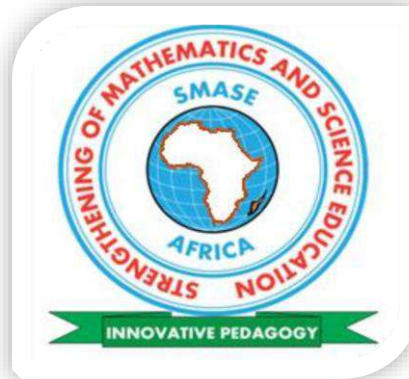




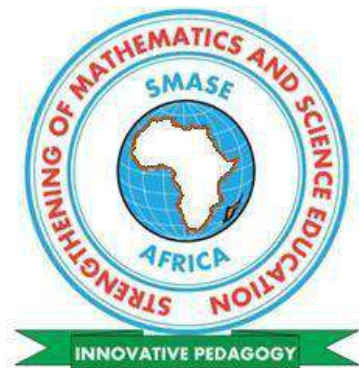
Strengthening Mathematics and Science

Education in Africa

[SMASE-AFRICA]

Journal for Science, Technology, Engineering and
Mathematics Education in Africa (JSTEMEA)





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[Secretariat]

National Science Centre (NSC)

Ministry of Education

Private Bag 5, Woodlands, Lusaka, Zambia

Tel +260-211-262391 or +260-211-266772

Email: jstemea@gmail.com

Contact Information

[Regional Secretariat]

Strengthening Mathematics and Science Education in Africa (SMASE-Africa) P. O. Box 22949-00505

Located inside the University of Nairobi - Kenya Science Campus, Ngong Road Nairobi, Kenya.

Tel: +254 720 073 533

E-mail: info@smase-africa.org

Website: www.smase-africa.org



*Journal for Science, Technology, Engineering and Mathematics Education in Africa (JSTEMEA),
Volume 1, Number 2, July 2026*

Strengthening Mathematics and Science Education in Africa

SMASE-AFRICA



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Preface

Welcome to Volume 1, Number 2, July 2026 Edition of the Journal for Science, Technology, Engineering and Mathematics Education in Africa (JSTEMEA)

The 22nd Conference on Mathematics, Science and Technology Education in Africa (COMSTEDA 22), held from 12th – 14th November 2025 at the Bingu International Conference Centre in Lilongwe, Malawi, brought together educators, policymakers, researchers, industry experts, and development partners from across the continent. Guided by the theme, “Reimagining STEM for a Pan-African Future: Bridging Education, Innovation, and Sustainable Development Towards Agenda 2063”, the forum reaffirmed the collective African commitment to reimagining STEM education in ways that equip learners with knowledge, skills, values, and attitudes relevant for 21st century living.

This edition of the journal captures a selection of fourteen (14) further peer-reviewed papers presented at the conference, complementing the fifteen papers published in Number 1 of this volume. These papers reflect the conference sub-themes, namely:

- 1. Decolonizing STEM Curricula: Centering African Knowledge Systems and Sustainable Practices**
- 2. Pan-African Innovation Hubs: Leveraging Technology and Entrepreneurship for Inclusive Growth**
- 3. Gender Equity in STEM: Empowering Women and Girls as Leaders of Africa’s Sustainable Future**
- 4. STEM for Climate Resilience: Adaptive Solutions for a Changing Africa**
- 5. Policy Harmonization and Cross-Border Collaboration for a Unified STEM Agenda**

Together, these contributions showcase both theoretical perspectives and classroom-based practices, enriching the ongoing dialogue on STEM education in Africa. They also highlight practical innovations ranging from localised, indigenous-knowledge-based assessment and gender-responsive pedagogies to virtual laboratories, industry–academia partnerships and the

reintroduction of Technology Studies, mirroring the dynamism of education systems across the continent.

Acknowledgements

We extend our deepest appreciation to the Government of the Republic of Malawi and the Ministry of Education, Malawi, for graciously hosting COMSTEDA 22 at the Bingu International Conference Centre in Lilongwe in partnership with SMASE-Africa.

We are equally indebted to the organizing committees, keynote speakers, and session chairs whose tireless efforts ensured a vibrant and engaging forum. Our thanks also go to SMASE-Africa partners, whose material, financial, and technical contributions enriched the conference. Finally, to all delegates, paper presenters, and participants onsite and online. We are grateful for your commitment, insights, and dedication to advancing STEM education in Africa.

Looking Ahead

As SMASE-Africa continues to serve as a continental hub for strengthening STEM education, this journal is more than a record of proceedings. It is a springboard for further inquiry and innovation. We hope that readers will find in these pages not only valuable research but also practical insights to inspire reforms in classrooms, policies, and institutions across Africa.

We look forward to building on the momentum of Lilongwe as we prepare for COMSTEDA 23, confident that each forum brings us closer to realizing the African Union's Agenda 2063 and the aspirations of SDG 4: Quality Education

About SMASE-Africa and COMSTEDA

SMASE-Africa was founded in 2001 to strengthen mathematics and science education in Africa. It is now a continental association uniting ministries of education, teacher educators, researchers, and development partners in advancing STEM education. With a **vision** “*to be a leading organization in promoting quality STEM education in Africa*”, SMASE-Africa works through research, professional development, policy advocacy, and collaborative networks. Its mission is to “*To promote quality STEM education through research, capacity development, advancing policies, good governance, collaboration, and linkages in Africa.*”

From **2001 – 2013**, the regional conference was known as **SMASE-WECSA (Strengthening of Mathematics and Science Education in Western, Eastern, Central and Southern Africa)**. In **2014**, the forum was renamed the **Conference on Mathematics, Science and Technology Education in Africa (COMSTEDA)** to reflect its continental scope.

The **Conference on Mathematics, Science and Technology Education in Africa (COMSTEDA)** is SMASE-Africa’s annual flagship platform for dialogue, research dissemination, and professional exchange. Since 2014, COMSTEDA has rotated among member countries, bringing together educators, policymakers, NGOs, and the private sector to deliberate on innovations and challenges in STEM education. Its scholarly outputs are published in the *Journal on STEM Education in Africa (JSTEMEA; ISSN 2617-6300)*, of which this volume is the 6th edition.

COMSTEDA Editions

- | | |
|----------------------|--------------------------------------|
| • COMSTEDA 14 | 2016, Nairobi, Kenya |
| • COMSTEDA 15 | 2017, Livingstone, Zambia |
| • COMSTEDA 16 | 2018, Maun, Botswana |
| • COMSTEDA 17 | 2019, Nairobi, Kenya |
| • COMSTEDA 18 | 2021, Virtual (hosted by Mozambique) |
| • COMSTEDA 19 | 2022, Blended (Kampala, Uganda) |
| • COMSTEDA 20 | 2023, Blended (Accra, Ghana) |
| • COMSTEDA 21 | 2024, Blended (Kaduna, Nigeria) |
| • COMSTEDA 22 | 2025, Lilongwe, Malawi |

The Objectives of COMSTEDA-22

The 22nd Conference on Mathematics, Science and Technology Education in Africa (COMSTEDA-22) was designed to:

1. **Provide a continental platform** for educators, governments, academic institutions, private sector, and development partners to interrogate issues and share best practices in STEM education.
2. **Improve the quality of education in Africa** by sharing impactful research findings and classroom practices that inform policy and practice.
3. **Present case studies and research outputs** that highlight innovative approaches in mathematics, science, and technology education across diverse African contexts.
4. **Promote and highlight the role of STEM education** in Africa's socio-economic development, aligned to Agenda 2063 and SDG 4.
5. **Foster networking, collaboration, and partnerships** among countries, institutions, and stakeholders to build collective capacity in STEM education.
6. **Interrogate emerging issues** such as ICT integration, artificial intelligence, equity, inclusion, and the competence-based curriculum shift, ensuring African learners are prepared for life challenges.

 *On behalf of SMASE-Africa and the Editorial Board, we present Number 2 of the first volume of the 2026 Edition of the Journal on STEM Education in Africa, containing a further fourteen research papers from COMSTEDA 22, Lilongwe. May these pages inspire, provoke, and guide collective action toward reimagining STEM for a Pan-African future.*

Editorial

Article 1

Benson Banda, Enock Nthiwa and Simon Kyaguba authored the paper titled: ***Localising Assessment for Sustainable Development: Integrating Indigenous Knowledge into Competence-Based STEM Tasks***. This qualitative study observed that localisation and sustainability were critical to Competence-Based Curriculum (CBC) reform in Africa, and examined how STEM educators integrated indigenous knowledge and local materials into competence-based assessment (CBA). Drawing on the multi-country AfriSTEM WhatsApp discussion held from 5 to 10 October 2025, the analysis explored the principles, benefits and challenges of contextualising assessment with indigenous resources. Three themes emerged: the use of local materials enhanced the accessibility and relevance of assessment; indigenous knowledge promoted creativity, environmental responsibility and entrepreneurship; and teachers needed safety guidelines and curriculum alignment to scale up the practice. The paper proposed a localisation framework that aligned CBC assessment with sustainable development and Agenda 2063.

Article 2

Gender-Responsive STEM Pedagogies in Rural Uganda: Lessons from SESEMAT Teacher Training Programs by John Watyekele and Moses Nagulam noted that gender disparities in STEM education persisted in rural Africa because of socio-cultural norms and limited resources, and examined Uganda's Secondary Science and Mathematics Teachers (SESEMAT) programme as a case study in promoting gender-responsive pedagogies. The study analysed how professional development reshaped classroom practices in the Bugisu-Sebei region. The findings revealed that trained teachers adopted gender-sensitive lesson planning, assigned roles equitably and integrated local contexts into STEM teaching, which improved inclusivity, enhanced girls' confidence and increased learner engagement. Teachers also reported a shift in their own attitudes, away from entrenched stereotypes towards more equitable expectations. However, challenges remained, including scarce resources, deep-rooted cultural norms and a shortage of female STEM role models. The study concluded that targeted teacher training was a critical catalyst for change but was insufficient on its own, and that sustainable gender equity in STEM required complementary systemic support and deeper community engagement. It presented the SESEMAT experience as a replicable model for similar rural contexts, in line with a Pan-African vision of equitable and inclusive education aligned with Agenda 2063.

Article 3

Benson Banda, David Bawa and Muyabi Dickens, in the paper ***Understanding STEM Endeavors: Conceptual Clarity and Pedagogical Implications in Africa***, observed that, although STEM

education played a pivotal role in driving innovation, economic growth and technological advancement, developing a clear and operational definition of STEM endeavours remained a persistent challenge, especially in Africa, where education systems were shaped by diverse cultural, social and economic conditions. The paper synthesised insights from a virtual discussion conducted under the Knowledge Co-Creation Programme (KCCP) 2025 in Zambia, which critically examined multiple interpretations of STEM endeavours, the dynamic relationship between process and product, the role of uncertainty in learning and the necessity of contextual adaptation within African communities. Building on these insights, the paper proposed an emerging operational definition of STEM endeavours and presented a contextually grounded framework for strengthening STEM education in Africa. It further offered strategic recommendations for localising STEM approaches, fostering innovation-driven learning and advancing hybrid STEM models that integrated Indigenous Knowledge Systems with contemporary scientific practices, in support of more relevant, inclusive and sustainable STEM education systems across the continent.

Article 4

Wambeye Kimweli Marakia authored the paper titled: ***Impact of Industry Academia Collaboration on Student Competency Acquisition in STEM-CBET Programs for Industrial Workforce Readiness***. The study investigated the impact of industry-academia collaboration on student competency acquisition in STEM-focused Competency Based Education and Training (STEM-CBET) programmes within Kenya's Technical and Vocational Education and Training (TVET) sector, with an emphasis on workforce readiness. Guided by the operationalisation of the Kenya National Qualifications Framework (KNQF) through Industry Advisory Committees (IACs), the research analysed the extent, patterns and gaps of industry involvement in curriculum development, instructional delivery and outcome assessment. Data were collected through structured online questionnaires administered to 233 IAC members and 350 TVET heads of department and industry liaison officers, complemented by qualitative interviews with 98 stakeholders. Correlation and regression analyses examined the relationship between industry collaboration factors and graduate employment rates as a proxy for competency acquisition. The findings revealed a modest but statistically significant influence of industry engagement on programme effectiveness ($R^2 = 0.169$, $p < 0.001$), with frequent, multifaceted industry support enhancing competency outcomes. Challenges persisted, including limited communication between academia and industry (65%), resource constraints, misalignment of KNQF descriptors with real job competencies and insufficient practical training. The study advocated scaling up industry partnerships beyond equipment donations to joint research, co-developed training and shared technology investment, and recommended stronger dialogue channels, public-private funding, expanded industry-led practical training and industry-led trainer certification.

Article 5

Decolonizing STEM Curricula: Centering African Knowledge Systems and Sustainable Practices by Maradonah Sichilenge and Sibeso Mubukwanu observed that STEM education across Africa had been shaped by colonial legacies that privileged Eurocentric knowledge systems and pedagogies, and argued that centring African Knowledge Systems and sustainable practices within STEM curricula could transform learning into a culturally resonant, socially just and environmentally responsible endeavour. Using a conceptual and comparative approach, and drawing on cases from Zambia, South Africa, Uganda and Zimbabwe, the paper examined policy frameworks, classroom practices and teacher readiness. It highlighted how traditional agricultural science, indigenous engineering and local ecological knowledge could be mobilised to enrich STEM learning. The paper proposed a framework for decolonising STEM that emphasised epistemic pluralism, community partnership, teacher capacity and a sustainability orientation, and offered recommendations for policymakers, teacher educators and curriculum developers. It contributed to ongoing debates about knowledge sovereignty, curricular justice and the role of STEM in advancing the Sustainable Development Goals (SDGs) in Africa.

Article 6

Faustin Nduwayezu, Ezechiel Nsabayezi, Jeannette Muterampundu, Pheneas Nkundabakura, Theophile Nsengimana and Eugenie Uwamariya, in the paper ***Leveraging Technological Innovations to Overcome Shortage of Laboratory Facilities for Teaching and Learning Mathematics and Science in Rwandan Secondary Schools***, noted that practical laboratory experience played a vital role in developing learners' conceptual understanding and scientific reasoning, yet many Rwandan secondary schools faced persistent challenges in establishing and sustaining fully equipped laboratories because of financial and infrastructural constraints. To address this gap, 30 Virtual Mathematics and Science Laboratories (VMSLs) were developed by the University of Rwanda-College of Education in partnership with the Rwanda Basic Education Board to complement PhET interactive simulations as a cost-effective way of simulating real experiments. Framed within a Design-Based Research methodology, the study investigated teachers' and learners' perceptions, participation and engagement with VMSLs embedded in lessons aligned with Rwanda's Competence-Based Curriculum. Data were collected from 200 students and 8 teachers through Likert-scale questionnaires, semi-structured interviews and classroom observations. The findings revealed overwhelmingly positive perceptions: the majority of students (93%) and teachers reported that VMSLs improved lesson clarity, fostered learner-centred participation and enhanced behavioural, emotional and cognitive engagement. Challenges such as limited ICT infrastructure, varying teacher readiness and technical disruptions were identified. The study recommended strategic investment in digital infrastructure, continuous professional development and policies to ensure equitable access, and concluded that VMSLs offered a transformative pathway for modernising STEM education in resource-constrained contexts.

Article 7

Lessly Malambo and Chipso Namakau Sakala authored the paper titled: ***Nurturing Competence and Creativity in Large Early Learning Classes: Insights from Learning the Concept of Patterns in a Grade 1 Zambian Classroom***. The study observed that large class sizes remained a persistent challenge in many Zambian early learning environments, limiting opportunities for creativity, exploration and competence development, and examined how a Grade 1 Creative and Technology Studies lesson on the concept of patterns was facilitated to promote engagement, collaboration and creativity in a double class of seventy-eight (78) pupils. A mixed-methods action research design was used, enabling the teacher-researcher to implement a learning sequence, observe learner responses and refine practice. Qualitative observations and learner artefacts were analysed alongside simple quantitative participation measures. The results indicated that contextualised, hands-on and culturally relevant learning experiences, supported by flexible outdoor learning spaces, enabled learners to demonstrate high levels of pattern identification (seventy percent) and moderate levels of independent creative pattern production (forty percent). The study offered practical guidance on how competence-based learning could be achieved in resource-constrained, large-class contexts.

Article 8

Yumi Sekiguchi Maguchi, in the paper ***Building a Teachers' Learning Platform for Fostering Reflective Practitioners: A Case Study of a Knowledge Co-Creation Programme in Zambia***, observed that teacher training conducted under international educational cooperation schemes had placed little emphasis on teachers' life experiences, educational views and individual beliefs as educators, and that cascade training, although able to reach large numbers of teachers quickly, had faced challenges in Zambia when external support ended and training content was not effectively reflected in schools. The paper explained that, from 2005, Zambia had pursued a different approach by introducing Lesson Study, enabling teachers to recognise and accept their own challenges and become change agents for educational improvement, and that since 2016 Zambia had run Third-Country Training Programmes (TCTP) for African educators built on the key concepts of "collaboration" and "co-creation." Focusing on the TCTP held in July 2025, the study analysed the training process from the perspectives of reflective practitioner theory and adult learning theory, and discussed the essence of teacher training that built a collaborative learning platform enabling trainees to develop as reflective practitioners.

Article 9

Balancing Formative and Summative Assessment for Competence Development in African STEM Education by Benson Banda, George Kwabena Kwakye, Marrio Chongo and Cleopatra Songolo observed that Competence-Based Curriculum (CBC) reform in African STEM education sought a workable balance between formative assessment, which nurtured competence through

continuous feedback, and summative assessment, which certified achievement. Drawing on the AfriSTEM WhatsApp dialogue held from 5 to 10 October 2025, the qualitative study explored educators' perspectives on this balance. Thematic analysis revealed broad agreement that formative assessment was central to competence development, but that its credibility depended on strong moderation structures and alignment with national policy. Participants proposed an 80/20 formative–summative weighting model, continuous teacher capacity-building and continental frameworks to ensure the equivalence of assessment practices. The paper recommended national policies that prioritised formative evidence, moderation hubs to strengthen reliability and the re-conceptualisation of summative examinations as authentic demonstrations of competence rather than recall-based tests, and concluded that competence grew within feedback-rich ecosystems rather than in examination halls.

Article 10

Munashe K.F. Chakamanga, Tom Muzenda and Luckmore Furidze, in the paper ***The Impact of Technology in Tertiary Education: A Case Study of Midlands State University (MSU) Bioinformatics Students***, examined the impact of technology on the academic experiences of bioinformatics students at Midlands State University (MSU), noting that the integration of technology in tertiary education had revolutionised teaching and learning through innovative approaches to curriculum delivery, student engagement and academic success. Using a mixed-methods approach, the research explored how tools such as virtual learning environments, online resources and specialised bioinformatics software enhanced learning outcomes, promoted collaborative work and addressed challenges unique to this interdisciplinary field. The study highlighted the benefits of technology in fostering critical skills, including data analysis and computational proficiency, while identifying barriers such as access disparities, inadequate infrastructure and the need for faculty training. The findings suggested that, while technology had significantly enriched the bioinformatics programme at MSU, strategic investments and policies were essential to optimise its potential, and the case study contributed to the broader discourse on technology adoption in higher education and its implications for advancing STEM disciplines.

