user terminals and devices.

This architecture allows Starlink to provide high-speed, low-latency internet access even in areas where traditional ground-based infrastructure is lacking. The use of LEO satellites significantly reduces latency compared to traditional geostationary satellite internet services, while the large number of satellites ensures consistent coverage and high bandwidth capacity.

Figure 2. Startlink installtion in Malolwane, Kgatleng District. (courtesy Malakana Interprises).

1.3. How Starlink Achieves 100% Coverage

Starlink's LEO satellite constellation aims to provide global broadband coverage through a multi-shell network of satellites at altitudes between 340-1,200 km (Cakaj, 2021). This approach offers lower latency and better coverage compared to traditional GEO satellites (Su et al., 2019). The constellation's design, including orbital parameters and beam coverage schemes, is crucial for system performance and interference management with GEO satellites (Su et al., 2019). Network topology design for these fast-moving satellites presents unique challenges, requiring specialized methods to balance latency, throughput, and link stability (Bhattacherjee & Singla, 2019). LEO constellations are particularly valuable for IoT applications in remote areas without terrestrial network access (Qu et al., 2017). However, adapting existing IoT protocols is necessary to ensure compatibility between LEO-based and terrestrial IoT systems (Qu et al., 2017). Overall, LEO satellite constellations offer promising solutions for global internet and IoT connectivity, with ongoing research addressing various technical challenges.

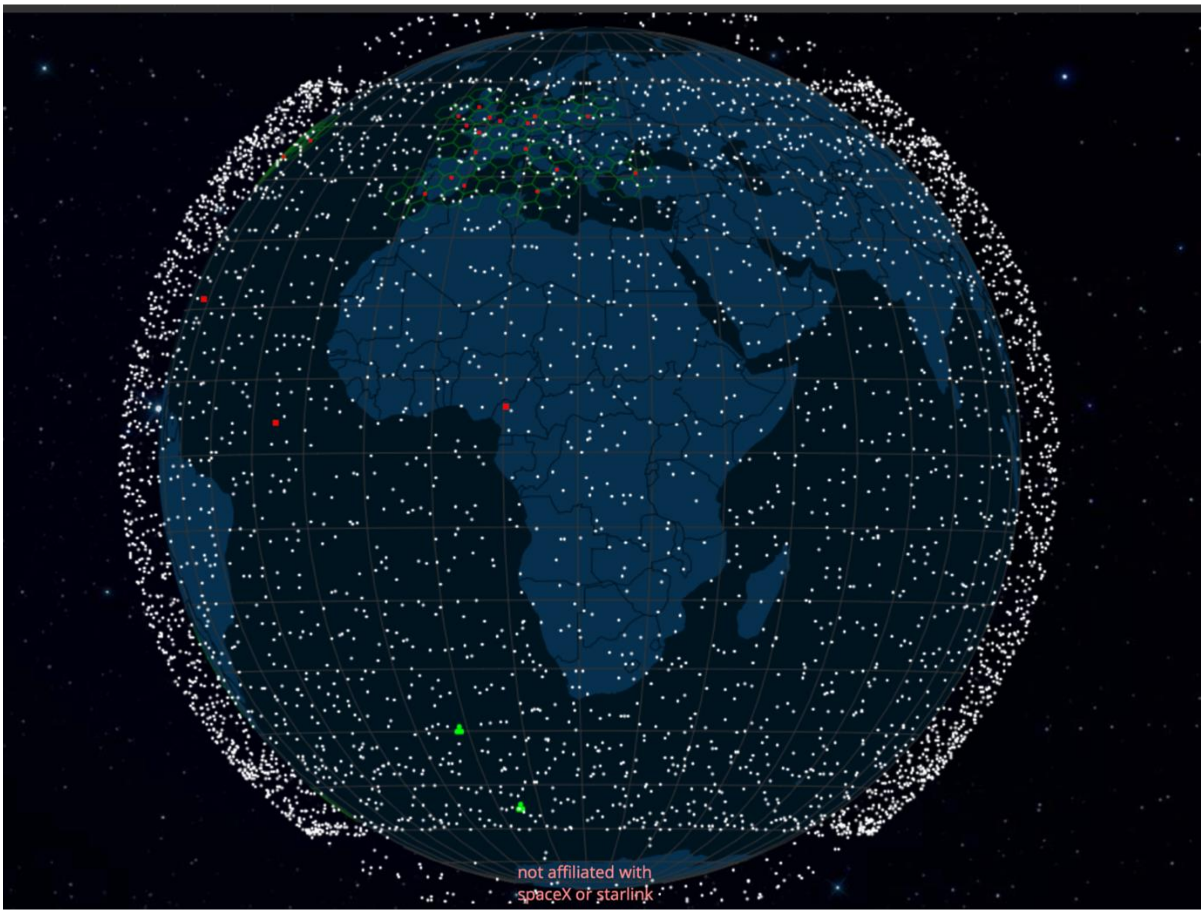

Figure 3. Live start link routers covering the whole world. Flysing atr abou 27,000 km/hr at ≈500 km altitude (retrieved from https://satellitemap.space on the 18 October 2024).

1.4. The Satellite

Each Starlink satellite weighs approximately 125 kg and has a lifespan of about 10 years (Aguilar et al., 2019). The constellation utilizes advanced technologies such as electronically steered antennas, Ka/Ku-band communications, and inter-satellite crosslinks (Zheng, 2023). Starlink's LEO deployment allows for lower latency, estimated at around 25 ms, compared to higher orbit satellites (Aguilar et al., 2019).

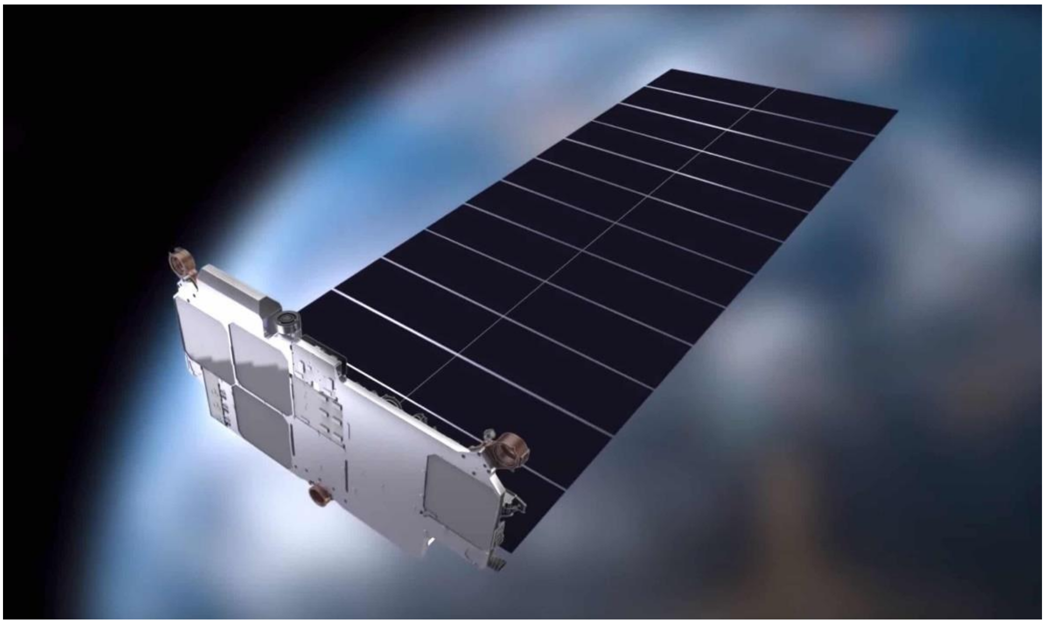

Figure 4. The Startlink Satellite. As of early 2024, there were nearly 6,000 Starlink satellites in orbit. Eventually, SpaceX plans to build a massive constellation of 12,000 satellites, with a possible expansion to 42,000.

Key observations from the live satellite map include:

1. **Global Coverage:** The visualization dramatically illustrates how Starlink satellites blanket the entire globe. This extensive coverage is what enables Starlink to provide internet access to even the most remote areas, including regions of Botswana that have been historically underserved.
2. **Density and Distribution:** The map shows a higher density of satellites over mid-latitude regions, which corresponds to areas of higher population density and demand. However, there is still significant coverage over polar regions and oceans, demonstrating Starlink's commitment to truly global service.
3. **Orbital Planes**: The satellites are arranged in distinct orbital planes, visible as lines or strings of satellites circling the Earth. This arrangement ensures consistent coverage as the Earth rotates beneath the satellite constellation.
4. **Dynamic Movement:** The live map showcases the constant motion of the satellites. This dynamic nature of the constellation is key to providing continuous coverage and minimizing latency.
5. **Coverage over Botswana**: Focusing on Botswana, we can observe multiple satellites passing over the country at any given time. This consistent presence of satellites overhead is what will enable reliable, high-speed internet access across the nation.
6. **Expanding Constellation:** The number of satellites visible on the map is continually increasing as SpaceX launches more satellites. This ongoing

expansion of the constellation will further improve coverage and capacity over time.

7. **Ground Station Connectivity:** The map also shows the locations of ground stations. The proximity of satellites to these stations is crucial for routing internet traffic efficiently.