Article 11

Debrah Mulenga Mwango and Anecetus Moonga authored the paper titled: ***From Knowledge Repositories to Skills Hubs: The Role of the National Science Centre in Information Provision for Competence-Based Education (CBE)***. The paper noted that Zambia's 2023 Education Curriculum Framework marked a transition from Outcome-Based Education (OBE) to Competence-Based Education (CBE), emphasising learners' ability to apply knowledge, skills, values and attitudes for life, work and entrepreneurship, and explored the role of the National Science Centre (NSC) in Lusaka as an information hub supporting CBE implementation. Using a descriptive design, data were collected in September 2025 through questionnaires and semi-structured interviews with 136 Business and Finance Heads of Department (HoDs) from Lusaka Province who were trained in two cohorts. Trainees used the Knowledge Co-Creation Dashboard

and a WhatsApp group to document reflections across four themes: exploration, prior knowledge, shifts in understanding and application. The findings revealed that initial resistance to change among HoDs shifted through reflective and hands-on learning, and that the training enhanced their capacity to mentor teachers, align departmental goals with CBE principles and foster learner-centred practices. The study further found that information provision at NSC played a transformative role in advancing CBE, and that by integrating technology and reflective learning NSC bridged the gap between policy and classroom practice. It affirmed NSC's role in curating competence-oriented resources, enhancing digital literacy and promoting project-based and collaborative learning.

Article 12

The Role of Technology Studies in Strengthening Science, Technology, Engineering, and Mathematics (STEM) Education: Evaluating the Impact of Technology Studies in Primary Schools by Anthony Foloko Msukwa explored the impact of reintroducing Technology Studies in Malawi's primary schools as part of broader efforts to strengthen STEM education at the foundational level. Technology Studies comprised Woodwork, Metalwork, Bricklaying, Drawing and Indigenous Technology as practical applications of science, engineering and mathematics, and the research was aligned with Malawi 2063 and Sustainable Development Goals 4, 8 and 9. Using a mixed-methods design across 15 pilot schools, the researchers conducted classroom observations, focus groups with learners and interviews with teachers and school leaders. The findings showed that early exposure to technical subjects boosted practical skills, creativity and interest in vocational careers, and that Technology Studies fostered active learning and strengthened school-community collaboration. However, schools faced challenges: 87% lacked metalwork tools and 40% had repurposed workshops for other classes or storage. The study concluded that the reintroduction of Technology Studies enhanced STEM learning and vocational interest, and recommended strategic investment in teacher training, infrastructure and curriculum support materials, together with policy alignment, to equip learners with 21st century skills and reduce youth unemployment.

Article 13

Benson Banda, Caroline Taliba, Mullah Mudenda and Shift Mweebo, in the paper ***Scenario, Case Study, or Project? Selecting Authentic Contexts for Competence-Based STEM Assessment in Africa***, observed that authenticity was pivotal in Competence-Based Curriculum (CBC) assessment but that authentic contexts varied in structure and complexity. The study synthesised African STEM educators' perspectives, drawn from the AfriSTEM WhatsApp dialogue held from 5 to 10 October 2025, on selecting between Scenario, Case Study and Project formats. Thematic analysis identified decision criteria based on competence targets, resource availability and safety constraints. Educators emphasised that the choice of context should reflect the intended competencies, allow realistic evidence to be captured and remain viable in actual school conditions.

The paper presented a selection framework to guide teachers in matching authentic contexts to assessment goals.

Article 14

John Ng'eda Purdul authored the paper titled: ***Influence of Gender Stereotype on Institutional Leadership in Public Secondary Schools in Kajiado County, Kenya***. The study investigated the influence of gender stereotypes on institutional leadership in public secondary schools in Kajiado County, observing that gender stereotypes determined the placement of women in leadership positions. It adopted a mixed methodology and a concurrent triangulation design, with a sample of 5 education officers, 25 principals, 25 deputy principals and 185 secondary school teachers selected through simple random and stratified sampling. Data were collected through questionnaires, interview guides and a document analysis checklist; quantitative data were analysed descriptively and inferentially, while qualitative data were analysed thematically. The study revealed that gender stereotypes impeded many female teachers from advancing to leadership positions in the education sector, and concluded that men dominated women in institutional leadership as a result of traditional and cultural views of women's place in society. It urged women to break the 'glass ceiling' between them and leadership positions, and recommended that the Ministry of Education and the Teachers Service Commission facilitate community sensitisation to build support for women in leadership positions in education, noting that women could demonstrate the same leadership skills and capabilities as their male counterparts.

Localising Assessment for Sustainable Development: Integrating Indigenous Knowledge into Competence-Based STEM Tasks.

Benson Banda, Enock Nthiwa, Simon Kyanguba

¹ bensonbanda2003@yahoo.co.uk, ² enockkaunda@gmail.com, ³ kyangubasimon@gmail.com

¹Ministry of Education, Directorate of National Science Centre, ² Mapunga High School, Kenya ³ Kafula Musungu Secondary School, Zambia

Abstract

Localisation and sustainability are critical to Competence-Based Curriculum (CBC) reform in Africa. This qualitative study examines how STEM educators integrate indigenous knowledge and local materials into competence-based assessment (CBA). Using the multi-country AfriSTEM WhatsApp discussion (5–10 October 2025) facilitated by the author, the analysis explores principles, benefits, and challenges of contextualising assessment with indigenous resources. Three themes emerged: 1) local material use enhances accessibility and relevance; 2) indigenous knowledge promotes creativity, environmental responsibility, and entrepreneurship; and 3) teachers need safety guidelines and curriculum alignment to scale practice. The paper proposes a localisation framework aligning CBC assessment with sustainable development and Agenda 2063.

Keywords: Indigenous Knowledge, Localisation, Sustainable Development, Competence-Based Assessment, Contextualised Learning.

1. Introduction.

1.1 Background and Context.

The contemporary educational landscape in Africa is undergoing a significant paradigm shift, moving away from content-heavy, examination-oriented pedagogies towards Competence-Based Curricula (CBC). This reform is driven by the urgent need to equip learners with practical skills, critical thinking abilities, and values that are relevant to their personal development and the socio-economic needs of their communities. Central to the philosophy of CBC is the principle of "learning by doing," which emphasizes the application of knowledge in real-life situations. In the specific domain of Science, Technology, Engineering, and Mathematics (STEM) education, this presents a unique opportunity. African classrooms are not isolated entities; they are embedded within communities that are rich with local materials from specific types of clay and plants to agricultural by-products and are custodians of profound Indigenous Knowledge Systems (IKS) that

have sustained societies for generations. This context provides a fertile, yet often underutilized, resource base. When STEM education draws directly from this local context, it ceases to be an abstract foreign import and becomes a tangible, relevant tool for understanding and interacting with the world. This process of contextualization, or "localisation," allows teachers to design authentic learning and assessment tasks that not only teach scientific principles but also promote environmental sustainability, cultural preservation, and community resilience, thereby aligning educational outcomes with broader continental goals like Agenda 2063.

1.2 Problem Statement.

Despite robust policy rhetoric at national and continental levels advocating for education that is culturally relevant and contextually appropriate, a significant implementation gap persists in many African classrooms. Teachers, often constrained by a lack of resources, inadequate training, and the lingering influence of colonial-era curricula, frequently default to using imported tools, standardized textbooks, and decontextualized assessment tasks. This practice creates a dissonance between the school environment and the learner's everyday reality. Students are assessed on their ability to recall facts about equipment they may never see again or to solve problems with no bearing on their community's challenges. This approach misses a critical opportunity for meaningful competence development. It fails to tap into the vast reservoir of indigenous knowledge, which can serve as a bridge to understanding complex scientific concepts, and overlooks the potential of local materials to make STEM education more accessible and affordable. Consequently, there is a risk of producing graduates who are theoretically knowledgeable but lack the applied, innovative, and culturally-grounded competencies required to drive sustainable development in their local contexts. This study, therefore, addresses the critical disconnect between the policy ideal of localised, competence-based education and the on-the-ground reality of classroom assessment practices in STEM subjects.

1.3 Research Objectives.

To systematically address the problem outlined above, this study is guided by the following primary objectives:

- i. To document and analyse the perspectives, experiences, and practical strategies of STEM educators across Africa regarding the integration of indigenous knowledge and local materials into the design and implementation of Competence-Based Assessment (CBA) tasks.
- ii. To identify and critically examine the perceived benefits, as well as the practical, ethical, and systemic constraints, associated with the localisation of STEM assessments.
- iii. To propose a practical and principled framework for localizing CBC assessment that explicitly links this pedagogical practice to the achievement of sustainable development goals and the aspirations outlined in Agenda 2063.

1.4 Research Questions.

The investigation is structured around the following research questions, which provide a clear focus for the inquiry:

- i. **RQ1:** How do secondary school STEM teachers in various African contexts utilise indigenous knowledge and locally available materials in designing and implementing competence-based assessment tasks?
- ii. **RQ2:** What are the key benefits (e.g., pedagogical, motivational, economic) and potential risks (e.g., safety, ethical, resource-related) that arise from the localisation of STEM assessments, as perceived by educators?
- iii. **RQ3:** How can the deliberate localisation of competence-based STEM assessment be structured to advance education for sustainable development and contribute to the specific objectives of Agenda 2063, such as fostering innovation and environmental sustainability?

1.5 Significance of the Study.

This research holds significance for multiple stakeholders in the African educational ecosystem. For policymakers and curriculum developers, the findings provide empirical evidence from practicing educators that can inform the creation of more realistic, supportive, and effective localisation guidelines and curriculum resources. It underscores the need to move beyond policy statements to concrete, teacher-supported implementation strategies. For teachers and school administrators, the study offers a compilation of peer-validated practices and insights, serving as a source of inspiration and a practical guide for making STEM education more relevant and engaging. It validates their innovative efforts and highlights the shared challenges they face, fostering a sense of community and shared purpose. For the academic community, this study contributes to the growing body of literature on decolonising education, contextualising learning, and implementing CBC in the Global South. It provides qualitative data on an under-researched aspect of CBC assessment and proposes a framework that connects classroom practice to macro-level development goals. Ultimately, the study is significant for learners and their communities, as it advocates for an education system that values their heritage, addresses their immediate environmental and economic challenges, and empowers them to become proactive agents of sustainable change.

1.6 Scope and Delimitations.

This study is deliberately scoped to ensure a focused and feasible inquiry. The research is confined to the analysis of Competence-Based Assessment within STEM subjects at the secondary school level. The geographical focus is pan-African, drawing on insights from educators across ten different countries, which allows for the identification of common patterns while acknowledging contextual diversity. The primary data source is a specific, time-bound qualitative dataset: the AfriSTEM WhatsApp discussion forum held from 5th to 10th October 2025. While this provides rich, real-time insights, it does not claim to be a comprehensive representation of all African educators' experiences. The study focuses on the "how" and "what" of teacher practices and

perceptions, rather than on measuring the quantifiable learning outcomes of students engaged in localised assessments. This delimitation allows for a deep qualitative exploration of the processes, rationales, and challenges involved in localising assessment.

1.7 Structure of the Paper.

The remainder of this paper is organised as follows: Chapter Two presents a review of relevant literature on Indigenous Knowledge Systems, authentic assessment, and Education for Sustainable Development. Chapter Three details the qualitative methodology, including the research design, data collection from the AfriSTEM forum, and thematic analysis procedure. Chapter Four presents the detailed findings organised according to the emergent themes. Chapter Five provides a comprehensive discussion, interpreting the findings in relation to the literature and the research questions. Finally, Chapter Six concludes the paper by summarising the key insights and offering concrete recommendations for policy, practice, and future research.

2. Literature Review.

The review of literature for this study provides a comprehensive review of literature relevant to the localisation of assessment in Competence-Based Curriculum (CBC) environments, with particular focus on STEM education in African contexts. It examines four key areas: Indigenous Knowledge Systems (IKS) and their educational relevance, theoretical foundations of authentic learning and assessment, principles of Education for Sustainable Development (ESD), and the intersection of CBC with local relevance in African educational reform. By synthesizing these bodies of literature, it establishes the theoretical framework for understanding how indigenous knowledge and local materials can be effectively integrated into competence-based STEM assessment.

2.1 Indigenous Knowledge Systems in Education.

Indigenous Knowledge Systems represent cumulative bodies of knowledge, practices, and representations maintained and developed by peoples with extended histories of interaction with the natural environment (Odora Hoppers, 2002). In the African context, IKS encompass sophisticated understanding of ecology, agriculture, medicine, astronomy, and mathematics that have sustained communities for generations. Dei (2012) argues that Indigenous philosophies offer critical epistemological alternatives to dominant Western educational paradigms, particularly through their emphasis of interconnectedness, community responsibility, and environmental stewardship.

The educational value of IKS lies in their potential to bridge the gap between formal schooling and learners lived experiences. As Semali and Kincheloe (1999) note, when students recognize their cultural heritage in the curriculum, they develop stronger academic identities and enhanced engagement. Furthermore, IKS provide practical, contextually appropriate solutions to local problems, making them particularly valuable in STEM education where abstract concepts can be grounded in familiar examples (Ogunniyi, 2007). For instance, indigenous construction techniques

can illustrate principles of physics and engineering, while traditional ecological knowledge can inform biological understanding of local ecosystems.

2.2 Theoretical Foundations of Authentic Learning and Assessment.

The concept of authentic assessment emerged in response to criticisms of traditional standardized testing, which often measures decontextualized skills rather than meaningful application of knowledge. Wiggins (1998) defined authentic assessment as engaging students in tasks that mirror the challenges and standards of real-world contexts in which adults operate. This perspective was expanded by Gulikers, Bastiaens, and Kirschner (2004), who developed a five-dimensional framework for authentic assessment comprising: the task, the physical context, the social context, the assessment result, and the criteria and standards.

In competence-based education, authenticity becomes particularly crucial. The fundamental premise of CBC is that students should develop demonstrable capabilities to apply knowledge in realistic situations. As Herrington and Herrington (2006) argue, authentic learning environments reflect the way knowledge will be used in real life, requiring students to engage in complex, ill-structured problems that have multiple solutions. When applied to assessment, this means moving beyond contrived exercises to tasks that mirror the kinds of challenges professionals in STEM fields actually encounter.

The localisation of assessment represents a powerful pathway to authenticity in African contexts. By designing tasks that utilize local materials and address community-specific issues, teachers can create assessments that meet Gulikers et al.'s (2004) criteria for physical and contextual authenticity. For example, assessing chemistry competencies through water quality testing of local water sources or evaluating engineering skills through the design of appropriate technology solutions for community needs.

2.3 Education for Sustainable Development and Agenda 2063.

Education for Sustainable Development (ESD) has evolved as a conceptual framework that prepares learners to address present and future global challenges (UNESCO, 2017). Sterling (2010) distinguishes between "education about sustainability" as a content area and "education for sustainability" as a transformative process that develops learners' capacities to think systemically and act responsibly. The latter approach aligns closely with competence-based education, as both emphasize the development of capabilities rather than mere knowledge acquisition.

In the African context, ESD finds concrete expression in Agenda 2063: The Africa We Want, the continental framework for transformative development. Agenda 2063 emphasizes self-reliance, African cultural identity, and people-driven development, with education identified as a critical catalyst for achieving these aspirations (African Union Commission, 2015). The integration of indigenous knowledge and local materials into STEM assessment directly serves these goals by valuing African heritage while developing practical problem-solving capacities relevant to continental development priorities.

The intersection of ESD, Agenda 2063, and STEM education creates a powerful rationale for assessment localisation. As Lotz-Sisitka et al. (2015) argue, transformative ESD requires

contextually relevant learning processes that enable learners to address sustainability challenges in their own communities. When STEM assessments task students with applying scientific principles to local environmental issues using indigenous knowledge and materials, they simultaneously develop academic competencies and contribute to sustainable community development.

2.4 Competence-Based Curriculum and Local Relevance in African Contexts.

The shift toward Competence-Based Curriculum in many African countries represents a significant departure from knowledge-focused educational approaches. CBC emphasizes the development of demonstrable capabilities in real-life contexts, making the issue of contextuality central to its implementation (UNESCO, 2021). Unlike previous educational reforms that often imported Western models with minimal adaptation, contemporary CBC initiatives increasingly recognize the importance of cultural and contextual relevance.

Research on CBC implementation in Africa highlights local relevance as both a pedagogical imperative and an equity strategy. Dei (2012) argues that education disconnected from learners' cultural contexts perpetuates epistemic violence and undermines learning efficacy. Conversely, when curriculum content and assessment tasks reflect local realities, students show improved engagement, deeper understanding, and enhanced ability to transfer learning to out-of-school contexts (Kanu, 2006).

The practical implementation of localised CBC faces significant challenges, however. Teachers often lack training in contextualizing curriculum, and educational systems frequently prioritize standardized examinations that discourage pedagogical innovation (Schweisfurth, 2013). Additionally, as O'Sullivan (2004) notes, deep-seated colonial attitudes about what constitutes "valid" knowledge can marginalize indigenous perspectives even in reformed curricula. These challenges highlight the need for systematic support for teachers attempting to integrate local knowledge and materials into their assessment practices.

2.5 Synthesis and Conceptual Framework.

The reviewed literature reveals converging rationales for integrating indigenous knowledge and local materials into competence-based STEM assessment. From IKS perspectives, this integration validates African epistemologies and enhances cultural relevance. From authentic assessment theory, it increases the fidelity between assessment tasks and real-world contexts. From ESD and Agenda 2063 frameworks, it aligns education with sustainable development priorities. And from CBC implementation research, it addresses equity concerns and improves learning outcomes.

This synthesis informs the conceptual framework guiding this study, which positions localised assessment as the intersection of four elements: indigenous knowledge systems, authentic competence demonstration, sustainable development goals, and cultural relevance. Effective localisation occurs when assessment tasks simultaneously draw on indigenous knowledge, require application of competencies in authentic contexts, advance sustainability principles, and reflect culturally meaningful practices. This framework provides the theoretical foundation for

investigating how STEM educators in African contexts are navigating this complex intersection in their assessment practices.

The literature also reveals significant gaps that this study addresses. While substantial scholarship exists on each of the individual components of this framework, less research examines their practical integration in day-to-day assessment practices of STEM teachers. Furthermore, the voices of practicing teachers regarding the challenges and opportunities of assessment localisation remain underrepresented in the literature. This study contributes to filling these gaps by documenting and analyzing educator experiences with localising STEM assessment in diverse African contexts.

3. Research Methodology.

3.1 Research Philosophy and Design.

This study was grounded in an interpretivist philosophy. Interpretivism posits that social reality is subjective and constructed through the meanings that individuals assign to their experiences. Given that the research aims to understand the personal perspectives, practices, and lived experiences of educators regarding the integration of indigenous knowledge into assessment, an interpretivist stance is highly appropriate. It allows for a deep exploration of how teachers interpret the concept of "localisation" and make sense of its benefits and challenges within their specific contexts.

Aligned with this philosophy, a qualitative research design was adopted. Qualitative inquiry is concerned with understanding phenomena from the perspectives of the participants, focusing on the 'why' and 'how' of human behavior. This design was selected because the research questions (RQs) demand rich, descriptive, and nuanced data that numerical data alone cannot provide. The objective was not to quantify the frequency of certain practices but to document the depth, variety, and underlying rationale of those practices. Specifically, a case study approach was applied, treating the concentrated, multi-country AfriSTEM WhatsApp discussion as a single, bounded case that provides unique insights into a contemporary phenomenon within its real-life context.

3.2 Data Collection: Context, Source, and Procedure.

The data for this study was generated from a single, rich source: the AfriSTEM Network WhatsApp group discussion.

- i. **Context and Participants:** The AfriSTEM Network is a community of practice comprising STEM educators, curriculum developers, and education researchers from across Africa. The discussion forum, titled "Localising STEM Assessment: Using Indigenous Knowledge and Local Materials," was actively facilitated by one of the authors over a six-day period from 5th to 10th October 2025. Participation was voluntary and open to all members of the network. The participants in this forum constituted a purposive sample; they were individuals with a known interest and presumed experience in the topic at hand, thereby ensuring the data collected was information-rich. The forum included educators from ten African nations, including Kenya, Zambia, Nigeria, Ghana, and South Africa, providing a pan-African perspective while acknowledging the diversity of local contexts.