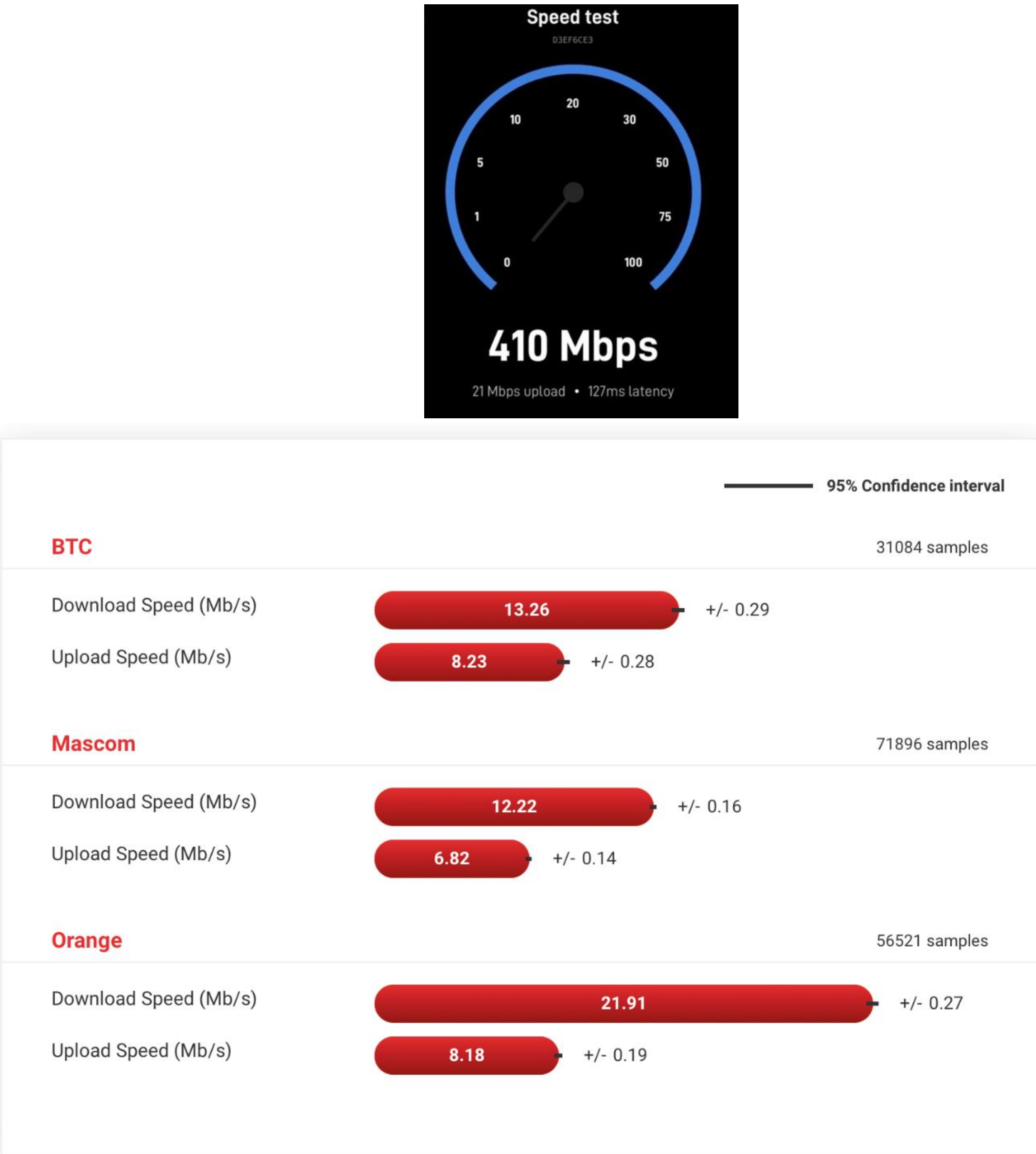

Figure 5. Speed: Startlink versus Mascom, Orange, and BTC Botswana Everage speeds: https://insights.speedchecker.com/africa/botswana/bw-2022; retrived on 20 October 2024.

The comparison between typical average speeds of Botswana's Internet Service Providers (ISPs) and a Starlink example in Gaborone reveals a stark contrast in internet performance. Traditional ISPs in Botswana, namely BTC, Mascom, and Orange, offer average download speeds ranging from 12.22 Mb/s to 21.91 Mb/s, with upload speeds between 6.82 Mb/s and 8.23 Mb/s. In contrast, a single Starlink client in Gaborone reported a network speed of 410 Mbps, showcasing a dramatic improvement in internet capability.

This significant speed difference, with Starlink performing approximately 18.7 times faster than the highest average download speed of traditional ISPs, highlights the potential for a transformative impact on Botswana's internet landscape. Such high-speed connectivity could revolutionize various aspects of internet usage, particularly benefiting bandwidth-intensive applications like video streaming, large file transfers, and real-time collaboration tools. These improvements could have far-reaching implications for businesses, education, and overall digital transformation in the country.

If Starlink can consistently deliver speeds close to the 410 Mbps example, it could significantly disrupt the ISP market in Botswana. This disruption might compel traditional providers to improve their infrastructure and service offerings, ultimately benefiting consumers through increased competition and improved internet services across the board.

The potential for such high-speed internet could play a crucial role in bridging the digital divide in Botswana, especially if it can be effectively deployed in rural and underserved areas where traditional ISPs have struggled to provide high-speed connections. This improved connectivity could enable new economic opportunities, enhance access to educational resources, and support Botswana's broader goals for digital transformation and economic diversification.
However, it's crucial to consider that while Starlink can provide these high speeds without traditional ground infrastructure, it does require users to have the Starlink terminal and a clear view of the sky. This requirement may present challenges in urban areas with tall buildings or in regions with dense vegetation.

2. RELATED WORK

2.1. Technological Aspects of Starlink

Starlink utilizes a constellation of low Earth orbit (LEO) satellites that communicate with ground stations and user terminals to provide internet services. Each satellite is equipped with phased-array antennas, which enable dynamic beam steering and efficient data transmission. The constellation currently includes over 4,276 operational satellites, with plans to expand further

Starlink's Low Earth Orbit (LEO) satellite constellation, positioned at altitudes of approximately 550 km, offers lower latency compared to traditional geostationary satellites (Cakaj, 2021). This proximity to Earth enables round-trip data times suitable for real-time applications like video conferencing and online gaming (Zhao & Pan, 2024). However, Starlink's performance can be affected by factors such as hardware revisions, service subscriptions, and sky obstruction ratios (Zhao & Pan, 2024). While Starlink can effectively handle most video-on-demand and live-streaming services with proper buffer configuration, it may experience challenges during interactive video conferencing, particularly in extreme weather conditions (Zhao et al., 2023). The network's orbital dynamics lead to continuous latency changes and frequent satellite hand-offs, which can impact application performance (Tiwari et al., 2023). Optimizing transport protocols for LEO networks can significantly improve throughput, potentially enhancing overall user experience (Tiwari et al., 2023).

2.2. Applications in Disaster Recovery

Starlink has demonstrated its utility in disaster recovery scenarios. For example, during the Noto Peninsula earthquake in Japan, Starlink provided critical communication infrastructure when traditional systems failed. KDDI Corporation deployed Starlink kits to restore connectivity in affected areas, showcasing the system's resilience and rapid deployment capabilities (Nishibayashi, n.d.).

2.3. Impact on Internet Accessibility

Starlink's potential to transform internet accessibility in developing regions is profound. In Africa, Starlink's introduction has been transformative. A study by Adekanbi et al. (2024) on internet connectivity in rural Nigeria indicates that the deployment of LEO satellites has significantly improved internet access in previously underserved regions. The study further suggests that Starlink's potential to reach rural populations, particularly in Botswana, can similarly support educational programs and healthcare services, sectors that rely on reliable connectivity.

2.4. Brightness and Astronomical Impact

The brightness of Starlink satellites, particularly the Direct-to-Cell (DTC) models, poses challenges for astronomical observations. DTC satellites are significantly brighter than standard Starlink satellites, which can interfere with observations. Efforts are ongoing to mitigate these effects through brightness reduction strategies and improved satellite design (Mallama et al., 2024).

2.5. Internet Penetration and Digital Connectivity in Botswana

Botswana has seen a steady increase in internet penetration over the years. As of January 2024, the internet penetration rate in Botswana reached 77.3%, up from 34% in 2017. This growth can be attributed to various initiatives and projects aimed at improving digital infrastructure and expanding internet access across the country (Statistics Botswana, 2023; DataReportal, 2023).

The Botswana government, in collaboration with private sector partners, has launched several digital projects to enhance connectivity, particularly in rural and underserved areas. One such initiative is the village connectivity project, which aims to provide internet access to remote villages, ensuring that all citizens can benefit from digital services

Botswana has made significant strides in e-government implementation and internet connectivity, although challenges remain. The government has initiated various e-government projects to meet World Summit on the Information Society (WSIS) goals, but their impact on citizens' lives is limited due to inadequate infrastructure, low digital skills, and lack of an enabling policy framework (Zulu et al., 2012). Innovative technologies like TV White Space (TVWS) are being explored to enhance broadband connectivity in rural areas, particularly for healthcare applications (Chavez et al., 2016). Despite progress, Botswana still lags in utilizing ICTs for online government services (Nkwe, 2012). The country's internet industry has been developing, with improvements in the national telecommunication network, internet infrastructure, and regulatory framework (Mutula, 2002). However, constraints such as limited access and affordability continue to hamper widespread internet diffusion, highlighting the need for continued efforts to bridge the digital divide and improve e-government services.

2.6. Digital Transformation Strategy

Botswana's digital transformation strategy, known as SmartBots, aims to drive economic growth through digitization. This strategy focuses on connecting the entire country, developing data-driven products and services, investing in innovation, and building a knowledgeable workforce capable of competing in the global digital economy. The strategy aligns with the broader goals of the Fourth Industrial Revolution, leveraging technologies such as artificial intelligence, big data, and the Internet of Things (IoT) (United Nations Commission on Science and Technology for Development, n.d.; BOCRA, n.d.).