- ii. **Data Collection Procedure:** The facilitated discussion served as a form of asynchronous, text-based, focused group discussion. The facilitator initiated the conversation with a central prompt and subsequent probing questions to stimulate depth and maintain focus. Participants shared their experiences, practical examples, successes, concerns, and recommendations in the form of text messages, which included written descriptions, links to images of student work, and shared lesson resources. At the end of the discussion period, the complete chat history, encompassing all participant contributions, timestamps, and unique participant identification numbers (e.g., Participant 68), was exported as a text file. This text file constituted the primary dataset for analysis. This method of data collection was advantageous as it captured spontaneous, peer-to-peer dialogue in a familiar digital space, encouraging candid sharing of ideas.

3.3 Data Analysis: Thematic Analysis Procedure.

The exported text data was subjected to a systematic process of thematic analysis, following the six-phase framework proposed by Braun and Clarke (2006). This process was conducted manually to allow for deep immersion in the data.

- i. **Familiarizing with the Data:** The researchers began by repeatedly reading the entire chat transcript to gain an overall understanding of the content and to note down initial ideas. This phase was crucial for immersing ourselves in the collective voice of the participants.
- ii. **Generating Initial Codes:** Systematic coding was then undertaken. A code is a word or short phrase that captures the essence of a salient feature of the data. We worked through the transcript line-by-line, identifying and labelling segments of text that were relevant to our research questions. Examples of initial codes included: "cost-effectiveness of local materials," "student engagement," "safety concerns," "link to entrepreneurship," "waste to wealth," "curriculum misalignment," and "community problem-solving."
- iii. **Searching for Themes:** In this phase, the various codes were collated and sorted into potential overarching themes. A theme is a patterned response or meaning that captures something important about the data in relation to the research questions. We examined how different codes could be combined to form a broader, significant pattern. For instance, the codes "cost-effectiveness," "accessibility in rural areas," and "relevance to student life" were aggregated to form the candidate theme "Local material use enhances accessibility and relevance."
- iv. **Reviewing Themes:** The candidate themes were then reviewed and refined at two levels. First, we reviewed all the coded data extracts for each theme to ensure they formed a coherent pattern. Second, we considered the validity of individual themes in relation to the entire dataset, ensuring that the thematic map accurately reflected the meanings evident in the data as a whole. This process led to the consolidation of some themes and the splitting or discarding of others.

- v. **Defining and Naming Themes:** Once a satisfactory thematic map was developed, we defined and refined the essence of what each theme captured. We identified the story each theme told and determined how it helped answer the research questions. The three final themes, as presented in the findings, were clearly articulated:
 - a. **Theme 1:** Local material use enhances accessibility and relevance.
 - b. **Theme 2:** Indigenous knowledge fosters sustainability and innovation.
 - c. **Theme 3:** Safety, ethics, and alignment.
- vi. **Producing the Report:** The final phase involved selecting vivid, compelling data extracts from the transcript to exemplify each theme and weaving them into a coherent and persuasive narrative for the findings chapter. The analysis was written up, ensuring a clear link between the data, the analytic narrative, and the research questions.

3.4 Ethical Considerations.

While the data was derived from a professional discussion forum, ethical principles were rigorously upheld. Informed Consent was obtained at two levels: firstly, through the general terms of membership in the AfriSTEM Network, which includes an understanding that discussions may be anonymized and used for research purposes; and secondly, through a specific announcement at the beginning of the focused discussion informing participants of the research intent and their right to opt-out. Anonymity and Confidentiality were ensured by removing all participant names, phone numbers, and other personally identifiable information from the dataset and the report. Participants are referred to only by their assigned numerical identifiers (e.g., Participant 68). The data was stored securely on a password-protected device, and access was restricted to the research team.

3.5 Limitations of the Methodology.

While this methodology yielded rich, contextual insights, it is important to acknowledge its limitations. The use of a purposive sample from a specific professional network means the findings are not statistically generalizable to all African STEM educators. The participants were likely more motivated and innovative than the average teacher, potentially presenting a more optimistic view of localisation practices. Furthermore, the text-based nature of WhatsApp, while convenient, may have limited the depth of description compared to in-person interviews or focus groups, as non-verbal cues and opportunities for immediate probing were absent. The asynchronous format also meant that the discussion lacked the dynamic, real-time interaction of a traditional focus group. Despite these limitations, the methodology was robust and fit-for-purpose, providing a unique and valuable window into the collective wisdom and shared challenges of a community of practicing educators at the forefront of contextualizing STEM education in Africa.

5. Findings.

The analysis of the AfriSTEM WhatsApp discussions revealed a rich tapestry of educator experiences, practical innovations, and critical reflections on integrating indigenous knowledge

and local materials into Competence-Based Assessment (CBA). The data coalesced around three central themes, which are elaborated below with verbatim excerpts and detailed interpretation.

i. Theme 1: Local Material Use Enhances Accessibility, Relevance, and Equity.

The most prominent finding was the overwhelming consensus on the practical and pedagogical benefits of using locally available materials. Educators emphasized that this practice directly addresses the chronic resource shortages plaguing many African schools, particularly in rural areas. By shifting the focus from expensive, imported laboratory equipment to everyday materials, teachers can democratize science education. Participant 186's statement, *"This makes science realistic and doable even in rural schools,"* encapsulates a powerful sentiment: localization is an equity strategy. It ensures that a child's learning experience is not determined by their school's budget but by the resourcefulness of their teacher and the richness of their immediate environment. Beyond mere accessibility, participants highlighted how local materials bridge the gap between abstract scientific concepts and students' lived realities, thereby enhancing relevance and engagement. The examples provided were not just theoretical but were concrete, actionable tasks. For instance, Participant 68 suggested, *"Use cassava or maize waste instead of purchased reagents,"* pointing to a dual benefit. Firstly, it teaches chemical or biological principles using familiar substances. Secondly, and more profoundly, it reframes agricultural "waste" as a valuable resource, instilling a lesson in resourcefulness and circular economy from a young age. Similarly, Participant 71's idea to *"Prepare ethanol from leftover nshima"* transforms a common household item into the subject of a scientific inquiry and value-addition process. This approach moves learning beyond rote memorization to "learning by doing" in a context that students understand and care about, making the knowledge gained more meaningful and durable.

ii. Theme 2: Indigenous Knowledge Fosters Sustainability, Innovation, and Entrepreneurship.

The discussions revealed that integrating Indigenous Knowledge (IK) is not merely a pedagogical tool but a vehicle for instilling values of environmental stewardship, innovation, and economic empowerment. Educators viewed CBA tasks rooted in IK as a direct contribution to sustainable development and the aspirations of Agenda 2063. Participant 12 powerfully connected classroom practice to continental goals, stating, *"Local bioethanol production, value addition, and environmental sustainability tasks like these contribute to the Africa we want."* This illustrates a shift in the purpose of assessment: from measuring isolated skills to evaluating competencies that contribute to community and planetary well-being.

Furthermore, participants observed that when assessments are anchored in solving authentic community problems, they naturally foster innovation and an entrepreneurial mindset. Participant 69 noted, *"When assessment focuses on community problems, learners become innovators."* For example, a task assessing knowledge of biology and chemistry through the local production of bioethanol from agricultural waste is also a lesson in entrepreneurship showing how science can

be leveraged to create value, reduce pollution, and generate income. This aligns competence with agency, empowering learners to see themselves not just as future job seekers but as problem-solvers and creators of sustainable enterprises. The knowledge systems that have sustained African communities for generations such as sustainable harvesting, natural medicine, and local construction techniques are thus positioned as a vital foundation for future-oriented innovation.

iii. Theme 3: The Imperative for Safety, Ethical Guidance, and Curriculum Alignment.

While the enthusiasm for localization was palpable, the conversations also surfaced significant pragmatic concerns, highlighting that successful integration requires more than just teacher motivation. A critical sub-theme was the paramount importance of safety and ethical considerations. Educators were keenly aware that "local" or "natural" does not automatically equate to "safe." Participant 176 issued a clear caution: *"Ensure prompts avoid hazardous materials and follow school safety rules."* This was reinforced by Participant 170, who asserted, *"Indigenous doesn't mean careless teachers must provide safe alternatives."* These comments reveal a professional understanding that the ethos of localization must be coupled with a rigorous commitment to student safety, requiring teachers to critically evaluate and adapt indigenous practices for the classroom context.

Beyond safety, a significant constraint identified was the lack of formal curriculum alignment and supportive guidelines. Teachers expressed a need for clear frameworks that show how these localized activities directly meet specific competency descriptors in the national curriculum. Without this, such innovative practices risk remaining extracurricular or dependent on individual teacher enthusiasm, rather than being scaled as a core component of CBA. The demand for structured support was implicit in the discussion's teachers need curriculum maps, exemplar tasks, and professional development to build their confidence and ensure that their creative assessments are formally recognized and validated. This points to a necessary synergy between grassroots teacher innovation and top-down policy support to institutionalize localization effectively and safely.

6. Discussion.

This study explored how STEM educators integrate indigenous knowledge and local materials into competence-based assessment, the associated benefits and challenges, and the potential of this localization to advance sustainability goals. The findings from the AfriSTEM network conversations reveal a dynamic landscape where teachers are actively reimagining assessment as a contextually relevant, sustainable, and transformative practice.

6.1 Localization as a Bridge to Authentic and Equitable Learning.

The strong emphasis on using local materials like cassava waste, leftover *nshima*, and other community resources (as cited by Participants 68 and 71) powerfully resonates with the literature on authentic learning and assessment. Wiggins (1998) and Gulikers et al. (2004) argued that for

tasks to be authentic, they must mirror the complexities and ambiguities of real-world challenges. The practices documented in this study achieve precisely this. By designing assessments that require students to produce ethanol from household waste or test soil pH with local indicators, teachers are moving beyond decontextualized textbook exercises. They are creating what Gulikers et al. (2004) would describe as a high-fidelity simulation of real-life scientific problem-solving, where the "test" is the ability to apply knowledge to a familiar, tangible context. This shift makes science, in the words of Participant 186, "realistic and doable," directly addressing the problem statement of teachers defaulting to imported, often irrelevant, tools.

Furthermore, this localization acts as a powerful lever for educational equity, a concern central to Dei's (2012) work on Indigenous philosophies in education. The reliance on expensive, standardized equipment inherently disadvantages under-resourced schools, predominantly in rural areas. By championing local materials, educators are democratizing access to quality STEM education. They are demonstrating that intellectual rigor is not contingent on sophisticated imports but can be cultivated through deep engagement with one's immediate environment. This decolonizes the learning space, valuing local resources not as "poor substitutes" but as legitimate and rich mediums for scientific inquiry.

6.2 Weaving Indigenous Knowledge into the Fabric of Sustainability and Innovation.

The second theme revealed that indigenous knowledge is not merely inserted into the curriculum as an additive component but is leveraged as a core driver of sustainability and innovation. Participant 12's vision of local bioethanol production contributing to "the Africa we want" directly aligns with the aspirations of Agenda 2063 and the principles of Education for Sustainable Development (UNESCO, 2021). When students engage in tasks that transform waste into energy, they are not just learning chemistry; they are embodying the principles of a circular economy and environmental stewardship advocated by Sterling (2010). This integration moves sustainability from a theoretical concept to a practiced competence, fostering what Sterling (2010) might call "resilient learners" equipped to navigate and address socio-ecological crises.

Moreover, the link between community-focused assessment and learner innovation, as noted by Participant 69, underscores the entrepreneurial potential of this approach. Odora Hoppers (2002) emphasized that Indigenous Knowledge Systems are dynamic and adaptive. By tasking students with solving local problems using local knowledge and materials, educators are activating this adaptive capacity. The assessment becomes a platform for value creation, where learners are encouraged to think not only as scientists but also as innovators and social entrepreneurs. This aligns competence-based education with broader economic development goals, transforming the classroom into a microcosm of the sustainable and self-reliant future envisioned in continental policy frameworks.

6.3 Navigating the Practicalities: Safety, Ethics, and Systemic Integration.

The enthusiasm for localization, however, is rightly tempered by pragmatic concerns regarding safety, ethics, and systemic support. The cautions raised by Participants 176 and 170 highlight a critical point: the ethical integration of IK requires careful negotiation and professional judgment. The notion that "indigenous doesn't mean careless" is a crucial pedagogical principle. It acknowledges that while IK systems hold profound wisdom, their direct application in a classroom setting must be filtered through modern understandings of safety protocols and child protection. This echoes a broader discourse in IK integration about respecting cultural practices while ensuring they are appropriate and safe for formal educational contexts.

The recurring need for curriculum alignment and guidelines points to a significant systemic challenge. For localization to scale beyond isolated, champion teachers, it must be systematically embedded within the educational architecture. Teachers require clear guidance on how to map local activities to specific competency descriptors in the national curriculum. Without this, their innovative efforts risk being perceived as supplementary rather than central to the assessment regime. This finding suggests that policy-level intervention is necessary to translate grassroots innovation into mainstream practice. The development of localized task exemplars, safety guidelines, and curriculum mapping resources is not a luxury but a prerequisite for the sustainable institutionalization of this approach. This calls for a collaborative model where policymakers, curriculum developers, and practicing teachers co-create the supportive frameworks needed.

7. Recommendations & Implications.

i. Policy:

- a. Develop localisation and safety guidelines for CBC tasks.
- b. Embed Agenda 2063 sustainability pillars in national assessment policies.

ii. Practice:

- a. Encourage project-based tasks solving local environmental or resource challenges.
- b. Use portfolios documenting sustainable practices and innovations.

iii. Capacity:

- a. CPD on safe material handling and environmental ethics.
- b. Teacher communities to share localised task exemplars.

Localisation transforms assessment into an engine for sustainable development, fostering ownership, creativity, and problem-solving.

8. Conclusion.

Integrating indigenous knowledge within competence-based STEM assessment connects learning with life, ensuring that education serves sustainable community transformation. Localisation is not ornamentation; it is the essence of Africa's competence-based future. Localisation of STEM assessment is more than a pedagogical technique; it is a transformative praxis. It repositions assessment from a terminal judgment of rote learning to an ongoing engine for sustainable development. It fosters a sense of ownership, as students see their culture and environment reflected

and valued in their education. It builds creativity and problem-solving skills by confronting learners with real-world challenges from their own communities. Ultimately, as the data and literature confirm, localization bridges the gap between school and life, ensuring that education fulfills its ultimate purpose: to equip learners with the competence and the conviction to contribute meaningfully to the sustainable transformation of their communities and the continent at large.

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Gender-Responsive STEM Pedagogies in Rural Uganda: Lessons from SESEMAT Teacher Training Programs

John Watyekele^{1*} and Moses Nagulam²

johnwatyekele5@gmail.com

¹SESEMAT Trainer, Bugisu-Sebei Region, Uganda

²Lecturer, Kumi University, Uganda

Abstract

Gender disparities in STEM education persist in rural Africa due to socio-cultural norms and limited resources (UNESCO, 2017). This study examines Uganda's Secondary Science and Mathematics Teachers (SESEMAT) program as case study in promoting gender-responsive pedagogies. It analyzes how professional development reshaped classroom practices in the Bugisu-Sebei region.

Findings reveal that trained teachers adopted gender-sensitive lesson planning, equitable role assignment, and integrated local contexts into STEM teaching. These strategies improved inclusivity, enhanced girls' confidence, and increased learner engagement. Teachers also reported a shift in their own attitudes, moving away from entrenched stereotypes towards more equitable expectations.

However, challenges remain, including scarce resources, deep-rooted cultural norms, and shortage of female STEM role models. The study concludes that while targeted teacher training is a critical catalyst for change, it is insufficient alone. Sustainable gender equity in STEM requires complementary systemic support and deeper community engagement. The lessons from SESEMAT offer a replicable model for similar rural contexts contributing to a broader Pan-African vision for equitable and inclusive education aligned with Agenda 2063.

Keywords: *Gender-responsive pedagogy, STEM education, rural Uganda, teacher training, girls' participation, Agenda 2063*

1. Introduction

1.1 Background and Context

Science, Technology, Engineering, and Mathematics (STEM) education is globally recognized as a cornerstone of national development, innovation, and competitiveness. Yet, women remain significantly underrepresented in STEM pipelines, a trend evident across continents (Lasekan et al., 2024; Ntumi & Bulala, 2025).

In high-income regions, gender inclusion efforts have focused on mentorship, stereotype reduction, and policy advocacy. However, in sub-Saharan Africa, the challenge is compounded by structural inequities such as limited educational resources, poverty, and entrenched patriarchal norms (Amegah, 2024; Makamure, 2025).

Across African education systems, multiple studies confirm that girls' participation in STEM decreases progressively from primary to tertiary education (Boateng, 2025; Mukagiahana et al., 2024).

These findings align with UNESCO and World Bank datasets showing that fewer than one-third of STEM graduates are female a figure even lower in engineering and physics disciplines (Castro Núñez & Santero-Sánchez, 2023; Boaler, 2023).

Table: 1: Selected national and regional indicators (2020–2024)

Indicator	Value/Note	Source
Female share of STEM graduates (global avg)	≈ 35% (UNESCO report summaries, 2021–2024)	(Lasekan et al., 2024), UNESCO (2021, 2024)
Girls' share of primary enrolment (Uganda, approx.)	≈ 49% (UBOS, 2022)	UBOS (2022)
Female share in advanced-level STEM subjects (Uganda, reported concerns)	Substantially lower than primary share; < 30% reported in national commentary (MoES/sector reports)	(MoES, 2021)
Regions with high rural STEM gender gaps (example)	Bugisu-Sebei and other remote districts often show lower female participation due to resources & norms (UN Women Uganda, 2024)	(Women, 2025)

Source: (Gary, 2025; Lido & Evangelista, n.d.; Women, 2025).

In Uganda, a youthful nation where 78 % of citizens are under 30, gender gaps in STEM remain stark. National surveys indicate that girls represent nearly half of primary enrolments but less than 30 % of advanced-level STEM candidates (Kaidu et al., 2024; Ozor et al., 2024).

Research from rural eastern regions such as Bugisu-Sebei shows that these gaps are reinforced by socio-cultural expectations assigning domestic roles to girls, promoting early marriage, and

positioning boys as natural leaders in science classrooms (Boateng, 2025; Mukagiahana et al., 2024).

A qualitative analysis by (Makamure, 2025) further reveals that teachers' implicit biases such as praising boys for "logical thinking" and girls for "hard work" shape gendered academic identities from an early age. The figure 1 below is a conceptual framework shows how micro policies influence student outcomes.

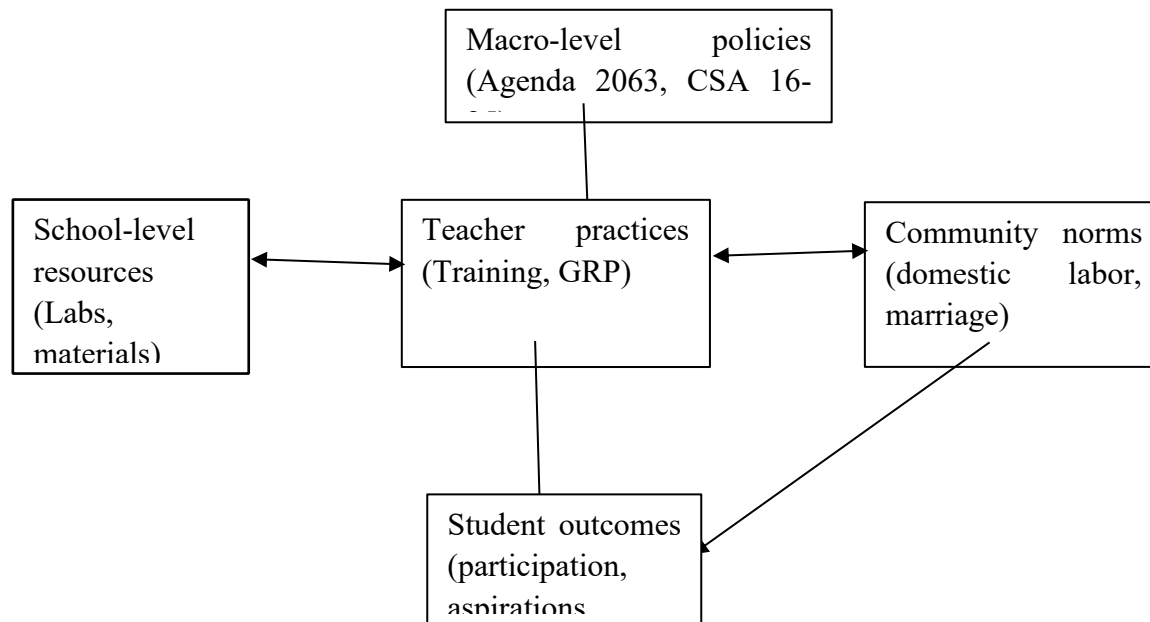


Figure 1: Conceptual diagram showing how macro policies, school resources, teacher practices, and community norms interact to influence student outcomes in STEM gender participation

These disparities are not due to differences in ability but to systemic and cultural barriers (Lasekan et al., 2024; Mukagiahana et al., 2024). Patriarchal norms, gendered labour divisions, and lack of female role models continue to hinder girls' sustained engagement in STEM pathways.