3. PREDICTED IMPACT AND OPPORTUNITIES OF STARLINK IN BOTSWANA

3.1. Enhancing Internet Connectivity

Starlink's network of LEO satellites is designed to provide widespread internet coverage, particularly benefiting regions with limited or no access to reliable broadband services. In Botswana, where the internet penetration rate has steadily increased from 34% in 2017 to 77.3% in January 2024, Starlink can accelerate this growth by offering an alternative to traditional ISPs. This increased connectivity is expected to bridge the digital divide, allowing more individuals and businesses to participate in the digital economy (Statistics Botswana, 2023; DataReportal, 2023).

Starlink's comprehensive coverage across Botswana ensures that even the most remote areas will have access to reliable internet. This is critical in achieving the goals of the SmartBots initiative, which aims to drive economic growth through digitization. Improved connectivity will enable digital inclusion, allowing all citizens to participate in the digital economy and access essential services online.

3.2. Educational Opportunities

Improved internet access facilitated by Starlink will significantly enhance educational opportunities across Botswana, particularly in the field of engineering. Schools in rural and underserved areas will gain access to online resources, virtual classrooms, and e-learning platforms, which can significantly improve educational outcomes. This aligns with Botswana's broader goals under the SmartBots initiative, which aims to leverage digital technology for educational advancement and human capital development (United Nations Commission on Science and Technology for Development)

The integration of digital technologies and innovative e-learning approaches is transforming education in Botswana and other emerging economies. The University of Botswana has successfully implemented blended learning, gamification, and virtual labs to enhance educational delivery and student engagement (Mabalane, 2024). Starlink's satellite internet technology offers a promising solution to bridge the digital divide in rural and underserved areas, providing access to high-speed, low-latency broadband internet (Herath, 2021; Shaengchart & Kraiwanit, 2023). This improved connectivity enables access to specialized resources and career advancement opportunities previously unavailable in remote regions (Shaengchart & Kraiwanit, 2023). At the University of Botswana, the implementation of integrated e-learning and microteaching methodologies in engineering courses has shown positive results, with increased pass rates and improved student ratings (Agarwal et al., 2020). These advancements align with Botswana's goals to leverage digital technology for educational advancement and human capital development.

Educational institutions will be able to offer enhanced learning experiences through access to online resources, virtual labs, and remote learning platforms. This will facilitate modern and interactive education methods, crucial for engineering education where hands-on experience and access to the latest information are vital.

3.3. Boosting Economic Growth and Market Disruption

By providing reliable internet access, Starlink can stimulate economic growth in several ways. Small and medium-sized enterprises (SMEs) will benefit from enhanced connectivity, enabling them to reach new markets, streamline operations, and adopt digital tools. Additionally, sectors such as agriculture, tourism, and finance can leverage improved connectivity to innovate and expand their services. The ICT sector, which contributed 2.6% to Botswana's GDP in Q1 2023, is likely to see further growth with the advent of Starlink (Statistics Botswana, 2023).

Starlink's superior speed and reliability have the potential to disrupt the current ISP market, leading to increased competition and potentially lower prices for consumers. This can lead to increased productivity, the creation of new business opportunities, and overall economic development. The retail partnerships mentioned for Starlink's launch will also boost the retail sector.

Starlink, SpaceX's satellite constellation project, has the potential to revolutionize global internet connectivity, particularly in remote areas (Shaengchart & Kraiwanit, 2024). Its low Earth orbit (LEO) satellites aim to minimize latency and maximize throughput, offering a significant advantage over traditional geostationary satellites (Hooda, 2023). Starlink's complete vertical integration, from satellite design to service provision, could lead to lower retail prices through economies of scale (Giannopapa et al., 2022). The COVID-19 pandemic has accelerated the need for high-speed internet, making Starlink's offerings particularly relevant (Hooda, 2023). While Starlink has proven effective in countries like Ukraine and Tonga, its impact may vary in markets with established fiber infrastructure and competitive pricing, such as Thailand (Shaengchart & Kraiwanit, 2024). The project aligns with the growing recognition of space as an enabler for digital transformation and sustainable socioeconomic growth (Giannopapa et al., 2022).

3.4. Promoting Innovation and Technology Adoption

Starlink's high-speed internet service will support Botswana's ambitions to become a leader in the Fourth Industrial Revolution. By facilitating access to cutting-edge technologies such as artificial intelligence, big data, and the Internet of Things (IoT), Starlink can drive innovation and help local businesses adopt advanced digital solutions. This is crucial for the country's SmartBots initiative, which aims to create a knowledge-based economy through digital transformation (United Nations Commission on Science and Technology for Development, n.d.; BOCRA, n.d.).

The advanced engineering of Starlink, particularly its innovative phased-array antennas, provides an infrastructure that supports technological innovation. This can lead to the development and implementation of new technologies in various fields. The reliable and fast internet connection will enable researchers and tech entrepreneurs to work more efficiently, fostering a culture of innovation and creativity.

3.5. Improving Healthcare Services

Healthcare services in remote and rural areas of Botswana can be significantly improved with better internet connectivity. Telemedicine, remote consultations, and access to digital health records will become more feasible, ensuring that healthcare providers can offer timely and effective care. This can enhance overall health outcomes and reduce disparities in healthcare access between urban and rural populations.

Telemedicine and digital health tools have the potential to significantly improve healthcare access and outcomes in rural areas of Botswana and other developing countries. TV White Space technology offers a promising solution for broadband internet connectivity in remote regions, enabling telemedicine applications (Chavez et al., 2016). Mobile telemedicine initiatives, such as "Kgonafalo" in Botswana, have demonstrated success in connecting patients with specialized care, though challenges like device malfunctions and cultural misalignment need to be addressed (Ndlovu et al., 2014). Satellite-based telemedicine can extend healthcare services to isolated communities, but issues with latency and data transmission need to be resolved (Bisu et al., 2018). Digital health tools, including mobile applications and educational platforms, can enhance community health literacy and empower individuals to manage their health more effectively. However, successful implementation requires overcoming barriers such as limited internet connectivity and low digital literacy rates (Maha et al., 2024).

3.6. Enhancing Public Services

Better internet connectivity will improve the delivery of public services, including healthcare, education, and government services. E-government services can become more efficient and accessible, improving the overall quality of public administration.

Starlink, with its satellite-based internet services, can offer high-speed, low-latency internet access even in remote or underserved areas. This would directly address the challenges of low internet speeds, limited access, and high tariffs that Botswana's citizens face (Mokeresete & Esiefarienrhe, 2020). By improving connectivity across the country, Starlink can ensure that more citizens gain reliable access to online government services, regardless of geographic location.

Furthermore, internet access could facilitate the development and widespread use of indigenous software applications, as these require stable and affordable internet to be effectively deployed and maintained. This aligns well with the e-government strategy's goals of enhancing public service delivery through localized solutions (Esiefarienrhe & Mokeresete, 2022).

With Starlink's support, Botswana's goal of universal broadband access could become more achievable. Enhanced internet infrastructure could also foster greater public trust in e-government services by improving the accessibility and reliability of online platforms. This would enable the government to engage citizens more effectively, offering an improved digital experience for accessing critical services and information.

3.7. Boosting Research and Development

The reliable and fast internet provided by Starlink will benefit research and development activities. Universities and research institutions can collaborate more effectively with international partners, access global databases, and conduct high-level research without the limitations imposed by poor internet connectivity. This can lead to significant advancements in various fields and position Botswana as a hub for scientific research in the region.

4. OTHER COMPETITION LEO INTERNET SERVICES

Other low Earth orbit (LEO) satellite internet technologies competing with Starlink include:

OneWeb: Partnered with governments and major telecoms, OneWeb aims to provide global broadband coverage, focusing heavily on underserved areas and enterprise markets. It is a leading satellite internet provider, aims to deliver global broadband coverage with a planned constellation of 648 satellites (Yoon et al., 2023). The company has made significant progress, with over 600 satellites deployed as of March 2023, focusing on high-speed, low-latency connectivity for high-latitude regions

Amazon's Project Kuiper: Amazon's upcoming LEO constellation aims to deploy over 3,000 satellites. It plans to leverage Amazon's massive distribution network, aiming for consumer and enterprise markets by providing fast, reliable internet. Amazon's Project Kuiper is part of a growing trend of Low Earth Orbit (LEO) satellite constellations aiming to provide global broadband internet. These megaconstellations, including Kuiper's planned 3,236 satellites, promise improved connectivity for remote areas but raise environmental concerns due to increased rocket launches (Ogutu et al., 2023).

Telesat Lightspeed: Telesat, a long-time satellite communications company, is developing the Lightspeed LEO constellation, focusing on delivering high-performance connectivity for enterprise applications, particularly in aviation, maritime, and backhaul sectors. Telesat LEO satellite constellation designed to provide global broadband connectivity with low latency and high performance (Nader Yared & G. Jansson, 2023). The system utilizes Optical Inter-Satellite Links (OISLs) for mesh network connectivity, enabling secure and resilient data transmission without the need for anchor relay stations (Nader Yared & G. Jansson, 2023).

China's Guowang: This is China's state-backed LEO satellite constellation initiative aimed at national coverage and competing internationally. Guowang aims to provide high-speed internet with over 13,000 satellites.

Astrome: Based in India, Astrome focuses on a smaller constellation to provide high-speed, affordable internet access in remote areas. They are also exploring new ways of increasing data capacity via millimeter-wave technology.

Viasat: Though more established in geostationary orbits, Viasat is expanding into LEO to enhance its capabilities for high-speed internet, particularly targeting underserved rural areas.

5. CONCLUSION

The introduction of SpaceX's Starlink in Botswana presents a transformative opportunity for the country's digital landscape. By providing high-speed, low-latency internet access across the entire nation, Starlink has the potential to bridge the digital divide, enhance educational outcomes, stimulate economic growth, and drive innovation across various sectors.

The predicted impacts and opportunities of Starlink operations in Botswana are far-reaching. From improving internet connectivity and supporting educational initiatives to boosting economic growth and promoting technology adoption, Starlink's presence aligns well with Botswana's digital transformation goals. The potential improvements in healthcare services, public administration, and research and development further underscore the significance of this technological advancement.

However, the successful implementation and utilization of Starlink's services will require addressing challenges such as affordability, competition with existing ISPs, and regulatory considerations. It will also be crucial to focus on digital literacy initiatives to ensure that all citizens can benefit from the improved connectivity.

As Botswana continues its journey towards becoming a knowledge-based economy, the integration of Starlink into its digital infrastructure marks a significant milestone. By leveraging this advanced satellite internet technology, Botswana is positioning itself at the forefront of the digital revolution in Africa, paving the way for inclusive growth and sustainable development in the digital age.

Compared to traditional ISPs in Botswana, these speeds represent a dramatic improvement, particularly in rural areas where internet connectivity has historically been slow and unreliable (Statistics Botswana, 2023).

As new satellites are deployed and more ground infrastructure is developed, Starlink's footprint continues to grow, prioritizing areas such as rural schools and clinics. This expansion process is essential to fulfilling Botswana's national digital transformation strategy, SmartBots, which aims for universal digital inclusion (SpaceX, 2024).

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EXPERIENCES AND ATTITUDES OF MATHEMATICS TEACHERS TOWARD THE USE OF TECHNOLOGY IN MATHEMATICS TEACHING AND LEARNING IN BOTSWANA SENIOR SECONDARY PUBLIC SCHOOLS: A QUALITATIVE RESEARCH

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Abstract: The purpose of this study was to establish how senior secondary teachers use technology in mathematics lessons. The study also investigated the attitudes of Botswana secondary school teachers toward the use of technology in mathematics education and the challenges that they encounter when integrating technology in mathematics instruction. The target population was mathematics teachers from public senior secondary schools in Gaborone. The sample was drawn from two public senior secondary schools in Gaborone and their mathematics teachers. Purposeful sampling was used to select the schools. The instrument was semi-structured interviews for the teachers. Validity was done by input of supervisor and pilot study. Qualitative data from the teachers' interview analysed to assist in responding to the research questions. The analysis was done by considering the similarities and convergence from the responses. The findings of the study revealed tha teachers demonstrated positive attitudes toward the use of technology in mathematics education. The findings also indicated that teachers are willing to integrate technology in mathematics education despite the challenges that they experience.

1. INTRODUCTION

There have been changes and reforms in Botswana education system concerning the curriculum, infrastructure, schools' enrolment, and teachers' education (Mafuraga & Moremi, 2017). The Revised National Policy on Education (RNPE), which guides educational policy, has improved the adoption and incorporation of science and technology in education. Conforming to this policy, computers have been provided to schools to promote information and communication technology (ICT) awareness such that both junior and senior secondary schools in Botswana have personal computer laboratories (Mpoeleng, 2016). This shows the extent to which the country is committed to ICT integration and use in its educational system. Since the late 1990s when the policy was first implemented, the curriculum that instils computer education has been made for schools. In order to upgrade and enhance teachers' knowledge and skills on computer technology, some short courses were provided. In addition, pre-service programs that instill computer courses have also been introduced in tertiary and higher education to equip teachers with technology in teaching. According to Presidential Task Force (1997) "all schools will have access to a computer, and to computer-based communications such as the internet" (p.7). The question then could be, to what degree has this been achieved and what challenges are there in efforts to ensure accessibility of computers by students and staff? Clearly, impediments are there as Asongu, Orim and Nting (2019) pointed to a significant inequality between urban and rural areas pertaining access to ICT services. The authors mention lack of electricity in rural areas and high internet charges among other challenges, which disadvantage the rural area residents as compared to those in the urban centers. Regardless of these challenges ICT in the modern world is vital in the teaching and learning process and life in general.

2. LITERATURE REVIEW

The Botswana government also introduced a national ICT policy called Maitlamo (Maitlamo, 2007). This policy is a document designed to guiding and transforming ICT use in the country. According to the document, its key goals are "creation of an enabling environment for the growth of an ICT industry in the country; Provision of universal service and access to information and communication facilities in the country; Making Botswana a Regional ICT Hub so as to empower Batswana and to make the country's service sector globally competitive" (Maitlamo, 2007, p. 4). This can be fairly noticed through the use of ICT in the school system. Maitlamo also has a component called ThutoNet which focuses on the promotion of e-learning which attempts to make sure that schools have computers and are connected to the internet, as well as outsourcing funds for continued ICT usage in the schools (Mogwe & Balotlegi, 2020). This is meant to increase ICT usage in education. All schools were supposed to be furnished with computers and have internet connectivity and all teachers should have learnt basic computer skills by the end of the year 2010 (Mogwe & Balotlegi, 2020). Siamisang, Kumar, Narayanan and Chandirakasan (2018) proclaimed that the country seeks to have very good ICT and lead the region in the invention and supply of information. This was verified by the formation of the Ministry of Infrastructure, Science and Technology in 2002 devoted to ICT infrastructural development. This shows that efforts are being made to make ICT available and affordable to the citizenry. All junior secondary schools in Botswana achieved fully equipped computer laboratories within no time. This was a breakthrough by the government to equip all junior secondary schools with these ICT resources even though they are not fully utilized due to several reasons.

According to Chen and Wu (2020) availability of resources in education is essential as at times the resources may be available but not accessed by the users: which makes them meaningless. Tabach and Trgalová (2019) found that teachers complain about the difficulty to access computers. "Computers had to be booked in advance and the teachers would forget to do so, or they could not book them for several periods in a row when they wanted to work on several projects with the students" (p. 50). This means that a teacher would fail to access ICT materials due to sharing limited resources with other teachers. The inaccessibility of ICT resources is not always merely because of non-availability of hardware and software materials within the school. It may be due to some factors like poor quality, poor resource organization or lack of interest by teachers (Hosman, 2018).

Hinostroza (2018) is of the view that teachers cannot be expected to overcome the challenges preventing them from using ICT without good technical support from both the classroom and whole school resources. Lack of technical support from both primary and secondary schools prevents ICT use in education (Van Niekerk, 2018). Technical problems such as waiting for websites to open, failing to connect to the internet, printers not printing, malfunctioning computers, and teachers having to work on old computers have a negative impact in education (Viberg, Grönlund, & Andersson, 2020). "Other important limitations were lack of adequate professional development concerning technology, limited physical resources, inadequacy of resources, limited access to technology and lack of technical support, competence and confidence" (Almanthari, Maulina, & Bruce, 2020, p. 3). ICT support in schools allows teachers to use ICT in teaching without wasting time fixing software and hardware problems (Djoub, 2017). According to Hosman (2018) addition of ICT in teaching requires a technician otherwise lack of technical support can be a very serious challenge. Poor technical support appeared to be one of the two main challenges to ICT integration in science education in schools in Turkey (Birgin, Uzun, & Akar, 2020). In Saudi Arabia, mathematics and science teachers would agree using computers in their lessons, but they argued that technical service or hardware problems were the main drawback (Kareem, 2018). Technical problems interfere with the smooth lesson delivery by teachers no matter the teaching experience they have in the field (Djoub, 2017).

The problem most commonly referred to in the literature is lack of effective training (Djoub, 2017; Hosman, 2018). One research in Turkey found that inadequate in-service teacher training was the main problem with implementing new ICT in education (Serrano, 2017). Viberg et al. (2020) established that the subject of training is surely difficult since a number of components need to be considered in order to ensure training effectiveness. These include time for training, pedagogical training, skills training, and an ICT use in initial teacher training. Similarly, research by Tenai (2017), concerning numerous subjects concluded that lack of training literacy, lack of pedagogic and informative training in how to use ICT in the classroom and lack of training concerning technology use in specific subject were obstacles to using new technologies in classroom practice. Some of the Saudi Arabian studies reported similar reasons for failure in using educational technology: the weakness of teacher training in the use of computers, the use of a delivery teaching style instead of investment in modern technology (Tenai), as well as the shortage of teachers qualified to use the technology confidently (Rosenberger, 2017).

3. THEORETICAL FRAMEWORK

This study was guided by the constructivist theory of learning. The basic tenet of constructivism is that students acquire knowledge through doing as opposed to observing. Students convey prior knowledge into a learning condition which allows them to evaluate and analyse their understanding of it. This learning process is repeated until they can show their understanding of the subject. The theory was selected because it builds on prior knowledge: students make connections to new material using what they already know. When students make these connections, they are learning new material and relating it to what they already know (Mattar, 2018). The principles which inform the study are readiness and generation, where the former deals with the experiences and contexts which enable learners to be eager to learn and the latter deals with operating beyond the information given (i.e. instructions must be generated in a way that simplifies extrapolation).

Many educators nowadays think that the constructivist theory is a relatively new theory in education while the tenets of constructivism can be traced back to Socrates. Socrates was well known for asking his students questions that would stretch their minds and force them to think in a higher level (Xie & Cai, 2018). Aseeri (2020) declared that, "thinking is one important topic that contributes to refining the learner's personality and developing him in all different areas of life. It is a mental activity that includes numerous different processes or skills that are capable of growth, development and learning." (p. 64). The mind's primary purpose is to create and to see things in a way that can be organized into a schema that helps the mind to see them as being real. Piaget was a strong supporter of cognitive development. He had a belief that as children grow older, they perceive the world through different experiences, and that, children have totally dissimilar viewpoints than adults (Mustapha et al., 2020). Piaget emphasized that when knowledge is constructed inside oneself, it is inspected against what is taking place in the real world in a similar way as scientific idea is tested.