Teacher preparation has emerged as a critical leverage point for transformation. Studies in Rwanda and Tanzania highlight that when teachers receive gender-responsive pedagogy (GRP) training, classroom participation among girls improves significantly (Mukagiahana et al., 2024; Kibona & Mbingamno, 2025).

At the policy level, the African Union's Agenda 2063 and Continental Education Strategy for Africa (CESA 16–25) emphasize gender-inclusive STEM education as vital for sustainable development.

National frameworks including Uganda's Gender in Education Policy (2016), National Strategy for Girls' Education (2019–2024), and STEM Education Policy Framework (2021) reflect these regional goals but face persistent implementation challenges at the grassroots level (Amegah, 2024; Lasekan et al., 2024).

Ultimately, evidence from cross-country studies in Africa suggests that transforming STEM education for gender equity requires more than access; it demands structural shifts in school culture, pedagogy, and community engagement (Makamure, 2025; Ntumi & Bulala, 2025).

1.2 The Pan-African Imperative: Agenda 2063 and Gender Equity in STEM

The African Union’s Agenda 2063, “The Africa We Want”, articulates a visionary framework for a prosperous, inclusive, and peaceful continent driven by its citizens’ full potential. Aspiration 6 explicitly calls for “an Africa whose development is people-driven, relying on the potential of African people, especially its women and youth” (Union, 2015). This vision underscores the centrality of education particularly STEM (Science, Technology, Engineering, and Mathematics) as a vehicle for achieving sustainable development, industrialization, and gender equality.

Within this framework, the Continental Education Strategy for Africa (CESA 16–25) prioritizes STEM as a key driver for human capital development and calls for gender-responsive pedagogical reforms to ensure equitable participation and outcomes (AUC, 2022; (Boaler, 2023). The African Girls Can Code Initiative (AGCCI) and the AU Strategy for Gender Equality and Women’s Empowerment (2019–2028) further highlight the importance of equipping African girls with digital and STEM competencies to thrive in the Fourth Industrial Revolution (Women, 2025).

Uganda, as a signatory to both Agenda 2063 and CESA 16–25, has translated these continental commitments into national frameworks. Key among these are; the National Strategy for Girls’ Education (2019–2024), emphasizing gender-responsive teaching and safe learning environments, the Gender in Education Policy (2016), which mandates mainstreaming gender in all education programs, the STEM Education Policy Framework (2021), which promotes inquiry-based learning, teacher capacity building, and digital integration in science teaching.

While these policies mark significant progress, their implementation at grassroots level particularly in rural and underserved regions remains inconsistent and underfunded (MoES, 2023; World Bank, 2022). Persistent barriers include inadequate monitoring, limited teacher training, and sociocultural resistance to girls’ participation in technical subjects (Kasirye, 2022; (Chapin & Warne, 2020). Consequently, there is an urgent need to bridge the policy practice divide through targeted interventions such as SESEMAT.

1.3 The SESEMAT Program, A Catalyst for Change

The Secondary Science and Mathematics Teachers (SESEMAT) program was launched in 2007 by Uganda’s Ministry of Education and Sports (MoES), with technical and financial support from the Norwegian Agency for Development Cooperation (Norad). Initially conceived to address the chronic shortage of qualified STEM teachers in rural secondary schools, SESEMAT evolved into a comprehensive professional development initiative aimed at improving content mastery, pedagogical competence, and learner-centered instruction (MoES, 2021; Asimwe & Nabbale, 2022).

Since 2018, SESEMAT has integrated Gender-Responsive Pedagogy (GRP) into its core curriculum, drawing on frameworks developed by the Forum for African Women Educationalists (FAWE, 2018; 2023) and guided by international best practices in inclusive teaching (Boaler, 2023). GRP training modules within SESEMAT emphasize; gender-aware lesson planning and classroom management; Equitable participation and feedback mechanisms; Addressing bias,

harassment, and stereotyping; Linking STEM content to local realities and indigenous knowledge systems.

This integration represents a paradigm shift from purely technical teacher upgrading to transformative pedagogy, where teachers act as reflective practitioners and social change agents (Unterhalter et al., 2022; Mukagiahana et al., 2024).

Empirical evidence indicates that SESEMAT-trained teachers demonstrate improved confidence, inclusivity, and student engagement in STEM classrooms (Chapin & Warne, 2020). The program also aligns with Uganda's Vision 2040 and Agenda 2063, situating teacher empowerment as a cornerstone for achieving gender parity in STEM participation (African Union, 2023; MoES, 2023).

This study, therefore, investigates how SESEMAT's GRP component has influenced teacher practices, student engagement, and gender attitudes within the Bugisu–Sebei sub-region a culturally rich yet economically marginalized area where gender norms remain deeply entrenched. Specifically, it seeks to answer; how has SESEMAT influenced teachers' classroom practices and attitudes toward gender equity? What effects have these changes had on girls' participation and confidence in STEM subjects? What systemic barriers continue to constrain the realization of equitable STEM education?

2. Literature Review

2.1 Global and African Perspectives on Gender and STEM

Globally, the persistent underrepresentation of women in Science, Technology, Engineering, and Mathematics (STEM) continues to attract scholarly concern. Recent meta-analyses attribute this gap to interlocking causes including implicit bias within education systems, limited exposure to female STEM role models, stereotype threat, and socialization processes that discourage girls from pursuing technical fields (Everaert et al., 2022; Tang et al., 2024).

Large-scale cross-national analyses show that gender differences in career choice and confidence appear as early as age 10–12, suggesting that cultural messaging about “masculine” and “feminine” subjects plays a formative role (Tang et al., 2024; Gary, 2025).

Interventions such as gender-responsive curriculum reform, mentorship programs, and bias training for educators have proven effective in narrowing these disparities in several high-income contexts (Miralles-Cardona et al., 2023).

In Africa, the context is more complex and intersectional. Structural poverty, limited infrastructure, and patriarchal cultural norms create multiple layers of exclusion for girls (Women, 2025); (Union, 2016; Amegah, 2024; Boaler, 2023) reports that women account for approximately 32% of researchers in Sub-Saharan Africa, but fewer than 12 % in engineering and ICT fields.

Recent research in East Africa shows that girls especially in rural areas are frequently withdrawn from school to undertake domestic labor or early marriage responsibilities, practices rooted in gendered assumptions about women's social roles (Ntumi & Bulala, 2025).

Classroom practices also perpetuate inequality. In Uganda, (Chapin & Warne, 2020) documented teachers who praise boys for “logic and reasoning” while attributing girls’ success to “hard work” or “luck.” These micro-interactions subtly reinforce perceptions that boys are innately better at STEM, shaping long-term academic identity and self-efficacy (Openjuru, 2021; Mukagiahana et al., 2024).

Similar teacher-bias patterns have been observed in Kenya, Tanzania, and Ghana, suggesting that gendered feedback is a widespread challenge in African education systems (Njoroge & Nyabuto, 2014; Makamure, 2025).

2.2 Theoretical Foundations of Gender-Responsive Pedagogy (GRP)

Gender-Responsive Pedagogy (GRP) is conceptually grounded in feminist pedagogy, critical theory, and inclusive education frameworks that seek to challenge and transform unequal power relations within learning environments. (Stromquist, 2021) describes GRP as “an approach that interrogates gender power relations in the classroom and actively constructs equitable learning environments.” Recent studies extend this definition by emphasizing GRP’s focus on learner agency, relational ethics, and intersectional awareness (Makamure, 2025; Mukagiahana et al., 2024).

Unlike “gender-neutral” teaching, which assumes that all learners have the same needs, GRP recognizes that girls and boys experience schooling differently because of socialization, identity construction, and access to resources (Lasekan et al., 2024; Uworwabayeho et al., 2018). Key principles of GRP include; ensuring that all students have equal opportunities to speak, lead, and contribute, representing diverse genders, cultures, and knowledge systems in teaching materials, addressing gender-based harassment and fostering mutual respect, encouraging both teachers and students to question traditional gender norms.

Linking STEM concepts to students’ lived realities and indigenous knowledge systems (Uworwabayeho et al., 2018; Makamure, 2025; Mukagiahana et al., 2024). In the African context, the Forum for African Women Educationalists (FAWE) operationalized GRP through its Gender-Responsive Pedagogy Toolkit, now used across 34 countries. The toolkit centers on teacher self-reflection, collaborative learning, and community engagement key components later integrated into Uganda’s SESEMAT teacher training program (Uworwabayeho et al., 2018); MoES, 2021).

Empirical work in Rwanda and Eswatini shows that teachers trained in GRP frameworks demonstrate more equitable classroom participation, reduced gender bias, and improved female student confidence in STEM subjects (Mukagiahana et al., 2024; Makamure, 2025).

2.3 Teacher Professional Development as a Lever for Equity

Teachers are not mere transmitters of knowledge but co-constructors of classroom culture (Openjuru, 2021). Recent research demonstrates that sustained teacher professional development (TPD) focused on GRP can significantly reshape classroom discourse and student engagement (Mukagiahana et al., 2024; Kibona & Mbingamno, 2025).

Effective GRP-oriented TPD should be a continuous and practice-based, moving beyond one-off workshops, context-specific, addressing local cultural and resource realities, reflective, enabling teachers to examine personal biases, supported by institutional policy and leadership (Makamure, 2025; Amegah, 2024; Uworwabaye et al., 2018).

Uganda's SESEMAT program embodies these principles. Since 2018, SESEMAT has combined residential training with school-based mentorship and peer-learning circles, guiding teachers to implement gender-equitable STEM pedagogies (MoES, 2021; (Chapin & Warne, 2020). This represents a shift from narrow technical upskilling toward transformative pedagogy where teachers act as agents of equity and social change (Lasekan et al., 2024; Ntumi & Bulala, 2025).

2.4 Gaps in Existing Research

While GRP implementation has been explored in urban and peri-urban African schools, there remains limited empirical evidence from deeply rural, culturally conservative contexts such as Bugisu-Sebei. Few longitudinal studies assess how GRP training transforms teacher attitudes or student achievement over time (Kibona & Mbingamno, 2025; Lasekan et al., 2024).

Moreover, cross-country comparisons are rare, and most research lacks attention to intersectionality how gender, geography, and poverty jointly shape STEM participation (Amegah, 2024; Ntumi & Bulala, 2025). This study fills these gaps by providing qualitative insights from rural Uganda, examining SESEMAT's GRP framework as both a pedagogical and sociocultural intervention.

3. Research Methodology

3.1 Research Design

This study adopted an interpretive qualitative case study design, suitable for exploring lived experiences and meanings constructed within specific socio-cultural settings (Creswell & Poth, 2016). The approach facilitated an in-depth understanding of how Gender-Responsive Pedagogy (GRP) training within the Secondary Science and Mathematics Teachers (SESEMAT) program influenced teaching and learning in the Bugisu–Sebei sub-region. The case was bounded by; time where teachers trained in GRP modules between 2020 and 2024; Place which included four districts (Mbale, Sironko, Bududa, and Kapchorwa); and Programmatic context of SESEMAT's gender mainstreaming after 2018. This design enabled multi-perspective inquiry through teachers, students, and school leaders while accounting for local sociocultural realities influencing pedagogy (Baxter & Jack, 2008; Merriam & Tisdell, 2016).

3.2 Study Setting

The Bugisu–Sebei sub-region in Eastern Uganda comprises two major ethnic groups: Bagisu and Sabiny, characterized by strong patriarchal traditions. Rituals such as the Imbalu circumcision ceremony mark gendered rites of passage and reinforce traditional masculinities (Kisembo et al., 2022). The local economy is predominantly agricultural, and schools often face systemic resource constraints including inadequate laboratories, limited electricity, and minimal internet connectivity

(UBOS, 2022; MoES, 2023). Teacher absenteeism and multi-grade teaching remain common challenges. Despite these barriers, modest progress in girls' enrollment has been achieved through government bursaries, FAWE scholarships, and NGO-led STEM camps (Kasirye, 2022; (Chapin & Warne, 2020).

3.3 Sampling and Participants

A purposive sampling strategy was employed to identify information-rich cases (Patton, 2015). Participants were selected based on experience with GRP training, teaching in government-aided secondary schools, and involvement in STEM subjects. The final sample included; 12 SESEMAT-trained teachers (6 male, 6 female) from eight schools; 48 students (24 girls, 24 boys) from Senior One to Senior Four enrolled in STEM subjects; and

4 school heads, purposively chosen for their leadership and involvement in SESEMAT activities. This combination ensured data triangulation across gender, position, and role (Creswell & Poth, 2016).

Table: 2: Summary of Respondents

Category	Number	Gender	Role	Selection criteria
Teachers	12	6M, 6 F	Stem teachers	Completed GRP training (2020–2024)
Students	48	24F, 24 M	Stem learners	Enrolled in stem subjects
School heads	4	2M, 2F	administrators	Supportive of SESEMAT

3.4 Data Collection Methods

Data were collected over a period of 12 weeks using multiple qualitative instruments to ensure triangulation and credibility (Denzin & Lincoln, 2011). They included; semi-Structured Interviews which was conducted with 12 teachers and 4 school heads, audio-recorded and transcribed verbatim. Interview prompts explored teachers' perceptions of GRP training, pedagogical changes, and classroom challenges (Mukagiahana et al., 2024), Focus Group Discussions (FGDs) where four FGDs (two all-girl, two mixed-gender), each comprising 12 students. Discussions probed classroom interactions, teacher encouragement, and inclusivity in STEM learning (Uworwabaye et al., 2018), Classroom Observations where each teacher was observed teaching two 80-minute STEM lessons. Observations employed a structured checklist adapted from the FAWE GRP Observation Tool, assessing calling patterns, participation rates, and gender balance in group activities (FAWE, 2023), and document Review where analysis of SESEMAT training manuals, sample lesson plans, and school gender policy documents provided institutional context and program alignment (MoES, 2021).

3.5 Data Analysis

Thematic analysis followed (Braun & Clarke, 2006) six-phase approach; familiarization with data, generating initial codes, searching for themes, reviewing themes, defining and naming themes, producing the report, coding was both deductive (guided by GRP principles) and inductive (allowing new themes to emerge). NVivo 14 software facilitated organization and retrieval. Member checking was conducted by sharing preliminary findings with two teacher participants for validation.

3.6 Ethical Considerations

Ethical approval was obtained from Kumi University's Research Ethics Committee. Informed consent was secured from all participants, with assurances of confidentiality and the right to withdraw. Pseudonyms were used for schools and individuals. Student participation was voluntary and supervised by a female research assistant to ensure comfort.

4. Results

This section presents the key themes emerging from thematic analysis of interviews, focus group discussions, classroom observations, and document review. Three dominant themes illustrated the transformation of teacher practices following SESEMAT's Gender-Responsive Pedagogy (GRP) training i.e. (a) gender-sensitive lesson planning, (b) equitable classroom interaction, and (c) contextualized and culturally relevant STEM teaching. These findings echo recent scholarship emphasizing how teacher agency and reflective practice are central to gender equity in STEM education.

4.1 Transformation of Teacher Practices

4.1.1 Gender-Sensitive Lesson Planning

All twelve participating teachers reported revising their lesson plans to incorporate GRP principles. Before SESEMAT training, examples in science lessons often featured male engineers, doctors, or inventors. Following the GRP modules, teachers deliberately included female Ugandan scientists and innovators such as Dr. Specioza Kazibwe, Prof. Monica Musenero, and local women entrepreneurs using biogas digesters or solar dryers.

This change aligns with (Lasekan et al., 2024), who emphasize that gender representation in classroom materials influences students' sense of belonging in STEM. Similarly, studies in Rwanda and Kenya have shown that gender-balanced lesson examples increase girls' engagement and performance in science subjects (Mukagiahana et al., 2024; Wrigley-Asante et al., 2023).

"I used to say, 'Imagine you're an engineer building a bridge.' Now I say, 'Imagine you're Engineer Sarah from Kapchorwa designing a water system for your village.' The girls sit up straighter." Mr. Okello, Physics Teacher, Mbale

Lesson objectives also expanded beyond cognitive outcomes to include affective and participatory goals, such as "students will demonstrate respect for diverse perspectives" and "girls will lead at

least one group activity.” This aligns with (Uworwabayeho et al., 2018) recommendation that affective goals be used to foster inclusive classroom climates as summarized in the table 3 below.

Table: 3: Examples of Gender-Sensitive Lesson Adaptations Post-GRP Training

Subject	Pre-GRP Example	Post-GRP Revision	Gender-Responsive Focus
Mathematics	Calculate company profits	Engineer Sarah from Kapchorwa designing a water system	Role model inclusion
Chemistry	Dr. John mixing solutions	Dr. Monica testing soil nutrients in Mbale	Representation & relevance
Physics	A male engineer building a bridge	pH analysis and nutrient testing	Builds relevance and confidence

4.1.2 Equitable Classroom Interaction

Classroom observations revealed marked shifts in teacher–student interaction patterns. Before GRP training, teachers often called on the first hand raised usually a boy. Post-training, teachers implemented structured inclusion techniques, such as; Random selection using name cards or digital randomizers; wait time, allowing 5–10 seconds for all students to think before answering; Equitable grouping, ensuring each group included at least two girls with rotating leadership; Girl-only “think time” before mixed discussions to build confidence.

In 20 of 24 observed lessons, girls initiated questions or corrections a behavior rarely seen before training. These findings mirror FAWE’s (2023) continental observation that gender-responsive facilitation significantly increases female participation and voice in STEM classrooms as depicted in the figure below

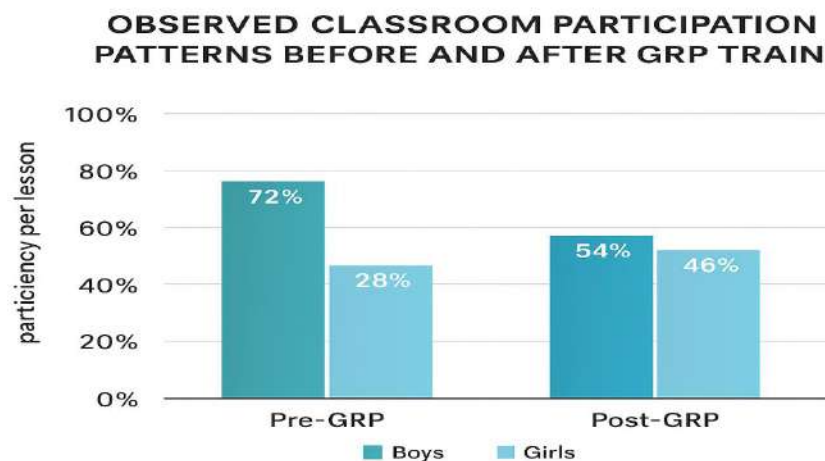


Figure 2: Observed classroom participation patterns before and after GRP train

The figure visually captures the narrowing gender gap in participation rates. Such trends reinforce the argument by (Makamure, 2025) that equitable interaction strategies cultivate more inclusive classroom dynamics and challenge implicit gender hierarchies.