4. RESEARCH METHODOLOGY

The goal of this study was to explore the use of technology by teachers in the teaching and learning of mathematics at senior secondary schools in Gaborone. The study was guided by the following research questions:

Research Question One: What are teachers' attitudes toward the use of technology in mathematics?

Research Question Two: How do secondary school teachers use technology in mathematics lessons?

Research Question Three: What challenges do secondary school teachers encounter when integrating technology in mathematics lessons?

This chapter describes the methodology of the study. The chapter comprises the following sections: Research Design; Research Method; Population and Sample; Instrumentation; Data Collection Procedures; Ethical Consideration; and Data Analysis Procedures.

4.1. Population and Sample

The study involved mathematics teachers at public senior secondary schools in the city of Gaborone. There are four public senior secondary schools in Gaborone namely; Ledumang, St. Joseph College, Naledi and Gaborone secondary schools. The population contained a total of about 60 mathematics teachers from the four public senior secondary schools in Gaborone (Ministry of Basic Education, 2021). The study was limited to Gaborone only because of time and financial constraints.

4.2. Sample

The study involved two (2) out of four (4) public senior secondary schools in Gaborone which constitute 50% of the public senior secondary schools in Gaborone. Purposive sampling was used to pinpoint two schools from the four (4) public senior secondary schools in Gaborone as well as to select the teachers as participants in the study. Mikalef et al. (2019) define purposive sampling as "a non-probability method in which the researcher selects participants based on personal judgement about which ones will be more informative and as such, it is sometimes called judgmental sampling" (p. 739). Only two schools namely Naledi senior secondary school and Gaborone senior secondary school were chosen.

Ten (10) mathematics teachers from the two chosen schools were selected to participate in the study using purposive sampling. Ten (10) mathematics teachers which formed about 16.7 % of the population of teachers was made up of five (5) female and five (5) male teachers. The researcher trusted that the sample was large enough to permit generalizability in Gaborone. Belotto (2018) stated that a sampling fraction of between 10 – 20% of the total population is acceptable in descriptive research.

4.3. Instrumentation

The instrument used for data collection in the study was interview protocol. This was found appropriate because the study was a descriptive survey design. According to Lemenkova (2019) descriptive survey is one of the best methods used in collecting original data for describing a population too large to observe directly and like many other methods this is done through the help of interview protocol. Interviews were conducted with the selected teachers.

4.4. Interviews

A semi-structured interview technique was used in this study to convey discussions that would produce valuable data that could be utilized in qualitative analysis (Belotto, 2018). Semi structured interviews offered participants permission to freely express their views (Lemenkova, 2019) and to dominate the flow of topics.

A total of ten (10) interview questions for this study were built using the previous studies and surveys related to this one. Both English and Setswana interview guides were prepared and the respondents were given a choice to decide the language they were comfortable with.

4.5. Validity of the instruments

To validate items of the instrument, the interview instrument was presented to the colleagues to assist on checking its appropriateness in collecting data, its significance to the study, the suitability of the language used and precision of items (face validity technique). Following the face validation process, some contents were revised and corrected in order to get rid of any vagueness.

A pilot study method was utilized to ensure the validity and reliability of the instrument. A pilot study helped the researcher to identify the deficiencies in the data collection instrument and probable difficulties that may be faced during data collection (Leung, 2015). The pilot study was carried out at Ledumang senior secondary school, and the school was not be included in the main study. Five teachers participated in the pilot study. The teachers took part in the interview session. The pilot assisted the researcher to find any ambiguities in the items. The data gathered from the pilot study was analyzed using the processes described in the data analysis section below, and the results were used to modify the interview questions.

4.6. Reliability of the instruments

The test-retest strategy (Lemenkova, 2019) was used to ensure reliability of this study. To measure this, the researcher asked some participants (pilot participants) to take part in the interview. Then the same participants repeated responding to the interview questions after five days. This data was finally analyzed using the qualitative procedures described in the data analysis section below and the results were used to modify the interview questions.

4.7. Ethical consideration

The researcher requested for permission to collect data from schools from MOBE. Afterwards permission was then requested from the director of South East regional education office under which the sampled schools fall. The researcher then asked for permission from the school heads at the respective schools before talking to mathematics senior teachers. Consent of the participants was requested as well. Participants were assured that information collected from them will be confidential and they were guaranteed anonymity.

4.8. Data Analysis Procedures

Data analysis procedures involved the qualitative method to find out their attitudes toward the use of technology in mathematics and how they use technology in mathematics lessons. This analysis took place in three stages. First, interview transcripts from the sound recorder were reviewed numerous times to check recurring regularities (Parameswaran, Ozawa-Kirk, & Latendresse, 2020; Belotto, 2018). The researcher highlighted the quotes from the interviews that were relevant and useful to the study. The researcher went back and forth along transcripts until consistent and distinct categories emerged, using the constant comparative method. The researcher labeled the categories, coded the transcripts and partitioned the labeled folders that represented each category. Secondly, the coded interview data was merged and a table was created to compare various coded interviews. Finally, the categories were combined until themes solidified.

5. RESULTS

5.1. Response rate

A total of 10 mathematics teachers were sampled in the study. All the 10 teachers sampled for the interview responded, representing a response rate of 100%.

5.2. Teachers' Use of Technology in Mathematics Lessons

This section determined the ways in which secondary school teachers use technology in mathematics lessons. The two emerging themes from the teachers' interviews were: Using technology as a teaching tool and the use of social media to share ideas with other teachers.

5.2.1. Using technology as a teaching tool

Most teacher interviewees noted that they mainly used technology as a tool which helps them complete tasks and activities easier. The most frequently used mathematically-related tools by the participants are calculators and computer software. One participant stated that:

Calculator technology is easily accessible in most homes and classrooms,

> *including basic four-function calculators and scientific calculators. Calculators offer a deeper understanding of math topics. When students are able to use a calculator, their basic skills in mathematics increase. When I teach my students some topics using calculators, their views on mathematics are more positive than working without a calculator. For example, my learners are confident when writing paper 2 exam than paper1 because the former requires the use of calculators while the latter strictly prohibits the use of calculators.*

Most participants indicated that they frequently used GPS, word processor and spreadsheets as computer software tools. One participant mentioned that "I prefer using GPS because it enables our students to visually see the mathematics being taught." The other interviewee emphasised this point by saying, "mostly I use GPS in transformation geometry (reflection, translation, rotation) and graphing various functions." The other one noted "the use of GSP provides my students with greater control over their learning; lessons become student-centred and experimentally-based rather than teacher-driven." The results indicate that most of the interviewees used word processing to prepare departmental meeting minutes and set tests and examinations. They preferred the use of spreadsheets to store student marks and when teaching mathematical topics such as statistics and percentages.

5.2.2. The use of social media to share ideas with other teachers

All the participants talked exceptionally profoundly of social media, particularly WhatsApp and Facebook and regarded them the foremost valuable resource for picking up innovative information. The shared items can be in the form of audio, video, photo or document file. One participant elucidated that the greater part of the exercises that she prepared for students arrived from thoughts she saw on WhatsApp groups. She added that, "numerous educators will exhibit their math questions and the various open critical thinking solutions they are utilizing in their classrooms or share helpful applications, which I am thankful of." The other participant shared the same sentiments and acknowledged WhatsApp as the asset liable for the entirety of the information she had in regards to mathematics teaching strategies. Most participant talked about their love for "Facebook and WhatsApp chats" which are discussions that happen between mathematics teachers almost every night on various topics related to education. They depicted these talks as their road for teaming up and offering thoughts to other teachers and supporting and gaining from one another.

Albeit an incredible asset, one interviewee accepted that a great deal of teachers doesn't draw in with social media on the grounds that they don't comprehend its instructive esteem or don't have time, which he comprehended as there never is by all accounts enough time in a teacher's day. With this stated, he clarified that if an instructor is keen on learning through Facebook and WhatsApp chats, they don't necessarily need to be actively online at all times. In the event that a teacher misses a chat, they can without much of a stretch search all of the archived chats. All participants implied the idea that with social media, there is no need to "reinvent the wheel."

5.3. Teachers' Attitudes toward the Use of Technology in Mathematics

This section determined teachers' attitudes toward the use of technology in mathematics. The two emerging themes from the teachers' interviews were: Effective use of technology and Technology integration is valuable in mathematics classroom.

5.3.1. Effective use of technology

Most participants believed that technology offers both mathematics teachers and students a way to effectively and efficiently work more on tasks and activities. They felt that the use of technology encourages teachers to be more organized and to modify and update instruction more quickly. Participants believed that technology could support thinking processes, stimulate motivation and self-esteem, promote equity, prepare students for the future, support changes in school structure, and explore technology capabilities. They perceived technology as a resource that benefits the teacher in areas such as planning, organizing, monitoring and evaluating procedures and processes that rely on availability of precise and timely information. Below is an excerpt from one participant:

> I believe that effective technology integration is attained when students are able to select technological tools to help them obtain information in a timely manner, analyze and synthesize the information, and present it in a professional way. This means that technology must be an essential part of how the classroom functions in terms of accessibility like in any other classroom learning tools. This evidently informs us that technology has become a key component of our educational system.

5.3.2. Technology integration is valuable in mathematics classroom

Participants in this study desired to access the specified technologies with a clear understanding of their impact in mathematics teaching and learning. The participants noted that incorporating technology into mathematics classroom is valuable, even though the technological tools were not always available. All participants comprehended the significance of having the technology readily accessible whether at home or school. They emphasized that technology is required for survival in everyday life. As indicated by one participant, students have an advantage when mathematics teachers integrate technology since "it helps students' to be technologically proficient." The other participant proclaimed, "Technology enhances exposure to different learning strategies." All the teachers interviewed believed that technology assists students to improve their mathematics performance and makes learning curriculum standards more thrilling. They stressed that the advantage of technology integration is that it makes learning become interactive.

Most participants asserted that cell-phones, when used correctly, can flawlessly facilitate the activities of learning and teaching in interactive classrooms. According to one participant:

> *Even though mobile phones are banned in a lot of schools, they perform an important role in teaching and learning. With mobile apps and the internet at their fingertips, teachers and students are now using phones as clickers to answer questions, providing feedback on student progress, and also to document labs, collaborate on group projects and capture teachers' notes.*

5.4. Challenges Encountered by Teachers when Integrating Technology in Mathematics Lessons

This section presents challenges encountered by teachers when integrating technology in mathematics lessons. The six emerging themes from the teachers' interviews were: Lack of technological resources affects learning; Insufficient access; Scarcity of time; Insufficient skills and competencies; Training necessity and Curriculum development.

5.4.1. Lack of technological resources affects learning

All participants were equally concerned about lack of access to technology outside the classroom by students. One participant remarked, "Technology in a mathematics classroom is good, but if it's not available then becomes useless," and the other stated, "majority of students don't have computer or Internet access when they are home." They noted that it is not helpful for an educator to plan for a lesson attempting to use technology only to find that the material is unavailable or limited. Without adequate hardware, software, internet access, and the like, teachers and media specialists may find it difficult to truly integrate technology. Shortage of technological equipment for teaching mathematics was a serious concern for all the interviewed participants. They stated that there were no computers or computer-related devices in their classrooms. Lack of computers in classrooms, as confirmed by one participant, is verified in the following quote:

> *We don't have any computers in the classrooms. The computers are only found in the computer lab, and sometimes in the staffroom or the office of the principal, but not in the classrooms. Unless, if a teacher brings his own laptop for a certain lesson.*

The participants' robust criticisms of the absence of computers in the classrooms and their fervent requests for computers in the classrooms summed up the situation of classrooms with respect to technology integration of computers in mathematics education in these schools.

5.4.2. Insufficient access

Participants highlighted lack of access to technology as a barrier because when the schools have insufficient funds and inadequate resources then technology integration becomes meaningless. "Even the library, which one could have thought to be the second most technologically dense area of the school after the computer lab, has a limited access", noted one participant. Students are only allowed to enter the library during their scheduled class visit time. One participant emphasized this point by the following excerpt:

> *the library does not have enough technological resources, the books are very few and outdated. It does not even have magazines, only the Botswana daily newspaper is available. There are only two working computers inside the library which are used by staff.*

Participants, nevertheless, specified that they had access to the computer labs, even though it was limited because some learners play games on the computers. The fact that some students play games in the lab forced the computer coordinators to come up with tight rules to be applied in the lab.

5.4.3. Scarcity of time

Participants believed that integrating technology into a mathematics classroom definitely consumes a lot of time, particularly when it must be aligned with the objectives of the syllabus. Teachers are expected to spend hours browsing websites, gaining familiarity with hardware and software, and informing themselves with numerous programs. Teachers who are eager to work extra hours to do this are depressed because they are not paid any overtime allowances due to lack of funds. Over and above the time consumed teaching the material that will be assessed, the absolute quantity of time that must be devoted to the assessment procedure itself can act as a challenge. Standardized testing is normally done frequently in a year, consuming a lot of time, thus reducing even more chances to integrate technology. Teacher workload tightens the schedule for teachers hence a barrier to professional growth. This was emphasized by one participant in the below excerpt:

> *School timetable is so congested in such a way that teachers volunteer for afternoon, evening, weekend and vacation lessons. This tightens their schedule such that even if they were to plan for technology integration workshops, time becomes so limited for them.*

The above excerpt also reveals another challenge that mathematics teachers are overwhelmed with work outside working hours which they are not paid to do.

5.4.4. Insufficient skills and competencies

Most respondents indicated that, even on the availability of appropriate resources, teachers usually tussle with an insufficient knowledge of specific technology and technology- strengthened pedagogy to use in mathematics classrooms. They felt that technology can be an alarming notion for many teachers, especially those who did not grow up operating computers or internet. One of the respondents had the following to say:

> *When I discover a particular technology to be confusing, it becomes unlikely for me to consolidate it into the topic of the day. Lack of training to operate specific technologies and lack of time to discover updated features are serious dissuasions for us as mathematics teachers to integrate technology into the classroom.*

5.4.5. Training necessity

Participants indicated that they needed a series of in-service workshops and training to acquire basic technological knowledge (computer use and application) and basic technological content knowledge (using technology in accessing subject content knowledge). They believed that obtaining these categories of knowledge on top of knowledge of teaching subject is essential but for effective use of modern technology incorporation in mathematics teaching. One participant alluded that:

> *Using technology innovatively in mathematics education as desired in the 21st century classroom requires teachers to possess good technological pedagogical knowledge and the skills of its application in teaching. This would enable teachers to gain the competence required in teaching in 21st century learning environment. The mathematics teachers' lack of sufficient ICT skills and competencies together with their limited knowledge of technology use in the classrooms is a serious concern and calls for more training.*

As a way of reducing the challenge of teachers' lack of knowledge and skills of technology use, participants expressed the significance of training programs that will offer them opportunities to integrate technology in the teaching and learning sessions. The following excerpt from one participant shows the need for training, "they must cater for computer literacy training, I guess the introduction of technology integration courses for us will help." Most participants felt it could be effective if each school had individuals within the building for technology integration training instead of having an outside person train them. They believed that if a teacher in the school building is well-versed on using technology to enhance mathematics lessons, then this teacher could assist others to promote enhanced integration.

5.4.6. Curriculum development

All the interviewees pointed out that there is need to redesign the curriculum that would enable students to use technology in mathematics instruction in the form of a continuous assessment. They stressed that the curriculum should introduce practical assessments that allow students to apply technological skills in some mathematics topics. One respondent noted that:

> *I think that the curriculum should be revised and permit us to teach learners practical sessions using technological tools which contribute to their continuous assessment just like they do in science labs. This will help learners to pay more particular attention knowing that the sessions are part of their exam marks.*

6. CONCLUSION

The findings of the study indicated that students and teachers use technology for different purposes both in mathematics instruction and outside the classroom. The results showed that teachers demonstrated positive attitudes toward the use of technology in mathematics education. The findings also showed that teachers are willing to integrate technology in mathematics education despite the challenges that they encounter. These challenges include lack of technological resources, insufficient access, scarcity of time, insufficient skills and competencies, inadequate training as well as lack of curriculum development.

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SUSTAINABLE MANAGEMENT MODEL FOR PROCESS QUALITY EFFECTIVENESS MEASURE

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Abstract: The need to manage quality to enhance process effectiveness through elimination of wastes is a pointer to sustainable productivity. The factors that are affecting process quality management were harnessed from industrial experts. Process Quality Effectiveness (PE) was analyzed using Traditional Effectiveness measure, and then using developed modified version by incorporating dynamism that can enable effectiveness measures through combination and isolation of quality factors (manpower, machine, material, energy, management, information / communication, money and marketing) simultaneously. Decision on process quality acceptability of a plastic company was made by comparing quality effectiveness measured with the universal quality standards (sustainable quality trend, global acceptable quality standard and industrial revolution quality class. The results indicated varying quality measures in isolation against combination. From the results, machinery factor was identified as the root cause of reduced process quality effectiveness and hence needs to be concentrated upon to enhance process quality effectiveness.

Keywords: Management, Process, Quality, Sustainability, Effectiveness Measure.

1. INTRODUCTION

Increase in quality rate means that there is less scrap and rework, reduces costs, and hence better quality rate [1,2]. Traditional method of measuring process quality effectiveness requires modification in terms of introducing dynamism to enable measurements on the basis of isolation or combination of quality factors [3,4]. Emerging process quality management factors which include management, energy, information/communication, and marketing [5,6,7] are required to be considered along with other traditional factors - manpower, machine, material and money/funding [8] for a robust measure of quality effectiveness. For effective utilization of these resources to enhance process quality effectiveness, there is the need for a policy that ensures access to qualitative education and training in resources management.

2. LITERATURE REVIEW

Series of activities are undertaken in manufacturing industry. This includes the production of different items, machines, equipment etc. There are a range of sections in the manufacturing industry, from the managerial section down to production, maintenance and inspection departments [9]. Competition among corporations, industries, businesses, firms and organizations, demands the need for quality enhancement. Every firm must have a good process quality effectiveness programme in place to ensure favorable competitiveness [10,11]. Quality effectiveness of a process is determined on basis of contribution of process factors to wastes and losses [4]. Quality is most critical because it determines the whole system effectiveness due to direct link with consumers. Quality is affected mainly by wastes due to defect, rework, start-up and scrap [4]

Every industry should have a competent management in place to ensure that the production process is always produces quality goods and/or renders quality services that compete well in industrial environments [10]. A competitive process contributes to a sustainable development goal attainment [11,12,13], under good infrastructural facility by enabling process wastes elimination [9,14,15,16]. Therefore, process quality and infrastructural facility are inseparable [17,18].

Many studies have been tailored to eliminate wastes to enhance process quality effectiveness. Among them are: development of dynamic error-proof Overall Equipment Effectiveness (OEE) model for a complex production system operational optimization [9,19]; automation of industrial processes to improve efficiency by eliminating loss time [20]; application of lean workforce to eliminate non-value added activities [21]; digitalization of processes to eradicate rework, scrap, start-up losses [22,23]; and utilization of intelligent based Information and Communication Technologies (ICT) to eradicate wastes in the process [24,25]; re-designing quality measures through linking quality sustainability with accountability [26,27]. The weakness of these works is inability to compare their outputs with external (sustainable quality) standards; this study considered that.