4.1.3 Contextualized and Culturally Relevant STEM

Teachers increasingly integrated local knowledge systems and community practices into STEM lessons, making abstract content accessible and meaningful, particularly for girls. Examples included; Using basket-weaving patterns to teach geometry; testing soil samples from students' home gardens in chemistry; Applying local crop yield data in mathematics problem-solving.

This approach validated girls' lived experiences and blurred the divide between domestic and academic knowledge, consistent with the African feminist pedagogical framework of contextual epistemology (Amegah, 2024; Lasekan et al., 2024).

“When Mr. Ssebunya used our millet harvest to explain ratios, I finally understood. It wasn't just numbers it was my life.” Female Student, Senior Three, Sironko District

This contextual pedagogy aligns with (Openjuru, 2021) assertion that linking formal curriculum to community knowledge empowers marginalized learners and improves retention, especially for girls in rural schools as seen in table 4 below.

Table: 4: Examples of Culturally Relevant STEM Integration in Classrooms

Subject	Local context used	Learning concept	Gender responsive benefit
Mathematics	Millet harvest yield data	Ratios and percentages	Connects STEM to girls' agricultural roles
Geometry	Basket-weaving patterns	Symmetry and tessellation	Recognizes women's craft knowledge
Chemistry	Soil samples from family gardens	pH analysis and nutrient testing	Builds relevance and confidence

4.1.4. Summary of Thematic Findings

This thematic synthesis confirms that GRP training under SESEMAT catalyzed a shift from teacher-centered to learner-centered pedagogy, embedding gender sensitivity into daily teaching practice. It demonstrates how reflective practice, local relevance, and institutional support interact to sustain gender equity in STEM education as shown in figure 3 below.

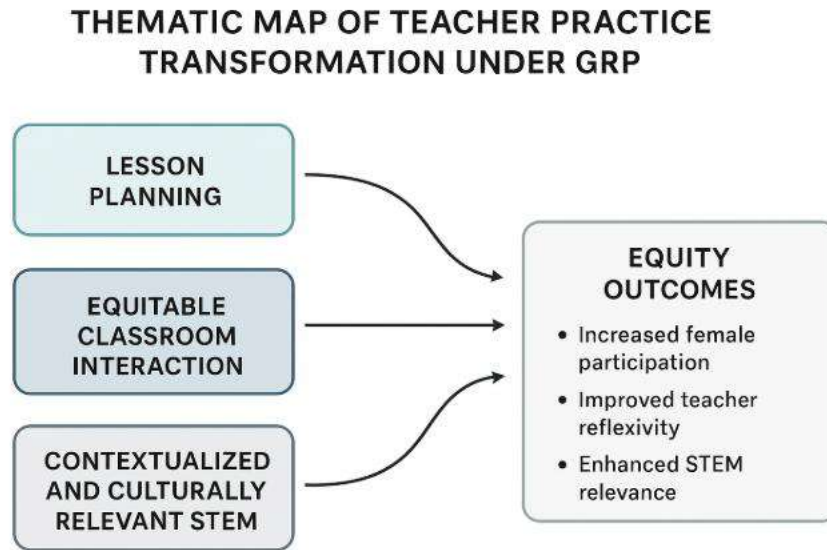


Figure 3: Thematic map of teacher practice transformation under GRP

4.2 Impact on Student Engagement and Confidence

4.2.1 Increased Participation by Girls

Focus Group Discussions (FGDs) and classroom observations revealed that girls’ participation and confidence in STEM subjects increased markedly after teachers implemented GRP strategies.

Girls consistently expressed feeling more “seen”, “valued”, and “capable” in previously male-dominated lessons. Their language shifted from fear and avoidance to curiosity and pride which is an important marker of affective engagement (Mukagiahana et al., 2024; Makamure, 2025).

“Before, I thought physics was for boys. Now, when I answer correctly, the teacher says, ‘See? You’re a scientist!’ It makes me want to try harder.” Grace, Senior Three, Kapchorwa

Boys also recognized these changes, noting increased collaboration and mutual respect in group work; “Now girls argue with us in group work. At first it was strange, but now we listen because they have good ideas.” Male Student, Senior Four, Bududa.

These findings align with FAWA’s (2023) regional data showing that girls’ classroom participation rises by 15–25% following GRP-focused interventions in Sub-Saharan Africa. Similar patterns were reported in Rwanda and Tanzania, where equitable participation techniques improved girls’ confidence and question-asking frequency (Kibona & Mbingamno, 2025; Ntumi & Bulala, 2025). The chart in figure 4 below shows a change in student participation rates by gender during post-GRP implementation.

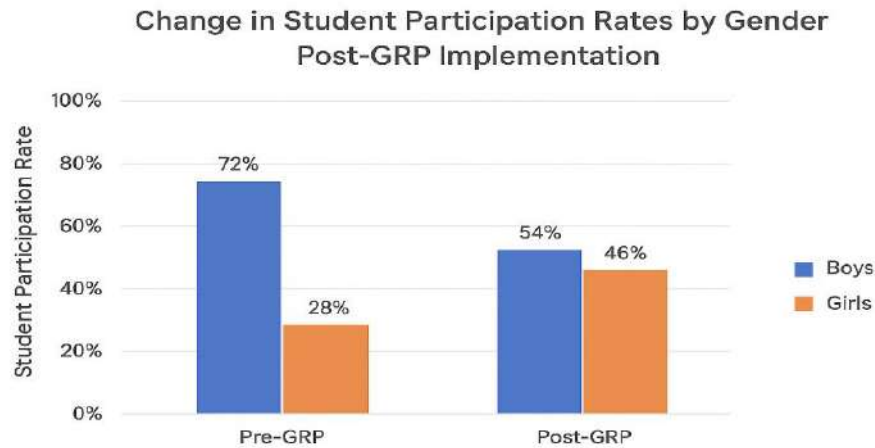


Figure 4: Change in student participation rates by Gender post-GRP implementation

4.2.2 Improved Academic Performance

While this was not a quantitative study, teachers and head teachers reported steady improvement in girls' STEM performance, particularly in mathematics and chemistry.

In one participating school, the mathematics pass rate for girls rose from 42% to 68% between 2022 and 2024, which represents:

$$\text{Absolute Increase} = 68\% - 42\% = 26\%$$

$$\text{Relative Improvement} = \frac{26}{42} \times 100 \approx 61.9\%$$

A 62% relative increase suggests that gender-responsive strategies can enhance academic outcomes, even in low-resource contexts (Uworwabayeho et al., 2018; Ojong & Kareem, 2025).

Table: 5: Sample School STEM Assessment Results Before and After GRP Integration

Subject	Year	Girl's pass rate	Boy's pass rate	Key GRP Strategy Introduced
Mathematics	2022	42	65	Gender-inclusive examples & group work
Mathematics	2024	68	71	Mentoring & equitable questioning
Chemistry	2022	38	60	Role model storytelling
Chemistry	2024	62	67	Collaborative labs

This outcome is consistent with broader African data showing that GRP-trained teachers improve both girls' academic performance and self-efficacy (Makamure, 2025; Lasekan et al., 2024).

4.2.3 Shifts in Aspirations

Another important impact was a transformation in girls' academic and career aspirations where participants expressed newfound interest in careers once considered "unfeminine," such as engineering, veterinary science, and computer technology. This aspirational shift signals self-efficacy and identity realignment, key indicators of long-term STEM persistence (Tang et al., 2024; Amegah, 2024).

"I want to be an agronomist. I'll help my village grow better crops. My teacher says I can." Female Student, Senior Two, Mbale

Teachers also reported increased career talk and mentoring sessions, further validating that representation and encouragement can reshape future trajectories for girls (FAWE, 2023; Ntumi & Bulala, 2025) as shown in the figure 5 below.

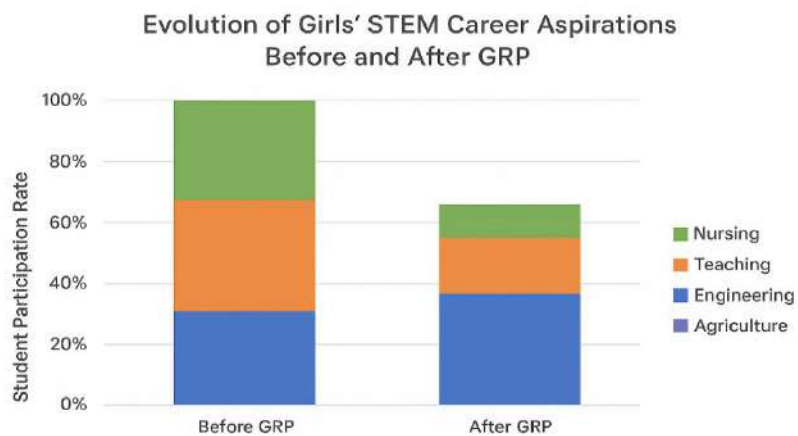


Figure 5: Evolution of Girl's STEM Career Aspirations before and after GRP

4.3 Teacher Attitudinal Change

A defining outcome of SESEMAT's GRP training was the transformation of teachers' mindsets where several educators admitted having held unconscious biases that limited girls' opportunities.

"I used to think girls were good at biology but weak in math. But after SESEMAT, I tested that belief. I gave the same problem to all. The top three were girls. I was wrong." Ms. Namatovu, Mathematics Teacher, Sironko

Such self-recognition represents cognitive dissonance leading to critical reflection, an essential element of sustained pedagogical change (Brookfield, 2017; Mukagiahana et al., 2024). Teachers began actively questioning entrenched stereotypes and cultural narratives;

"Why do we say girls can't fix engines? Who decided that?" Male Teacher, Mbale District.

This reflective transformation aligns with feminist pedagogy's emphasis on teacher reflexivity and critical consciousness (Parr et al., 2021; Makamure, 2025) as summarized in the table 6 below.

Table: 6: Illustrative Teacher Attitudinal Shifts Post-GRP Training

Pre-GRP Belief	Post-GRP Realization	Reflective Change
Girls can't handle math	Girls outperform when equally encouraged	Adjusted questioning strategy
Boys are natural leaders	Leadership depends on exposure, not gender.	Introduced group rotation
STEM is masculine	STEM benefits all communities	Integrated gender-balanced examples

4.4 Persistent Challenges

Despite notable progress, several barriers continue to hinder full realization of gender equity in STEM. Teachers improvised with local materials due to limited resources. As one lamented;

“I want to do a chemistry lab on acids and bases, but we have no litmus paper. How can I make it equitable if no one can do it?” Male Chemistry Teacher, Bududa

Cultural resistance also persists. Some parents withdrew girls for marriage or dismissed GRP as “Western” and “anti-cultural.” Only two of the twelve participating teachers were female STEM educators, limiting girls’ access to role models. Schools further lacked gender policies and safe reporting mechanisms for harassment.

“A boy touched me during lab. I didn’t tell anyone. Who would believe me?” Female Student, Sironko

These findings echo challenges documented in Uganda and Tanzania, where gender norms, infrastructural gaps, and weak policy enforcement constrain GRP sustainability (Kibona & Mbingamno, 2025; Chapin & Warne, 2020).

5. Discussion

5.1 SESEMAT as a Model of Transformative Teacher Development

The findings affirm that SESEMAT’s integration of Gender-Responsive Pedagogy (GRP) has catalyzed significant changes in teacher practices, particularly in lesson planning, classroom interaction, and contextualized learning. By blending practical instructional strategies (such as equitable grouping, gender-inclusive questioning, and localized examples) with critical reflection on gender bias, SESEMAT moves beyond surface-level inclusion toward transformative equity (Openjuru, 2021; Abraha et al., 2021). This transformation aligns with Freirean concepts of conscientization, where education empowers both teachers and learners to recognize and challenge oppressive structures (Stromquist, 2021). In this sense, SESEMAT has not only enhanced teaching quality but also nurtured teacher agency as a tool for social change. Moreover, the contextualization of STEM content using local agricultural examples, indigenous technologies, and familiar problem contexts reflects an Afrocentric epistemology that validates indigenous knowledge systems (Wa, 1986). When girls see their community realities represented in the curriculum, STEM becomes a vehicle for empowerment and innovation, not a distant or foreign subject (Tessema, 2019) as

summarized in figure 6 shows the conceptual model of SESEMAT's Transformative impact on STEM Equity.

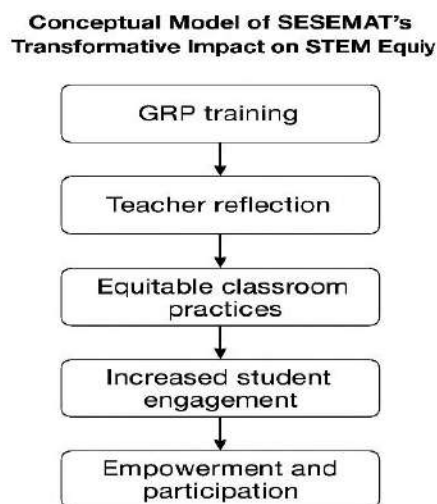


Figure 6: conceptual model of SESEMAT's Transformative Impact on STEM Equity

5.2 The Limits of Pedagogical Innovation without Systemic Support

Despite these gains, the findings reveal the fragility of progress in the absence of systemic support. Teachers' efforts toward equitable pedagogy are constrained by structural factors such as limited teaching resources, weak institutional gender policies, and entrenched patriarchal norms. As (Stromquist, 2021) argues, schools mirror broader societal inequalities; therefore, pedagogical transformation alone cannot sustain gender equity if the broader ecosystem remains unchanged. The withdrawal of girls for early marriage, lack of female STEM mentors, and the absence of safe learning environments mirror trends documented across Sub-Saharan Africa (Boaler, 2023; Ojong & Kareem, 2025; Chapin & Warne, 2020). These findings echo global evidence that sustainable equity requires multi-level interventions in teacher and student mindset shifts, inclusive policies and facilities, parental and cultural support, national legislation and funding (Women, 2025; Gutfleisch & Nennstiel, 2025; Haßler et al., 2021).

5.3 Implications for Pan-African STEM Education

The SESEMAT experience contributes meaningfully to the Pan-African vision of education as articulated in the African Union's Agenda 2063 and the Continental Education Strategy for Africa (CESA 16–25). By fostering gender-equitable STEM participation, the program advances Aspiration 6 an Africa driven by its people, particularly women and youth (Union, 2016). Empowering rural girls as knowledge creators and innovators aligns with current African scholarship emphasizing decolonized, inclusive, and problem-solving education systems. The SESEMAT model, grounded in teacher capacity building and community integration, is not only contextually relevant but also replicable across East and Central Africa with minor localization adjustments as in the figure 4 below.

**Proposed Model for Scaling
GRP within East African STEM
Teacher Development Frameworks**

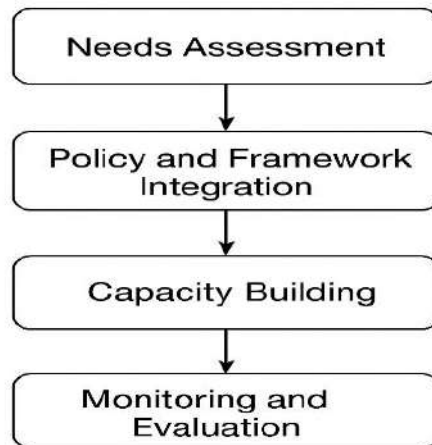


Figure 7: Proposed Model for scaling GRP within East African STEM Teacher Development frameworks

6. Recommendations

Drawing from the study's findings and aligned with current scholarship on gender-responsive pedagogy (GRP) and STEM equity, this section proposes a multi-tiered framework of recommendations targeting teachers, schools, communities, policymakers, and regional education bodies. The approach reflects the ecological systems theory (Bronfenbrenner, 1979) as adapted in education by (Tuwor, 2023) emphasizing that sustainable gender transformation requires simultaneous interventions across individual, institutional, and systemic levels.

6.1 For Teacher Training Institutions

Teacher preparation remains the foundation of equitable STEM education. Research highlights that teachers' gender awareness strongly predicts inclusive instructional practices and student engagement (Mukagiahana et al., 2024; Chapin & Warne, 2020). Therefore mandate GRP modules in all pre-service and in-service STEM teacher programs, ensuring that pedagogy integrates gender, culture, and critical reflection (Unterhalter et al., 2022). Develop localized GRP toolkits featuring examples from rural Ugandan contexts such as agriculture, crafts, and community problem-solving to enhance relevance (FAWE, 2023) and establish mentorship networks where trained teachers provide peer support and co-develop classroom resources through professional learning communities.

6.2 For Schools and School Leaders

Institutional commitment is critical for translating GRP training into sustainable practice. Studies show that supportive leadership and visible policies reduce gender-based exclusion and harassment (Women, 2025). Therefore adopt school-wide gender equity policies, including clear codes of conduct, anti-harassment guidelines, and safe reporting mechanisms, create STEM clubs for girls, coordinated by female teachers or alumni, to build confidence and provide peer learning spaces and display posters and digital visuals of African women in STEM, such as engineers, scientists, and innovators, to normalize female participation and counter gender stereotypes.

6.3 For Communities

Community engagement is vital, as cultural norms and parental attitudes remain powerful determinants of girls' educational choices (Chapin & Warne, 2020) i.e. Organize community dialogues involving parents, elders, and cultural leaders on the socio-economic benefits of girls' STEM participation, engage male champions (fathers, brothers, local chiefs) to act as public advocates for girls' education and challenge restrictive gender norms (Njoroge & Nyabuto, 2014), facilitate mentorship exchanges linking schools with local women entrepreneurs and professionals in agriculture, health, or technology sectors.

6.4 For Government and Development Partners

National policy alignment and resource provision remain crucial for scaling GRP. Evidence from sub-Saharan Africa indicates that targeted funding and gender audits enhance implementation effectiveness (Boaler, 2023). Therefore increase funding for rural STEM infrastructure, including laboratories, ICT equipment, and teacher training materials, Expand bursary and scholarship programs specifically for girls pursuing STEM subjects at secondary and tertiary levels, Institutionalize GRP monitoring within national education quality reviews and inspectorate frameworks.

6.5 For Regional Bodies (AU, EAC)

The African Union (AU) and East African Community (EAC) play strategic roles in harmonizing education standards and promoting gender parity. Their frameworks such as Agenda 2063 and CESA 16–25 call for the mainstreaming of gender equity across education systems (Union, 2016). Therefore integrate GRP indicators into CESA 16–25 and Agenda 2063 performance monitoring frameworks, facilitate regional exchanges to share best practices from successful initiatives like SESEMAT across East Africa. Support longitudinal and comparative research on the long-term impacts of GRP on student performance and teacher professional identity formation (Miralles-Cardona et al., 2023).

7. Conclusion

This study provides compelling evidence that gender-responsive pedagogy (GRP) when institutionalized through structured professional development initiatives like SESEMAT (Secondary Science and Mathematics Teachers Program) can transform classroom cultures and

pedagogical norms even in resource-constrained, patriarchal rural contexts. Teachers in the Bugisu–Sebei sub-region of Uganda demonstrated that equitable, contextually grounded instructional practices can challenge entrenched stereotypes, amplify girls’ participation, and foster a sense of belonging in STEM education.