The three sustainable quality standards called external standards on which process quality effectiveness is evaluated are enumerated in Table 1. The choice of sustainable process quality is based on the stated standards (Table 1), which are jointly considered. The evaluation is done on the basis of process quality effectiveness (PE) should not go below that of the standards' values [13] - global acceptable quality standard, $PE \geq 0.85$; sustainable trend quality standard, $0.5 < PE \leq 1.0$, and industrial revolution quality class, $0.85 \leq PE \leq 1.0$:

Table 1. Sustainable Standard Measures of Effectiveness.

Sustainable Standards/Classes	**Process Effectiveness PE range**	**Sources**
Global Standard,	PE≥ 0.85	[19,28]
Sustainable Trend,	0.5 <PE≤ 1.0	[13,29]
Industrial Revolution class (4.0)	0.85≤PE≤1.0	[13,24]

3. METHODOLOGY

3.1. Framework for Model Development

Factors that influence management of process quality effectiveness (PE), are grouped into internal (that are within the processing unit) and external (that are outside the processing unit) factors. Manpower, money, machine, energy, management, information/ communication, material and marketing are considered as internal factors while quality standards- sustainable trend, industrial revolution, and global acceptable quality are external factors. Process quality effectiveness (PE) are acceptable if and only if it meets any or all of these quality standards, otherwise process improvement is desirable to satisfy customers' quality demands. Fig. 1 depicts the internal factors, external factors and improvement required for a processing unit. In traditional quality effectiveness measures the internal factors are combined in assessing the process quality, and the same time external quality standards are not considered in the measures. In order to meet global competition, there is the need to isolate those factors that are responsible for low quality effectiveness for early preventive treatment.

Traditionally, quality (Q) effectiveness is measured as a ratio that describes the ability of a processing unit to produce products according to set standards termed external factors and was mathematically expressed as:

$$Q = \frac{Processed\ amount - defect\ amount}{Processed\ amount} \quad (1)$$

Where, the defect amount represents the number of items rejected during processing that required rework or scrapped.
Then, process quality effectiveness (PE) can be estimated using Eqn. 2.:

$$PE = QM \quad (2)$$

Quality management (QM) is measured on the basis of:

$PE = 1,$ quality is perfect or the process is excellent (3)

$PE = 0,$ quality is poor or the process has collapsed, (4)

$PE < 1,$ quality is gradually reducing but process can still survive (5)

By introducing external factors – sustainable trend, global standard and industrial revolution class a distinction is made between quality acceptability and rejection in a competitive marketing environment. On this basis, an acceptable QM is based on the following relations:

$If\ PE \geq 0.85,$ quality is acceptable based on global standard (6)

$If\ 0.5 < PE \leq 1.0,$ quality is acceptable based on sustainable-trend standard, (7)

$If\ 0.85 < PE \leq 1,$ quality is acceptable based on industrial revolution class (8)

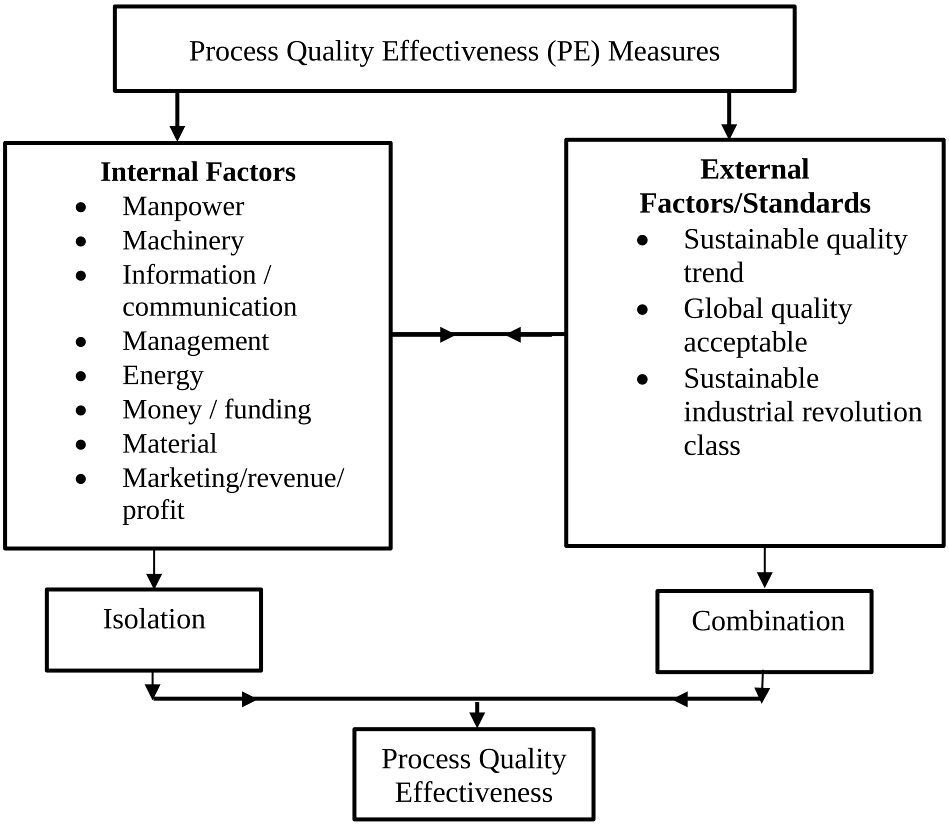

Figure 1. Factors Relationship to Process Quality Effectiveness.

The formulated models (Eqns 1- 8) considered the internal factors in combination. The effects of these internal factors on quality management can be best assessed by considering individual factor in isolation to enable good identification of actual factor that contributes to quality failure in the process. Therefore a new model is developed to isolate internal factors and incorporate dynamism into the quality management process. With internal factors considered in isolation, quality effectiveness managed on each factor using the following equation.

$$PE = Q_i = \frac{\frac{\sum_{i=1}^{N} t_i^P}{N_P} - \frac{\sum_{i=1}^{N}\sum_{j=1}^{M} t_{ij}^S}{N_L \times M}}{\frac{\sum_{i=1}^{N} t_i^P}{N_P}} \quad (9)$$

where:

$N,$ is the number of internal factors, N_P, is number of processing time, N_L, number of loses time, $M,$ number of loses identified, $i,$ is a counter for internal factors, while j is a counter for types of loses.

Eqn. (9) is applied for determining contribution of each factor to process quality. Total number of eight (8) internal factors was considered- manpower, material, machinery, money/capital, management, energy, information/communication technology, and marketing.

Total Process Quality Effectiveness PE^T for combined factors is obtainable using Eqn 10.

$$PE^T = \frac{\sum_{i=1}^{N} Q_i}{N} \tag{10}$$

Where, Q_i is the Process Quality Effectiveness (PE) for each factor i count.

The quality management levels of the process effectiveness are determined using Eqns. (6-8). On this basis factors that contributed to process quality deficiency are isolated for possible improvement.

4. PROCESS QUALITY DATA AND ANALYSIS

Relevant data were collected using questionnaire and oral interview conducted in a selected company, producing plastic products. The data were collected on production process, working hours, downtime, product rejection rate, etc. These data were used for estimating relevant quality parameters as contained in the model. Overall Process Quality Effectiveness(PE), and decisions on process quality sustainability were made based on global quality standard (PE≥ 0.85), sustainable trend quality standard (0.5<PE≤ 1.0) and industrial revolution quality class standard (0.85≤PE≤1.0) criteria. The summaries of the data collected from the plastic company are shown in Table 2. By treating factors in isolation the analysis id done as follows (Eqns. 1- 9):

$$PE = Q_i = \frac{Process\ amount - Defect\ amount}{Process\ amount}$$

$$PE = Q_i = \frac{\frac{\sum_{i=1}^{N} t_i^P}{N_P} - \frac{\sum_{i=1}^{N}\sum_{j=1}^{M} t_{ij}^S}{N_L \times M}}{\frac{\sum_{i=1}^{N} t_i^P}{N_P}}$$

where:

$N, Number\ of\ internal\ factor\ considered\ (i = 1,2, \dots ,8) = 8$

$N_P, Number\ of\ processing\ time$ = 1 (isolation)

$N_L, Number\ of\ losses\ time$ = 1 (isolation)

$M, Number\ of\ losses\ identified$ = 4

(i) Man-power (mp) Input factor:

$$PE^{mp} = Q_1 = \frac{\frac{1200}{1} - \frac{\sum_{i=1}^{4}(25+10+5+2)}{1\times 4}}{\frac{1200}{1}} = \frac{1200-10.5}{1200} = 0.9913$$

(ii)Machinery (m) Input factor:

$$PE^{m} = Q_2 = \frac{\frac{1000}{1} - \frac{\sum_{i=1}^{4}(50+22+12+3)}{1\times 4}}{\frac{1000}{1}} = \frac{1000-21.75}{1000} = 0.9783$$

(iii) Info./Communication (ict) Input factor:

$$PE^{ict} = Q_3 = \frac{\frac{950}{1} - \frac{\sum_{i=1}^{4}(15+5+5+1)}{1\times 4}}{\frac{950}{1}} = \frac{950-6.5}{950} = 0.9932$$

(iv) Management (mg) Input factor:

$$PE^{mg} = Q_4 = \frac{\frac{700}{1} - \frac{\sum_{i=1}^{4}(20+14+5+7)}{1\times 4}}{\frac{700}{1}} = \frac{700-10.25}{700} = 0.9853$$

(v) Energy (e) Input factor:

$$PE^{e} = Q_5 = \frac{\frac{1500}{1} - \frac{\sum_{i=1}^{4}(22+12+5+4)}{1\times 4}}{\frac{1500}{1}} = \frac{1500-10.75}{1500} = 0.9928$$

(vi) Money/funding (mf) Input factor:

$$PE^{mf} = Q_6 = \frac{\frac{2000}{1} - \frac{\sum_{i=1}^{4}(50+15+7+5)}{1\times 4}}{\frac{2000}{1}} = \frac{2000-19.25}{2000} = 0.9904$$

(vii) Material (ma) Input factor:

$$PE^{ma} = Q_7 = \frac{\frac{1150}{1} - \frac{\sum_{i=1}^{4}(12+20+20+7)}{1\times 4}}{\frac{1150}{1}} = \frac{1150-14.75}{1150} = 0.9872$$

(viii) Marketing (mk) Input factor:

$$PE^{mk} = Q_8 = \frac{\frac{1100}{1} - \frac{\sum_{i=1}^{4}(11+20+18+2)}{1\times 4}}{\frac{1100}{1}} = \frac{1100-12.75}{1100} = 0.9884$$

Total Process Quality Effectiveness PE^{T} in combination can be evaluated from:

$$PE^{T} = \frac{\sum_{i=1}^{N} Q_i}{N}$$

$$PE^{T} = \frac{0.9913+0.9782+0.9932+0.9853+0.9928+0.9904+0.9872+0.9884}{8}$$

$$PE^{T} = \frac{7.9064}{8}$$

$$PE^{T} = 0.9883$$

5. RESULTS AND DISCUSSION

Analysis of the data collected, revealed varying contributions of processing factors to the output quantities (kg). Machinery performance and money/funding challenges contributed highest quantities, 87 and 77 kg respectively, as shown bolded in Table 2. Similarly, energy and money/funding availability have been highest contributors to output of 1500 and 2000 kg, bolded in Table 2, respectively. The poorest contributor to the output was management style (700 kg), while the best contributor to the realization of the least total quantity of defects (26 kg) was information/communication technology adopted by the company. Results in Table 2, generally revealed that number of rework was highest, followed by number of defects, start-up losses, while scraped losses was the least. This shows that the company did more rework activities on wastes rather than scrapping them out. The results (Table 2) shown further that the company management needs to concentrate more at improving their machinery's quality performance in order to reduce amount of wastes (87 kg) generated in the process.

Table 2. Process Quality Analysis of Plastic Company.

Effectiveness factor	Amount processed (kg)	Waste / defective quantities in kg.				
		Rework quantity	Defective quantity	Start-up losses	Scrapped losses	Total quantity Defective
Manpower	1,200	25	10	5	2	42
Machinery	1,000	50	22	12	3	**87**
Info./comm	950	15	5	5	1	26
Management	700	20	14	5	2	41
Energy	**1500**	22	12	5	4	43
Money/fund	**2000**	50	15	7	5	**77**
Material	1150	12	20	20	7	59
Marketing	1100	11	20	18	2	51

In Table 3, it was revealed that information/communication technology contributed highest measure of process quality effectiveness (0.9932) as bolded, followed by energy, manpower, money/funding, marketing, material while machinery performance contributed the least (0.9783), as bolded, respectively. Poor performance of machinery could be attributed to the highest quantity of wastes generated through its operation. This machinery poor process quality performance calls for its isolation and application of sustainable improvement/maintenance strategy. The traditional or combined measure of process quality effectiveness yielded effectiveness result (0.9883) which cannot directly fitted to any of the factors' measures of effectiveness if they are treated in isolation (Table 3). On this basis, it could be difficult for industrial practitioners to identify the main root cause of ineffectiveness in a production system. The new approach has enabled the identification of cause of problem (machinery's quality performance) without any stress. The evaluation of the process based on the two approaches has showcased flexibility of the new approach over the tradition one. As shown in Table 3, output from the traditional approach (0.9883) has revealed some variations (bias) when compared with the actual contributions of individual factors to the process quality effectiveness. It can be seen clearly that only marketing performance (0.9884) has a close effectiveness to traditional measure (0.9883) out of the eight (8) processes quality factors considered (Table 3).

Table 3. Process Quality Effectiveness Measure.

Effectiveness Factor	Process Quality Effectiveness in Isolation	Process Quality Effectiveness in Combination
	PE	PE^T
Manpower, PE^{mp}	0.9913	0.9883
Machinery, PE^{m}	**0.9783**	
Info./comm., PE^{ict}	**0.9932**	
Management, PE^{mg}	0.9853	
Energy, PE^{e}	0.9928	
Money/fund, PE^{mf}	0.9904	
Material, PE^{ma}	0.9872	
Marketing, PE^{mk}	0.9884	

However, process quality effectiveness outcomes for the company are all sustainable (Table 4) when compared with external factors called quality standards- acceptable trend, global standard, and industrial revolution class (0.85≤PE, $PE^T \leq$ 1.0). It can be seen in Table 4 that the quality effectiveness measures under isolation, PE (range between 0.9783 and 0.9932) and combination PE^T (0.9883) are within the standards (Fig. 2). This shows that the company's process Quality Management (QM) is sustainable and hence acceptable (A) based on the three standards applied (Table 4).

Table 4. Process Quality Management Effectiveness Comparison.

Effectiveness factor	Process Quality Effectiveness in Isolation	Process Quality Effectiveness in Combination	Comparison with Acceptable Trend, Global Standard and Industrial Revolution Class	Quality Management (QM) Acceptance (A)/Rejection (R)
	PE	PE^T	0.85≤PE, $PE^T \leq$ 1.0	A
Manpower, PE^{mp}	0.9913	0.9883	0.85≤PE, $PE^T \leq$ 1.0	A
Machinery, PE^{m}	0.9783		0.85≤PE, $PE^T \leq$ 1.0	A

Info./comm., PE^{ict}	0.9932		0.85≤PE, $PE^T \leq$ 1.0	A
Management, PE^{mg}	0.9853		0.85≤PE, $PE^T \leq$ 1.0	A
Energy, PE^{e}	0.9928		0.85≤PE, $PE^T \leq$ 1.0	A
Money/fund, PE^{mf}	0.9904		0.85≤PE, $PE^T \leq$ 1.0	A
Material, PE^{ma}	0.9872		0.85≤PE, $PE^T \leq$ 1.0	A
Marketing, PE^{mk}	0.9884		0.85≤PE, $PE^T \leq$ 1.0	A

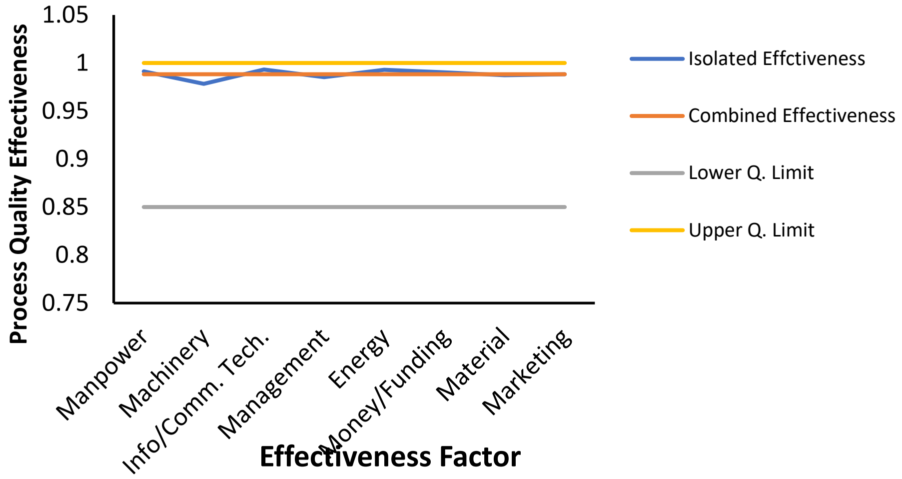

Figure 2. Process Effectiveness Quality Control.

6. CONCLUSION

A model that capable of resolving process quality sustainable challenges of production process was developed and applied to a plastic company. A traditional quality effectiveness measures was modified by isolating each of the factors responsible to quality effectiveness and then applied to a plastic company. The outcomes of the two measures- traditional and modified one are subjected to external (standard) factors comparison- acceptable trend quality, global quality standard, and industrial revolution quality class in order to evaluate the process quality management acceptability and sustainability of the company.

The results obtained by applying the models to a plastic company, revealed the following conclusions:

i. Machinery performance and money/funding challenges contributed to highest wastes in the company.
ii. Energy and money/funding availability were contributors to highest output, while management style contributed poorly to the output.
iii. Information/communication technology adopted by the company enabled the company to generate least quantity of defective items.
iv. Quantity of rework, defects, and start-up losses are relatively high as compared to scrap losses; and the company carried out more rework activities on wastes.
v. The company management is requested to concentrate more at improving their machinery's quality performance in order to reduce amount of wastes in the process.
vi. Information/communication technology contributed highest measure of process quality effectiveness out of quality effectiveness factors, while machinery performance contributed the least, due to high waste generation. This calls for isolation and improved maintenance to enhance performance.
vii. Quality effectiveness measure using traditional and new techniques was not totally compatible, hence cannot directly be fitted to any of the factors' measures of effectiveness in isolation. An improved version of the model is provided to enable industrial engineer identify and isolate the main root cause of the process quality failure.
viii. The modified approach has enabled identification of machinery's quality performance as the root cause of the company's process quality effectiveness challenge, and has showcased flexibility of this new approach over the traditional one.
ix. Process quality effectiveness outcomes for the company are all sustainable under the influence of external factors (standards) - acceptable trend, global standard, and industrial revolution class, which means that the company's process quality effectiveness is acceptable.

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DATA AVAILABILITY STATEMENT

Data are readily available and adequately analyzed for and applied to this study.

DECLARATION OF INTEREST

There is no conflict of interest as regards the publication of this manuscript.

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