These findings align with emerging global evidence that teacher agency and gender-aware pedagogy are key levers for advancing equity and learning outcomes in STEM (Unterhalter et al., 2022; Mukagiahana et al., 2024; Miralles-Cardona et al., 2023). By linking local knowledge (e.g., agricultural data, household innovations) with scientific reasoning, GRP redefines STEM as a culturally responsive and socially transformative discipline (Chapin & Warne, 2020; Boaler, 2023). However, as (Women, 2025) and World Bank (2022) emphasize, pedagogical innovation cannot substitute for systemic reform. True transformation requires multi-level coordination where government policy, school leadership, community norms, and teacher practice reinforce one another. Without addressing the structural barriers that continue to marginalize girls (e.g., early marriage, gender-based violence, inadequate facilities), classroom-level gains risk being isolated and unsustainable. The SESEMAT model nonetheless offers a proof of concept demonstrating that gender equity in STEM is achievable when teacher development integrates reflection, relevance, and relationality. As Africa advances toward the African Union’s Agenda 2063, investing in gender-responsive STEM education is not a peripheral goal but a foundational strategy for inclusive growth, innovation, and sustainable development (Union, 2016). Therefore empowering teachers to teach equitably is not only a pedagogical act but it is a political and developmental imperative.

8. Limitations and Future Research

8.1. Limitations

While this study provides valuable insights into GRP implementation in rural Uganda, several limitations warrant cautious interpretation.

The research was confined to one sub-region Bugisu–Sebei and focused exclusively on SESEMAT-trained teachers. Therefore, findings may not be generalizable to other contexts with different cultural or institutional dynamics. The qualitative design prioritized depth over breadth, which, while revealing rich narratives, limits statistical inference.

Self-reported data from teachers and students may have been influenced by social desirability bias, where participants respond in ways they believe are expected or favorable. Although triangulation (interviews, FGDs, classroom observation, document review) was used to mitigate this, future studies should incorporate mixed-methods designs that combine qualitative insight with quantitative validation.

8.2 Future Research

To build on this foundation, future research could be done to conduct longitudinal studies tracking the long-term effects of GRP on girls’ academic performance, STEM retention, and career pathways, implement quasi-experimental designs to measure causality between GRP training and

student learning outcomes across diverse Ugandan regions, evaluate cost-effectiveness and scalability of GRP integration within national teacher training systems, investigate digital GRP interventions, such as mobile mentoring, e-learning toolkits, and gender-aware virtual STEM labs, particularly for remote and underserved communities, and explore intersectionality, analyzing how gender intersects with socioeconomic status, disability, or ethnicity to shape STEM participation.

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Article 3

Understanding STEM Endeavors: Conceptual Clarity and Pedagogical Implications in Africa

Benson Banda, David Bawa, Muyabi Dickens

Directorate of National Science Centre, Lusaka, Zambia

bensonbanda2003@yahoo.co.uk, bawadavid3@gmail.com, muyabidickens709@gmail.com

Abstract

Science, Technology, Engineering, and Mathematics (STEM) education plays a pivotal role in driving innovation, economic growth, and technological advancement globally. However, developing a clear and operational definition of STEM endeavors remains a persistent challenge, especially within the African context where educational systems are shaped by diverse cultural, social, and economic conditions. This paper synthesizes insights from a virtual discussion conducted under the Knowledge Co-Creation Program (KCCP) 2025 in Zambia. The discussions critically examined multiple interpretations of STEM endeavors, the dynamic relationship between process and product, the role of uncertainty in learning, and the necessity of contextual adaptation within African communities.

Building on these insights, the paper proposes an emerging operational definition of STEM endeavors and presents a contextually grounded framework for strengthening STEM education in Africa. It further offers strategic recommendations for localizing STEM approaches, fostering innovation-driven learning, and advancing hybrid STEM models that integrate Indigenous Knowledge Systems with contemporary scientific practices. Through this contribution, the study seeks to support the development of more relevant, inclusive, and sustainable STEM education systems across the African continent.

Keywords: *STEM Education, Conceptual Clarity, Pedagogical Implications, African Context, Knowledge Co-Creation Program (KCCP)*

CHAPTER ONE: INTRODUCTION

1.1 Background to the Study

The increasing global emphasis on Science, Technology, Engineering and Mathematics (STEM) education reflects its central role in preparing learners for participation in technology-driven economies and knowledge societies. Governments, international agencies, and educational institutions increasingly recognize STEM as a catalyst for innovation, economic growth, and sustainable development. Through STEM education, learners are expected to develop critical thinking, creativity, problem-solving skills, and technological competencies essential for addressing complex real-world challenges.

However, despite its global prominence, the concept of **STEM endeavors**, defined broadly as the active engagement of learners in integrated STEM learning processes, remains ambiguously articulated. In many contexts, it is loosely used interchangeably with terms such as STEM integration, STEM engagement, or STEM practice, resulting in conceptual inconsistency across educational systems. This ambiguity becomes even more pronounced in African contexts, where STEM education operates within diverse sociocultural realities, infrastructural limitations, and varying policy environments.

In Africa, challenges such as limited resources, inadequate infrastructure, disparities in teacher training, and minimal integration of Indigenous Knowledge Systems (IKS) further complicate the implementation of STEM initiatives. While multiple STEM-related policies and initiatives have been introduced across African countries, their effectiveness is often constrained by the absence of a clear and shared operational understanding of what constitutes STEM endeavors. Without such clarity, efforts to design, implement, and evaluate STEM education programs risk becoming fragmented, inconsistent, and contextually misaligned.

1.2 Problem Statement

Although STEM education is widely promoted as a solution to Africa's development challenges, the **operational definition of STEM endeavors** remains vague and fragmented. Across different educational contexts, STEM endeavors are variously conceptualized as project-based learning, inquiry-based activities, innovation tasks, or simply the integration of science and mathematics with technology tools.

This lack of a cohesive and contextually grounded understanding has led to inconsistencies in how STEM is practiced, assessed, and promoted within African education systems. As a result, STEM initiatives are often imported from Western contexts without sufficient adaptation to local realities, leading to poor sustainability, limited scalability, and reduced impact on local educational and socio-economic challenges.

Furthermore, the absence of a common operational definition hampers curriculum development, teacher training, pedagogical consistency, and policy formulation. It also weakens the potential of STEM to address critical local concerns such as renewable energy access, agricultural innovation, environmental management, and community-level problem-solving.

1.3 Research Question

- To address this conceptual and practical challenge, this study is guided by the following research question:
- What is the operational definition of STEM endeavors in the African context, and how can this definition be adapted to address local educational needs?
- This question seeks to move beyond theoretical generalizations by grounding the understanding of STEM endeavors in the perspectives and experiences of African education stakeholders.

1.4 Objectives of the Study

The study was guided by the following objectives:

- i. To explore educators' and stakeholders' interpretations of STEM endeavors within diverse African educational contexts.
- ii. To examine the interplay between STEM as a process and STEM as a product, highlighting how learning activities and tangible outputs intersect.
- iii. To assess the role of uncertainty in shaping STEM learning and innovation processes.
- iv. To propose a contextually grounded framework for STEM endeavors suitable for African educational settings.

1.5 Context of the Study

This study draws on insights generated from a virtual collaborative discussion organized under the **Knowledge Co-Creation Program (KCCP) 2025**, hosted in Zambia. The discussion involved educators, curriculum developers, policy-makers, and researchers from multiple African countries. Participants engaged in a structured dialogue aimed at unpacking the meaning of STEM endeavors and examining how the concept can be adapted to African realities.

The KCCP platform provided a unique knowledge-sharing space that allowed participants to reflect on their practical experiences, policy environments, and cultural contexts. It also enabled cross-country dialogue, thereby enriching the study with diverse perspectives and insights.

1.6 Significance of the Study

This study contributes to ongoing discourse on STEM education in Africa by offering:

- A clarified and contextually grounded operational definition of STEM endeavors.
- A framework for adapting STEM practices to African educational realities.
- Empirical insights to inform curriculum design, teacher training, and STEM policy development across African countries.

By centering African perspectives, this study seeks to move STEM discourse away from a purely imported model toward a culturally responsive and locally grounded approach.

1.7 Scope and Delimitation of the Study

This study focuses specifically on the conceptualization and operational definition of STEM endeavors within African educational contexts. It examines how educators, policy-makers, and researchers from selected African countries understand STEM endeavors and how this understanding informs their practices and perspectives. The study is delimited to participants involved in the Knowledge Co-Creation Program (KCCP) 2025 virtual engagement and does not attempt to generalize findings to all African countries or all STEM stakeholders. Instead, it provides in-depth insights based on the perspectives of educators and related stakeholders who actively participated in the program. The research does not focus on measuring student performance outcomes or comparing national STEM policy documents. Rather, it prioritizes stakeholder perspectives and conceptual clarity regarding STEM endeavors.

1.8 Assumptions of the Study

The study was guided by the following assumptions:

- Participants provided honest and reflective responses based on their professional experiences.
- The WhatsApp discussion platform provided sufficient space for meaningful knowledge sharing and collaborative reflection.
- Participants' interpretations of STEM endeavors were shaped by their cultural, institutional, and professional backgrounds.
- A shared understanding of STEM endeavors can contribute positively to improved STEM practices in African education systems.

CHAPTER TWO: LITERATURE REVIEW

2.1 Reconceptualizing STEM Endeavors

Contemporary scholarship increasingly views STEM endeavors as more than the simple integration of science, technology, engineering, and mathematics. Rather, they are conceptualized as complex learning paradigms grounded in inquiry, persistence, uncertainty, and sociocultural contexts. Dewey's (1938) philosophy of experiential learning underscores this understanding, emphasizing that authentic education emerges from meaningful engagement with real-life situations. His perspective continues to inform modern pedagogical models such as project-based learning (PBL) and problem-based learning, which prioritize sustained inquiry, collaboration, and interdisciplinary knowledge construction (Thomas, 2000; Blumenfeld et al., 1991).

Expanding this conceptualization, Boakye-Yiadom, Donkor, and Mensah (2025) situate STEM endeavors within cultural semiotics in the Ghanaian context. Their meta-synthesis demonstrates how indigenous symbols such as Adinkra can serve as cognitive and cultural scaffolds in STEM instruction. They reconceptualize the notion of "endeavor" not merely as effort, but as a meaning-

making process rooted in learners' cultural identity and lived experiences. This perspective aligns with broader calls for culturally responsive STEM education, especially in African contexts where learning is deeply intertwined with communal values and heritage.

2.2 Uncertainty and Innovation in STEM Learning

Uncertainty plays a central role in authentic STEM learning. Schwartz et al. (2007) argue that learning environments characterized by uncertainty stimulate deeper cognitive engagement, as learners must hypothesize, test, revise, and reflect on their solutions. Similarly, Dweck's (2006) theory of growth mindset highlights the importance of perceiving failure and challenges as opportunities for development rather than indicators of inability.

Building on these psychological foundations, Moemeke and Chukwunenye (2025) emphasize the concept of *productive uncertainty* within inquiry-based learning in African STEM classrooms. They argue that when uncertainty is situated within indigenous cognitive and cultural frameworks, it fosters epistemic equity by allowing learners to construct knowledge from familiar sociocultural standpoints. This suggests that innovation in STEM learning is not only cognitive but also cultural, emerging through learners' negotiation of uncertainty within their local knowledge systems.

2.3 Indigenous Knowledge Systems and Hybrid STEM Models

The integration of Indigenous Knowledge Systems (IKS) into STEM education has gained increasing attention as a means of ensuring cultural relevance and sustainability in African education. The African Union (2020) advocates for hybrid educational models that combine scientific reasoning with indigenous knowledge to drive context-specific innovation. Ayithey (2017) and Sunzuma et al. (2025) reinforce this position by emphasizing that IKS is fundamental to community-based problem-solving, environmental sustainability, and social cohesion.

One practical expression of this integration is the Ethno-STEM framework proposed by Babalola and Keku (2024). This approach embeds traditional ecological knowledge and cultural practices into PBL-centered STEM instruction. Similarly, Sunzuma, Zezekwa, and Chikuvadze (2025) provide a Zimbabwean framework for integrating IKS into STEM education, demonstrating how indigenous practices can enhance critical thinking, innovation, and community engagement among learners.

2.4 Conceptual Frameworks for STEM Pedagogy in African Contexts

Effective integration of STEM education in African contexts requires pedagogical frameworks that acknowledge resource constraints and sociocultural diversity. Retno et al. (2025) propose the STEM-PjBL model, which offers adaptable strategies for implementing project-based STEM learning in under-resourced settings. Their framework emphasizes flexibility, local resource utilization, and teacher professional development.

In addition, Luluja and Pranjol (2024) advocate for decolonized pedagogical and assessment models that move beyond Eurocentric standards of learning. They argue that assessment practices must reflect community values, lived realities, and indigenous epistemologies, particularly in rural and peri-urban African communities. These frameworks contribute to a growing body of literature calling for context-sensitive STEM pedagogy tailored to African educational environments.

2.5 Project-Based and Inquiry-Based Learning in Practice

Empirical studies across African contexts provide evidence of the effectiveness of PBL and inquiry-based learning in enhancing STEM outcomes. Kadonsi's (2025) meta-analysis of Zambian mathematics classrooms demonstrates that PBL significantly improves learners' problem-solving abilities, conceptual understanding, and independent thinking.

Similarly, Luthuli, Epizitone, and Phokoye (2025) report that South African higher education institutions implementing PBL observed increased student engagement and motivation, despite challenges such as limited resources and initial resistance to pedagogical change. Furthermore, Chitamba et al. (2025) link PBL to entrepreneurship development in STEM, arguing that STEM endeavors should extend beyond theoretical competence to include innovation, enterprise, and economic application. This aligns with broader regional development goals emphasizing education as a driver of industrialization and job creation in Africa.

2.6 Educational Equity, Policy, and Justice in STEM

Issues of equity and justice remain central to contemporary STEM education discourse. Chikuvadze and Makuvire (2025) critique the dominance of Western-centric curricula in African education systems and propose a decolonized STEAM framework that integrates arts, humanities, indigenous languages, and African histories. Their work highlights the need for curricula that reflect learners' sociopolitical realities and cultural identities.

From a global perspective, DeCoito et al. (2024) similarly advocate for STEM frameworks grounded in social justice, equity, and community relevance. They argue that such frameworks must deliberately address power imbalances, access to resources, and representation in STEM fields. In African contexts, this translates into policies that support inclusive curriculum design, teacher capacity building, and community participation in STEM education reform, as discussed by Ayittey (2017), is essential for addressing Africa's specific challenges, including climate change, energy access, and food security.

CHAPTER THREE: METHODOLOGY

3.1 Research Design

This study employed a qualitative research design to explore educators' perspectives on STEM endeavors within African educational contexts. A moderated WhatsApp discussion forum was used as the primary data generation space, as it allowed geographically dispersed participants to engage in collaborative discourse in a familiar and accessible digital environment.

The qualitative approach was appropriate because the study sought to capture participants' lived experiences, perceptions, meanings, and interpretations rather than quantify predefined variables. The design enabled rich, context-sensitive insights into how STEM endeavors are conceptualized and practiced across diverse national and institutional settings.

3.2 Participants

A total of 56 educators from 11 African countries participated in the study. Participants were selected through purposive convenience sampling and voluntarily joined a moderated WhatsApp group created specifically for this research.

The participants represented diverse professional backgrounds, including primary, secondary, and tertiary-level STEM educators, teacher trainers, and curriculum implementers. This diversity enriched the dataset by providing varied perspectives on STEM endeavors across different levels of education and contexts.

3.3 Data Collection

Data collection was conducted over a two-day period through structured and moderated WhatsApp discussions. Participants were provided with guided prompts designed to elicit reflections on their understanding, experiences, challenges, and approaches related to STEM endeavors.

Participants shared their responses through:

- Text messages
- Images
- Narrative reflections and professional experiences

In total, 234 messages and contributions were generated during the discussion. These data were exported from the WhatsApp platform and compiled into a qualitative dataset for further analysis.

3.4 Dataset Description

The dataset consisted of 234 contributions, including textual responses and multimedia inputs. All contributions were anonymized, and participant identifiers were removed to ensure confidentiality. The dataset was organized chronologically and thematically to support systematic qualitative analysis.

Where necessary, voice notes or image content were transcribed or described in textual form to enable consistent thematic coding.

3.5 Data Analysis

The data were analyzed using thematic analysis, following the phases proposed by Braun and Clarke (2006):

- Familiarization with the data
- Initial coding
- Searching for themes
- Reviewing themes
- Defining and naming themes
- Producing the report

Codes were developed both inductively (from the data) and deductively (informed by the conceptual framework). The analysis focused on identifying recurring categories related to STEM teaching practices, perceived challenges, innovations, and opportunities for STEM development in African contexts.

3.6 Ethical Considerations

Ethical clearance was obtained prior to data collection. Participation was voluntary, and all participants were informed about the purpose of the study, data usage, and confidentiality measures.

Participants gave informed consent before joining the WhatsApp group and were notified that their contributions would be used solely for research purposes. All data were anonymized and stored securely. No real names, phone numbers, or identifying information were included in the final analysis or reporting.

Furthermore, participants were allowed to withdraw from the study at any point without any negative consequences.

3.7 Trustworthiness of the Study

To ensure trustworthiness, the study applied the four qualitative rigor criteria proposed by Lincoln and Guba (1985):

a) Credibility

Credibility was enhanced through prolonged engagement in the discussion forums, active moderation, and the inclusion of participants from multiple countries with diverse contexts. Member-checking was done informally by clarifying and confirming participants' meanings during discussions.

b) Transferability

Although the study focused on a specific group of African educators, thick descriptions of the context and participant contributions have been provided to allow readers to determine the applicability of the findings to their own contexts.

c) Dependability

A clear audit trail of the research process, including data collection procedures and analytical decisions, was maintained to enable consistency and transparency.

d) Confirmability

To reduce researcher bias, findings were grounded directly in participants' responses. Reflexive journaling and peer review of emerging themes were also employed to strengthen objectivity during analysis.

3.8 Limitations of the Study

Despite its contributions, the study has several limitations. First, the use of a WhatsApp platform restricted participation to educators with smartphone and internet access, which may exclude voices from resource-limited settings.

Second, the short data collection period (two days) may have limited the depth of engagement and the quantity of reflections.

Third, since participation was voluntary, there may be a self-selection bias, with more motivated or technologically comfortable educators being overrepresented.

Finally, the study relied on self-reported data, which may be subject to personal biases, memory constraints, or social desirability effects.

CHAPTER FOUR: FINDINGS

This section presents the findings derived from the thematic analysis of 234 WhatsApp contributions made by 56 educators across 11 African countries. The aim was to explore how educators conceptualise and implement STEM endeavors, including their experiences with uncertainty in STEM teaching and learning. Six major themes emerged from the data, reflecting both pedagogical practices and contextual challenges across African educational settings.

4.1 Conceptions of STEM Endeavors Among Educators

Participants demonstrated varied but interconnected understandings of STEM endeavors. While many initially defined STEM as the integration of science, technology, engineering, and mathematics, deeper engagement revealed broader interpretations linked to innovation, problem-solving, and socio-community development.

Several educators emphasized STEM as a transformative process:

“STEM is a way of teaching learners to solve problems in their own environment using science and local materials.”

Others viewed STEM endeavors as tools for developing learners’ creativity, critical thinking, and technological competencies necessary in modern economies. Notably, some participants framed STEM not merely as a pedagogy, but as a cultural and developmental process contributing to community improvement in areas such as renewable energy, sanitation, agriculture, and environmental protection.

4.2 STEM Pedagogical Practices in African Classrooms

Participants reported the widespread adoption of project-based learning (PBL) and inquiry-based approaches as primary modes for implementing STEM education. Despite limited resources, educators demonstrated innovative strategies in facilitating hands-on and problem-centered learning.

Key pedagogical practices included:

- Construction of models using locally available materials
- Community-based problem investigations
- Group design challenges and exhibitions
- Integration of real-life contextual problems into classroom activities

One participant noted:

“We use waste materials like cartons, bottles, and wires to construct STEM models instead of waiting for ideal resources.”

This illustrates that STEM instruction in African contexts is characterized by improvisation, adaptability, and creativity, especially within under-resourced school environments.

4.3 Challenges in Implementing STEM Endeavors

Despite positive attitudes towards STEM endeavors, participants identified several systemic challenges affecting effective implementation:

4.3.1 Resource Constraints

Participants frequently mentioned lack of laboratories, insufficient instructional materials, unreliable electricity supply, and limited access to digital tools and internet connectivity.

4.3.2 Teacher Preparedness

Many educators reported limited training in integrated STEM and inquiry-based methodologies. Teachers trained within traditional single-subject frameworks expressed difficulties in implementing interdisciplinary STEM approaches.

4.3.3 Curriculum and Assessment Misalignment

Participants highlighted that national curricula and examination systems often prioritize theoretical knowledge and rote learning over practical and inquiry-oriented STEM activities, thereby discouraging teachers from fully embracing innovative STEM pedagogies.

4.4 STEM Endeavors and Uncertainty

A central and powerful theme emerging from the data was the role of uncertainty in STEM learning. Participants conceptualized uncertainty not as a weakness in teaching, but as an essential pedagogical resource that promotes creativity, resilience, and innovation.

4.4.1 Uncertainty as a Catalyst for Innovation

Participants consistently emphasized that uncertainty is an inherent aspect of authentic STEM work. As one educator remarked:

“STEM work always involves uncertainty unless you deliberately avoid it.”

Educators explained that when learners confront uncertain and open-ended problems, they are required to experiment, hypothesize, and refine solutions through iterative processes. This aligns with Schwartz et al. (2007), who argue that uncertainty promotes deeper engagement and creative problem-solving.

4.4.2 Failure as a Constructive Learning Opportunity

Failure was frequently linked to uncertainty as a productive stage in the learning process. One participant observed:

“Failure in STEM is not failure; it’s a reflection point where we reassess our approach and adjust.”

This aligns strongly with Dweck’s (2006) growth mindset theory, where challenges and errors are framed as opportunities for cognitive development rather than indicators of inability. Educators emphasized that allowing learners to make mistakes enhances persistence, resilience, and long-term confidence in STEM learning.

4.4.3 The Role of Teachers in Navigating Uncertainty

Participants underscored the teacher’s role as a facilitator of productive uncertainty. One educator explained:

“Teachers must create environments where uncertainty is embraced, allowing students to fail, learn, and retry.”

This supports the arguments of Blumenfeld et al. (1991), who highlight the importance of teacher scaffolding in inquiry-based and project-based learning. Effective teachers were described as those who guide students through uncertainty without removing the cognitive struggle necessary for deep conceptual understanding.

4.4.4 Summary of the Uncertainty Theme

Overall, uncertainty emerged as a pedagogical strength rather than a limitation. When properly structured and guided, it promotes innovation, critical thinking, learner autonomy, and resilience, all of which are essential to sustainable STEM education.

4.5 Opportunities and Innovations in STEM Endeavors

Despite existing constraints, participants identified several emerging opportunities and innovative practices across their contexts, including:

- Integration of Indigenous Knowledge Systems (IKS) into STEM projects
- Use of community-based problems as learning platforms
- Establishment of STEM clubs and innovation hubs
- Adoption of low-cost and recycled materials for project construction

These initiatives indicate that African educators are not passive adopters of external STEM models but active agents shaping contextually relevant and culturally grounded STEM practices.

4.6 Perceived Impact of STEM Endeavors on Learners

Participants reported that engagement in STEM projects had significant positive outcomes on learners, including:

- Increased motivation and classroom engagement
- Improved problem-solving and critical thinking skills
- Enhanced collaboration and teamwork
- Greater confidence in experimenting and innovating
- Increased interest in STEM-related career pathways

Educators also observed that learners involved in STEM endeavors demonstrated improved capacity to apply knowledge to real-life challenges in their communities.

4.7 Emerging Model of African STEM Endeavors

From the data, an emergent model of African STEM endeavors was identified, characterized by:

1. Community relevance and problem orientation
2. Resource improvisation and local innovation
3. Integration of indigenous knowledge and cultural resources
4. Inquiry-driven and collaborative learning environments
5. Focus on sustainable development priorities

This model reflects a contextually grounded interpretation of STEM education rooted in African realities.

4.8 Summary of Key Findings

In summary, the study reveals that:

- i. African educators conceptualize STEM endeavors as processes of innovation, identity formation, and community transformation.
- ii. Uncertainty plays a central, productive role in promoting creativity and deeper learning.
- iii. Teachers serve as facilitators of productive struggle and cognitive growth.
- iv. Despite systemic challenges, educators demonstrate significant innovation and adaptability in STEM teaching.
- v. STEM endeavors positively influence learner engagement, critical thinking, and career aspirations.

CHAPTER FIVE: DISCUSSION

This chapter interprets the study findings in light of the extended conceptual reflections from the KCCP 2025 discussions and relevant literature. It deepens the analysis by focusing on the meaning of *endeavor* in STEM, the process–product relationship, pedagogical implications, contextual African perspectives, and the synthesis of an operational definition suitable for African educational systems.

5.1 Reconceptualizing “Endeavor” in STEM Education

A major theoretical contribution of this study is its clarification of the concept of *endeavor* in STEM education. Participants at KCCP 2025 moved beyond superficial definitions and presented deeper interpretations that reposition STEM endeavor as a dynamic, human-centered, and effort-driven construct.

5.1.1 Endeavor as a Long-Term Process

Some participants conceptualized STEM endeavor as a lifelong engagement in learning and exploration, rather than a short-term academic activity. This aligns with Dewey’s (1938) view of education as a continuous process of growth, where learning is not a destination but an evolving journey of experience and discovery. This interpretation places STEM learning within a developmental framework that emphasizes continuity, curiosity, and lifelong intellectual engagement.

5.1.2 Endeavor as Effort and Persistence

Another dominant interpretation positioned endeavor as sustained effort, resilience, and persistence in the face of challenges. As one participant stated:

“STEM endeavors are about cultivating the effort, persistence, and resilience necessary to overcome challenges.”

This aligns with Dweck’s (2006) growth mindset theory, which highlights effort and perseverance as central to learning success. In the African context, where learners often encounter resource constraints and systemic challenges, this perspective is particularly relevant, as it reframes hardship as a space for developing resilience and adaptive problem-solving capacity.

5.1.3 Endeavor as Competence-Based Engagement

Participants also connected endeavor to a competence-based educational model, where learners actively engage in tasks that develop skills, not just knowledge recall. This perspective resonates

with contemporary competency-based education frameworks, which emphasize the application of knowledge, problem-solving, collaboration, and creativity rather than rote memorization.

This further supports the study's argument that STEM endeavors should be understood as active, effort-driven, competence-building engagements rather than static curriculum activities.

5.2 The Process–Product Interplay in STEM Endeavors

The debate on process versus product emerged as a central theoretical and pedagogical issue in the KCCP discussions.

5.2.1 Product-First Perspective

Some participants emphasized that a clearly defined final product (such as a sustainable innovation or technological solution) gives direction to the learning process:

“Starting with a clear product in mind helps guide the process and refine methods.”

This aligns with goal-oriented learning theories where outcomes shape instructional design and inquiry.

5.2.2 Process - First Perspective

Other participants argued that learning should prioritize the process of exploration, allowing products to emerge naturally. This position is consistent with constructivist learning theories (Piaget, 1976), which emphasize knowledge construction through active engagement and reflection.

5.2.3 Reciprocal (Process–Product) Perspective

A majority of participants supported a reciprocal model:

“A weak process results in a weak product, while a strong product vision can refine the process.”

This view aligns with design thinking principles (Brown, 2009), which emphasize cyclical iterations between process and product. In African STEM contexts, this balance is critical, as products often aim to solve real social problems while processes develop problem-solving competencies.

This study therefore strengthens the argument that STEM endeavors are best understood as iterative relationships between process and product, rather than privileging one over the other.

5.3 Pedagogical Implications for STEM Endeavors

The findings strongly validate the relevance of inquiry-driven pedagogies for cultivating authentic STEM endeavors.

5.3.1 Active Learning Pedagogies

Participants identified Problem-Based Learning (PBL), Inquiry-Based Learning, and Project-Based Learning as essential pedagogies for fostering STEM endeavors. These approaches position learners as active problem-solvers, engaging them directly with real-world challenges.

5.3.2 Concept - to - Content Learning Approach

An innovative pedagogical strategy discussed was concept-to-content learning, where teaching begins with a broad concept such as agriculture, renewable energy, or hospitality, and allows specific content to emerge through student-driven inquiry.

This aligns with constructivist and interdisciplinary curriculum models and offers a powerful approach for African contexts where learning must connect directly to socio-economic realities.

5.4 Contextual and African Perspectives on STEM Endeavors

The study clearly demonstrates that STEM endeavors cannot be defined through a universal, one-size-fits-all framework. Participants strongly argued for contextualized definitions tailored to African realities.

5.4.1 Context - Specific Definitions

Participants emphasized that STEM education in Africa must reflect local cultures, resources, and development challenges:

“In Africa, STEM must reflect our local realities—our cultures, resources, and needs.”

This supports Mji and Makgato’s (2006) argument that African education must be context-responsive and culturally embedded.

5.4.2 Hybrid STEM Models

The study further introduces the concept of High-Pitched Hybrid STEM, which blends Indigenous Knowledge Systems (IKS) with modern scientific practices. This hybrid model resonates with the African Union’s vision for sustainable development and reflects Ayithey’s (2017) argument on integrating traditional knowledge with modern science to solve African-specific problems.

This approach strengthens the cultural legitimacy, relevance, and sustainability of STEM education in African contexts.

5.5 Relevance and Debate Around the Term “Endeavor”

A conceptual debate emerged around whether the term *endeavor* is necessary in STEM discourse. Some participants argued that it may be redundant, while others defended its conceptual significance.

Supporters of the term argued:

“The word endeavor captures the persistence, trial-and-error, and innovation-driven process that STEM learning represents.”

This aligns with Dweck’s (2006) emphasis on effort and Schwartz et al. (2007) on uncertainty and iteration. Thus, while the term may seem redundant linguistically, it offers conceptual depth in emphasizing the effortful and iterative nature of STEM learning.

5.6 Proposed Operational Definition of STEM Endeavors

From the synthesis of findings and discussions, this study proposes the following operational definition:

A STEM endeavor is a purposeful, learner-driven engagement with real-world problems, where uncertainty, trial, and refinement are embraced as part of an interdisciplinary approach to producing innovative and context-relevant solutions.

This definition reflects four core dimensions:

- i. Purposeful, learner-driven engagement (Blumenfeld et al., 1991)
- ii. Uncertainty and iteration (Schwartz et al., 2007; Dweck, 2006)
- iii. Contextual relevance (Mji & Makgato, 2006)
- iv. Interdisciplinary integration

This operational definition addresses your central research question directly.

5.7 Implications for African STEM Education

5.7.1 Curriculum Implications

STEM curricula must be flexible and allow adaptation to local contexts. Integration of Indigenous Knowledge Systems and community problems should be prioritized.

5.7.2 Pedagogical Implications

Inquiry-based, project-based, and problem-based learning must be emphasized, as they align naturally with the iterative and effort-driven nature of STEM endeavors.

5.7.3 Teacher Professional Development

Teachers must be trained to facilitate uncertainty, resilience, and iterative learning, including the development of growth mindsets among learners.

5.7.4 Community and Industry Collaboration

Partnerships between schools, local industries, and communities must be strengthened to make STEM learning authentic and solution-driven.

5.8 Synthesis of Key Findings

From KCCP 2025 discussions and this study's analysis, the following key conclusions emerged:

1. STEM endeavors are deeply context-dependent.
2. Uncertainty and failure are productive and essential in STEM learning.
3. Hybrid models combining IKS and modern STEM are crucial for Africa.
4. Process and product must be seen as interdependent.

These findings contribute a uniquely African perspective to global STEM discourse.

5.9 Chapter Conclusion

This chapter has expanded the conceptual understanding of STEM endeavors by situating them within African socio-cultural, pedagogical, and developmental contexts. By reconceptualizing endeavor as effort, persistence, process, and innovation, this study offers a grounded framework for contextualized STEM education in Africa.

CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

This chapter presents the concluding insights of the study and outlines strategic recommendations for strengthening STEM education in Africa, grounded in the findings and discussions from the Knowledge Co-Creation Program (KCCP) 2025.

6.1 Conclusion

This study set out to clarify and operationalize the concept of **STEM endeavors** within African educational contexts. The findings demonstrate that STEM endeavors cannot be understood merely as interdisciplinary classroom activities but must be viewed as **purposeful, learner-driven, and contextually grounded engagements** that integrate uncertainty, iteration, and real-world problem-solving.

The discussions from KCCP 2025 revealed that STEM endeavors in Africa are deeply shaped by local realities, including cultural values, infrastructural limitations, community needs, and Indigenous Knowledge Systems. Educators framed STEM endeavors as processes that cultivate resilience, effort, critical thinking, and creativity while also producing tangible innovations addressing pressing societal challenges such as renewable energy access, food security, environmental sustainability, and technological inclusion.

The operational definition proposed in this study—

A STEM endeavor is a purposeful, learner-driven engagement with real-world problems, where uncertainty, trial, and refinement are embraced as part of an interdisciplinary approach to producing innovative and context-relevant solutions— provides a practical and flexible framework for conceptualizing STEM education in African contexts.

The study further established that uncertainty and failure are not weaknesses but essential components of meaningful STEM learning. By embracing a process–product balance and promoting hybrid knowledge systems, African STEM education can move toward a more inclusive, innovative, and development-oriented paradigm.

6.2 Recommendations for Strengthening STEM Education in Africa

Based on the study findings and the emerging operational definition of STEM endeavors, the following recommendations are proposed:

6.2.1 Localization of STEM Definitions and Approaches

African countries should develop context-specific and culturally grounded definitions of STEM endeavors that reflect their unique educational environments, indigenous knowledge systems, and socio-economic realities.

Localized definitions will help ensure that STEM education addresses practical community needs rather than importing external models that may not align with African contexts.

6.2.2 Promotion of Hybrid STEM Models

Governments and educational institutions should actively support High-Pitched Hybrid STEM models that integrate Indigenous Knowledge Systems with modern scientific and technological practices.

Such hybrid models can generate sustainable solutions to African challenges in areas such as:

- Climate change adaptation
- Food security and agriculture
- Water resources and sanitation
- Renewable energy access

This integration strengthens both cultural relevance and global competitiveness of African STEM innovations.

6.2.3 Emphasis on Process-Oriented and Inquiry-Driven Learning

Educational systems should prioritize process-oriented pedagogies such as problem-based, inquiry-based, and project-based learning.

Learners should be encouraged to:

- Embrace uncertainty and experimentation
- Learn from failure and iteration
- Engage in hands-on problem-solving

This approach promotes critical thinking, resilience, creativity, and innovation—core attributes required for addressing complex real-world challenges.

6.2.4 Increased Investment in STEM Infrastructure

African governments, private institutions, and development partners should increase investment in **STEM infrastructure and resources**, including:

- Science and technology laboratories
- Digital learning tools and internet connectivity
- Maker spaces and innovation hubs
- Teacher training facilities

Improved infrastructure will enhance hands-on learning, experimentation, and innovative thinking among learners.

6.2.5 Integration of Entrepreneurial Education into STEM

To support innovation-led growth and job creation, STEM curricula should integrate **entrepreneurial skills development**, including:

- Design thinking
- Innovation management
- Business development and problem pitching
- Community-based enterprise creation

This will help learners transition from knowledge consumers to solution creators and societal innovators.

6.3 Final Reflection

The KCCP 2025 discussions provided a rich platform for rethinking the nature of STEM endeavors in African education systems. By grounding STEM education in local realities, embracing uncertainty, valuing indigenous knowledge, and fostering innovation through inquiry-driven learning, African countries can build resilient education systems capable of addressing both present and future challenges.

This study therefore provides a conceptual and practical roadmap for transforming STEM education in Africa into a **contextually relevant, culturally responsive, and innovation-driven framework** aligned with the continent's development aspirations.

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Article 4

Impact of Industry Academia Collaboration on Student Competency Acquisition in STEM-CBET Programs for Industrial Workforce Readiness.

Wambeye Kimweli Marakia (PhD)

jokimawa@gmail.com

Kibabii University, Kenya

Abstract

This study investigates the impact of industry-academia collaboration on student competency acquisition in STEM focused Competency Based Education and Training (STEM-CBET) programs within Kenya's Technical and Vocational Education and Training (TVET) sector, emphasizing workforce readiness. Guided by the operationalization of the Kenya National Qualifications Framework (KNQF), which aims to align TVET qualifications with labor market demands through active industry participation via Industry Advisory Committees (IACs), this research analyzes the current extent, patterns, and gaps of industry involvement in curriculum development, instructional delivery, and outcome assessment. Data were collected through structured online questionnaires administered to 233 IAC members and 350 TVET heads of departments and industry liaison officers, complemented by qualitative interviews with 98 stakeholders across various STEM and non-STEM sectors. Quantitative analysis included correlation and regression models examining relationships between industry collaboration factors such as forms of support, engagement frequency, partnership effectiveness, and curriculum alignment and graduate employment rates as a proxy for competency acquisition. Findings reveal a modest but statistically significant influence of industry engagement on program effectiveness ($R^2 = 0.169$, $p < 0.001$), with particular emphasis on frequent, multifaceted industry support enhancing competency outcomes. However, challenges persist, including limited communication between academia and industry (65%), resource constraints, misalignment of KNQF descriptors with real job competencies, and insufficient practical training. The study advocates for scaling up industry partnerships beyond equipment donations to include joint research, innovative training co-development, and shared technology investments. Recommendations highlight strengthening dialogue channels, increasing funding through public private partnerships, expanding industry-led practical training, and introducing industry led trainer certification programs to improve curriculum relevance and graduate employability. This multi-pronged approach is essential to fully harness the potential of STEM-TVET programs in Kenya and ensure alignment with rapidly evolving industrial demands.

Keywords: Industry-academia collaboration, STEM-CBET, TVET, Competency acquisition, Workforce readiness, Curriculum alignment, Employability.

1.1 Background

Technical and Vocational Education and Training (TVET) plays a crucial role in equipping learners with the skills demanded by rapidly evolving economic sectors. In Kenya, the Kenya National Qualifications Authority (KNQA) spearheads the implementation of the Kenya National Qualifications Framework (KNQF), designed to standardize qualifications and align them with local and international labor market requirements (Kenya National Qualifications Authority [KNQA], 2015; KNQA, 2024). The KNQF emphasizes competency-based education and training (CBET), which prioritizes the acquisition of practical, measurable skills tailored to industry needs (KNQA, 2018–2023).

The integration of Industry Advisory Committees (IACs) within TVET institutions represents a key strategy to tether education to labor market realities. These committees comprise industry practitioners, educators, and policymakers who collaborate to co-develop curricula, guide instructional delivery, and participate in competency-based assessments (Kenya Vision 2030 Secretariat, 2020). This approach aligns with global trends advocating for strengthened industry-academia linkages to bridge the skills mismatch, a challenge widely documented in developing countries (ILO, 2019; UNESCO-UNEVOC, 2021).

Research indicates that such collaborations improve the relevance and quality of training programs by incorporating emerging technologies and workplace practices into curricula (OECD, 2020; AfDB, 2022). The Kenya Vision 2030 blueprint underscores the imperative to modernize STEM education within TVET to drive industrialization and innovation (Kenya Vision 2030 Secretariat, 2020). However, implementation bottlenecks including limited resources, insufficient practical infrastructure, and communication gaps between academia and industry persist, curbing full realization of these goals (KNQA, 2018–2023).

The criticality of STEM education for national development has gained amplified attention globally. The Fourth Industrial Revolution (Industry 4.0) demands workforce readiness in fields such as artificial intelligence, robotics, and the Internet of Things (IoT) (World Economic Forum (WEF), 2018; UNESCO, 2023). In response, Kenyan TVET institutions are urged to integrate these emerging disciplines systematically into STEM curricula (KNQA, 2024). This transformation also necessitates equipping instructors with updated knowledge and practical exposure to new technologies, underscoring the need for mandatory industry attachments and professional development (African Union Commission, 2021; World Bank, 2022).

Gender inclusivity constitutes a central pillar in the nationwide effort to improve STEM participation rates. Despite notable progress, women remain underrepresented in engineering and technology sectors, confronting socio-cultural and institutional barriers (UN Women, 2023). Initiatives such as Young Africa Works-Kenya TVET demonstrate promising outcomes by introducing gender-responsive curricula and mentorship schemes, leading to a reported 30% increase in female STEM enrollment (African Development Bank (AfDB), 2022). Encouraging female participation not only promotes social equity but also addresses talent shortages critical for economic competitiveness (ILO, 2019; UNESCO, 2023).

Furthermore, competency based training inherently requires assessment frameworks that go beyond theoretical knowledge to practical demonstrations of skill mastery (KNQA, 2018–2023;

Wagacha & Patel, 2020). The KNQF prescribes levels of qualification descriptors that articulate specific competency standards intended to match employer expectations (KNQA, 2024). Nevertheless, recent studies reveal gaps between KNQF descriptors and industry job competencies, partly due to the slow pace of curriculum review and outdated teaching methods (Kamau & Olwande, 2021). Addressing these misalignments requires robust communication channels and joint development initiatives between educational institutions and industry (Wangari & Mberia, 2023; Ngugi & Mwangi, 2022).

Public private partnerships (PPPs) have emerged as effective mechanisms to overcome resource constraints hampering TVET sectors in Kenya and across Africa (African Union Commission, 2021; AfDB, 2022). Through PPPs, STEM labs can be equipped with industry-standard equipment, enabling practical training reflective of current workplace environments. Innovative training modalities such as virtual simulations and blended learning models further offer cost-effective means to teach complex or hazardous technical processes safely (World Bank, 2022; UNESCO-UNEVOC, 2021). The Kenyan government's commitment through the ICT Master Plan 2023 also aims to leverage technology for enhanced STEM teaching and learning (Kenya Ministry of Education, 2023).

The labor market linkage remains fundamental to the success of TVET training programs. A dynamic STEM skills forecasting system, incorporating real-time feedback from industry bodies such as the Kenya Private Sector Alliance (KEPSA) and the Federation of Kenya Employers (FKE), can guide curriculum adjustments to align with evolving technological and economic landscapes (KEPSA, 2024; Ngugi & Mwangi, 2022). Additionally, platforms such as graduate employability dashboards facilitate monitoring of employment outcomes, providing transparency and accountability for training institutions (World Economic Forum, 2019).

While international frameworks inform local efforts, efforts have been made to harmonize Kenyan TVET qualifications with global standards, such as the European Union's STEM Competence Framework (EU STEM CF), to enhance mobility and recognition of competencies (KNQA, 2024; European Commission, 2020). Industry led certification for STEM graduates is increasingly advocated to certify not just academic qualifications but practical competencies that meet international benchmarks (Wagacha & Patel, 2020; AfDB, 2022).

However, challenges such as staff resistance to curricular changes, inadequate focus on emerging technologies, and insufficient stakeholder collaboration inhibit full adoption of these reform measures (Kamau & Olwande, 2021). An understanding of these systemic barriers, informed by both quantitative data and qualitative stakeholder feedback, is vital for designing effective interventions (KNQA, 2018–2023; Wangari & Mberia, 2023).

African Union's Agenda 2063 recognizes the centrality of STEM education for Africa's innovation, industrialization, and sustainable development. It prioritizes expanding quality STEM education access especially for women and youth to create a skilled workforce and build a knowledge-driven economy (African Union, 2015; World Bank, 2023; NACOSTI, 2022). Initiatives include developing infrastructure, advancing teacher training, and fostering public-private partnerships and

collaborations between industry and academia (UNESCO/AU, 2024). Strengthening STEM aims to reduce reliance on foreign expertise, promote research and innovation, and elevate Africa's global competitiveness (African Union, 2015; World Bank, 2023). Empowering women and girls in STEM is highlighted as essential for inclusive growth and for addressing critical challenges across sectors (World Bank, 2023; NACOSTI, 2022). Strategic investment and coordinated action remain key to translating Agenda 2063's vision into transformative impact for Africa's future (African Union, 2015; NEPAD, n.d.; UNESCO/AU, 2024; World Bank, 2023; NACOSTI, 2022). Across Kenya's TVET subsector, comprising National Polytechnics, Technical and Vocational Colleges, Kenya School of TVET, and Vocational Training Centres, STEM courses dominate enrollment figures with a STEM to non-STEM ratio of approximately 7:1 (TVET Authority, 2024).

Table 1 Disaggregated Enrolment, Graduation Rates and Dropouts from TVETs in Year 2023

	Enrollment Trends Year 2023		Graduation Rates for the Year 2023		Dropouts Year 2023	
	STEM	Non-STEM	STEM	Non-STEM	STEM	Non-STEM
National Polytechnics	129,712	22,260	20%	27%	2.26%	2.87%
Kenya School of TVET(KSTVET)	2,920	982	66%	62%	0%	0%
Technical and Vocational Colleges (TVCs)	227,412	40,783	25%	30%	4.5%	5.8%
VOCATIONAL TRAINING CENTRES	107,273	987	37.3%	41.2%	19.6%	10%

Source: TVET Authority, 2024

This underscores the emphasis placed on equipping trainees with practical, industry-relevant skills in emerging technical fields. However, despite this growth, challenges remain evident in trainer capacity and gender balance. Most trainers hold bachelor's degrees, but shortages persist, particularly in public institutions where trainer-to-trainee ratios exceed recommended standards for both STEM (1:28) and non-STEM (1:24) programs, potentially affecting training quality (TVET Authority, 2024).

Table 2 Trainer to Trainee Ratio in STEM and Non-STEM

	STEM			Non-STEM		
Institution Type	Trainers	Trainees	Ratio	Trainers	Trainees	Ratio
Public	7073	207480	1:33	1420	30597	1:20
Technical and Vocation College	5805	180157	1:33	1125	26015	1:25
Underline Ministry	884	20585	1:25	111	2230	1:20
University TVET Training Institute	384	6738	1:17	184	2352	1:13
Private	1365	19932	1:14	620	10186	1:17
Technical and Vocation College	1329	19876	1:14	599	10136	1:17
University TVET Training Institute	36	56	1:2	21	50	1:2
Overall	8438	227412	1:25	2040	40783	1:20

Source: TVET Authority, 2024

Gender disparities remain a concern; male trainees outnumber females in STEM subjects, though non-STEM courses see more balanced or female-majority enrollment. Inclusion of persons with disabilities is also low, with only 0.54% of total trainees identified as having disabilities, signaling a need for wider accessibility and inclusive policy implementation (TVET Authority, 2024).

Graduation and dropout rates illustrate ongoing system inefficiencies, with an overall graduation rate of 27% below the expected minimum of 33%, and dropout rates higher in STEM compared to non-STEM courses. These metrics highlight the importance of curriculum relevance, practical training quality, and learner support to improve retention and successful competency acquisition (TVET Authority, 2024).

1.2 Statement of the problem

Technical and Vocational Education and Training (TVET) institutions play a pivotal role in developing Kenya's skilled workforce, yet STEM-focused Competency-Based Education and Training (CBET) programs continue to face substantial challenges in equipping students with industry-relevant skills. Despite nationwide implementation of CBET methodologies in STEM disciplines, a persistent skills mismatch remains evident, with only 20.77% of enrolled students successfully completing their programs while 76.88% remain in academic limbo. This competency acquisition crisis is particularly pronounced in STEM programs, where male dropout rates reach 3.35% in certain institutions, indicating systemic deficiencies in skills development frameworks.

The growing disconnect between TVET curricula and industry requirements is further aggravated by inadequate industry-academia collaboration, leaving STEM-CBET programs poorly aligned with the evolving demands of Industry 4.0 sectors. This misalignment is compounded by gender-specific challenges, as female students in STEM-CBET tracks encounter unique barriers to competency development, reflected in distinct dropout patterns across different institutions. These

multifaceted challenges underscore the urgent need to examine how structured industry-academia partnerships can enhance competency acquisition in STEM-CBET programs.

The current study addresses three critical gaps in Kenya's TVET landscape: first, the absence of institutionalized frameworks for meaningful industry participation in curriculum design and delivery; second, inconsistent implementation of competency-based teaching methodologies across TVET institutions; and third, gender-specific obstacles in STEM skills development. This research carries particular urgency given Kenya's Vision 2030 development goals and the TVET Act (2013) provisions mandating industry-aligned skills training. Without establishing effective collaboration mechanisms, STEM-CBET programs risk continuing to produce graduates lacking the essential competencies demanded by rapidly transforming industrial sectors, thereby exacerbating youth unemployment and hindering national economic progress. The study's findings aim to provide actionable insights for bridging these critical gaps in Kenya's technical education system.

1.3 Research Objectives,

1. To examine the relationship between industry-academia collaboration models and competency acquisition levels in STEM-CBET programs,
2. To evaluate the extent and effectiveness of industry engagement in STEM-CBET program design, delivery, and assessment processes

1.4 Research Questions

RQ1: To what extent does industry engagement influence the effectiveness of STEM-CBET program design, delivery, and assessment processes?

RQ2: What are the current patterns and gaps in industry participation across STEM-CBET curriculum development, instructional delivery, and outcome assessment?

RESEARCH METHODOLOGY

2.1 Methodology

This study adopted a descriptive cross-sectional survey design to evaluate the involvement of Industry Advisory Committee members in curriculum development within Kenya's TVET sector. The design is suitable for capturing current practices, perceptions, and gaps in industry-academia collaboration at a specific point in time.

2.2 Population and Sampling

TVET institutions with established Industry Advisory Committees were systematically selected. The research targeted three primary groups from these institutions: IAC members, TVET Heads of Departments, and Industry Liaison Officers. This work was situated within the context of the Young Africa Works-Kenya initiative, a five-year program (2020-2025) aimed at enhancing the quality and relevance of TVET institutions and systems nationwide.

Table 3 : IAC Member's Sectorial Representation

Sector	Category	IAC members	TVET institutions
Agribusiness	STEM	239	Nyeri NP, Friends College Kaimosi, Meru NP, Nyandarua NP, Konoin TTI, Rift Valley Inst, Kitale NP, Eldoret NP, Northeastern NP
Building & Construction	STEM	196	Keroka TTI, Bondo TTI, Mathenge TTI, Nyandarua NP, Sigalagala NP, Kitale NP, Maasai Mara TVC, Kenya Coast NP, Eldoret NP, Baringo TVC, Lodwar VTC
Manufacturing	STEM	91	Keroka TTI, Kisii NP, Coast Inst of Tech, Weru TVC, Kabete NP
Hospitality	NON-STEM	97	Sangalo Inst, Coast Inst of Tech, Kenya Coast NP, Baringo TVC, North Eastern NP
Digital Sector	STEM	6	Bondo TTI, Kabete NP
Blue Economy	STEM	17	Mawego TTI
Tourism	NON-STEM	7	Maasai Mara TVC

To ensure the research findings accurately reflect the diverse needs of Kenya's workforce, a stratified sampling strategy was used. This method ensured representation. By capturing input from a wide range of sectors, the study provides a comprehensive overview of how industry engagement is shaping TVET curricula to meet the evolving demands of the labor market.

Table 4 Sampling Frame (Stratified by Sector)

Sector	Category	IAC Members Population (N)	IAC Members Sample Size (n)	TVET Heads of Department (HODs) and ILO Population (N)	TVET Heads of Department (HODs) and ILO Sample Size (n)
Agribusiness	STEM	239	110	240	138
Building & Construction	STEM	196	90	180	114
Manufacturing	STEM	91	42	123	53
Hospitality	NON-STEM	97	45	55	57
Digital Sector	STEM	6	3	13	4
Blue Economy	STEM	17	8	18	10
Tourism	NON-STEM	7	3	13	4
Total		653	301	642	380

2.3 Data Collection Methods

2.3.1 Data Collection Methods

Structured online questionnaires were distributed to both IAC members and TVET HODs as well as ILOs to gather comprehensive data for this study. The questionnaires incorporated a mix of closed-ended questions and Likert-scale items, enabling the research team to quantitatively assess key variables such as sectoral representation, specific roles within the committees, duration of service, frequency and depth of engagement, and the various forms of industry support provided to TVET institutions. This structured approach allowed for the systematic collection of comparable data across diverse respondents and sectors.

To enrich the quantitative findings and capture more insights, the questionnaires also included open-ended questions. These qualitative items invited participants to elaborate on their experiences and perspectives regarding curriculum alignment with industry needs, inclusivity practices, and suggestions for improving industry-academia collaboration.

Table 5: Questionnaire Distribution

Sector	CATEGORY	Questionnaires for IAC Members	Questionnaires for TVET Heads of Department and ILOs
Agribusiness	STEM	80	130
Building & Construction	STEM	72	106
Manufacturing	STEM	32	47
Hospitality	NON-STEM	35	52
Digital Sector	STEM	3	3
Blue Economy	STEM	8	9
Tourism	NON-STEM	3	3
Total		233	350

Additionally, interviews were conducted. This allowed for follow-up with selected respondents to clarify questionnaire responses and explore complex issues in greater depth. The combination of structured surveys and targeted interviews ensured a robust, multi-faceted understanding of IAC engagement and its impact on TVET curriculum development in Kenya.

Table 6 Interview Distribution

Sector	Category	Interviews for IAC Members	Interviews for TVET Heads of Department and ILO
Agribusiness	STEM	30	8
Building & Construction	STEM	18	8
Manufacturing	STEM	10	6
Hospitality	NON-STEM	10	5
Digital Sector	STEM	0	1
Blue Economy	STEM	2	1
Tourism	NON-STEM	3	1
Total		68	30

2.4 Data Analysis

Quantitative data were analyzed using descriptive statistical techniques, including frequencies, percentages, means, medians, and measures of distribution such as skewness, to summarize patterns of engagement, roles, and forms of industry support across the sampled TVET institutions. Cross-tabulations were conducted to compare responses among different stakeholder groups namely, IAC members, HODs, and ILOs in order to identify variations in perceptions and practices. Qualitative data derived from open-ended questionnaire items and follow-up interviews were analyzed using thematic coding. Responses were systematically reviewed to identify recurring themes, concerns, and suggestions related to curriculum alignment, inclusivity, and industry-academia collaboration. The resulting themes provided contextual depth to the quantitative findings and informed the development of actionable recommendations for enhancing IAC involvement in curriculum development within Kenya's TVET sector.

2.5 Ethical Considerations

The study complied with relevant ethical research standards and observed the provisions of the Data Protection Act, Cap 411C regarding the collection, processing, and storage of personal data. Participation was voluntary and confidential. Data were anonymized to protect respondent identities, and findings were reported in aggregate to ensure impartiality and integrity

3 Findings

3.1 Industry Linkages and Curriculum Alignment in TVET Institutions

This report examines critical aspects of industry-academia collaboration within Kenyan Technical and Vocational Education and Training (TVET) institutions, focusing on four key variables: curriculum alignment with the Kenya National Qualifications Framework (KNQF), the presence of functional Industry Advisory Committees (IACs), types of industry support provided, and the frequency of Labor Market Assessments (LMAs). The analysis is based on complete data from 240 respondents, with no missing values, ensuring robust findings.

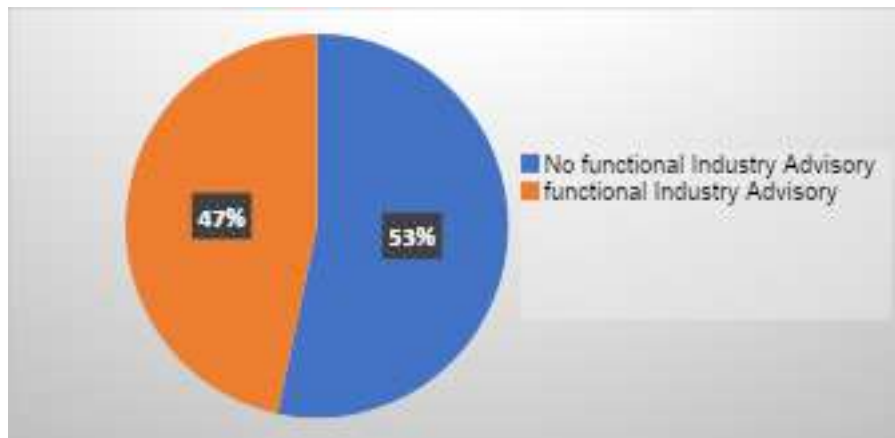


Figure 2 presence of functional Industry Advisory Committee (IAC)

The findings reveal that all participating institutions (100%) assessed their curriculum alignment with KNQF standards, indicating widespread awareness and adherence to national competency

frameworks. This suggests that TVET institutions are making concerted efforts to align their programs with nationally recognized qualifications, which is crucial for ensuring the relevance and quality of training. Similarly, all institutions reported on the functionality of their IACs, demonstrating a universal commitment to formalizing industry partnerships through structured advisory bodies. This is a positive indicator of institutional efforts to bridge the gap between education and industry needs.

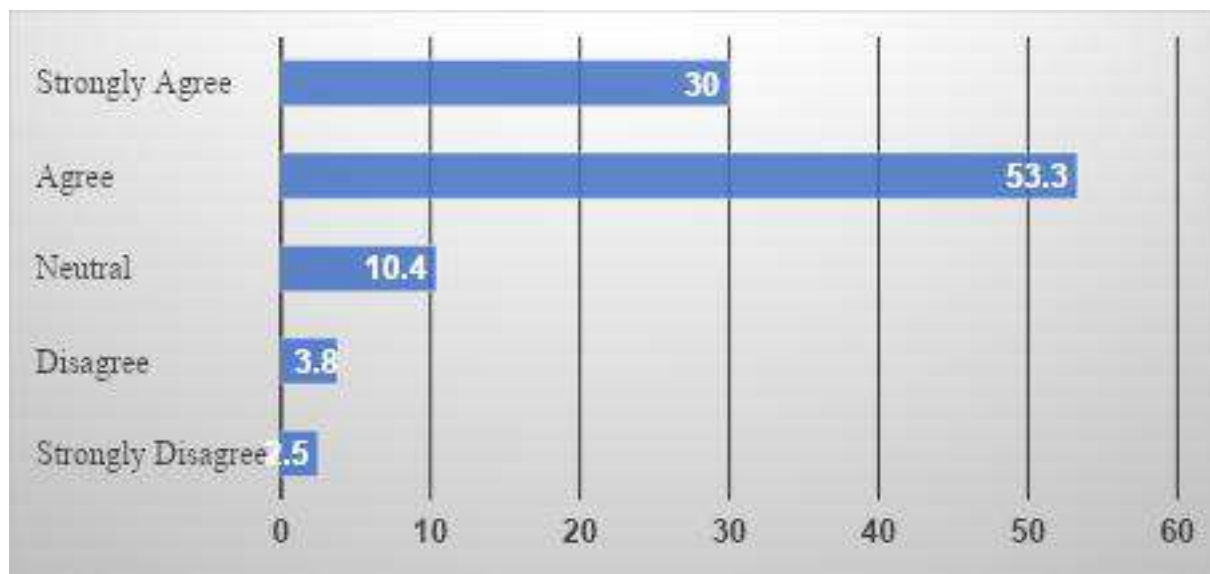


Figure 3 the curriculum alignment with KNQF level descriptors.

Regarding industry support, the data shows that all institutions receive some form of collaboration from industry partners. Further analysis is needed to categorize and rank the specific types of support provided such as internships, equipment donations, or joint curriculum development to identify the most prevalent and impactful forms of collaboration. Additionally, the frequency of LMAs was reported by all institutions, highlighting their engagement in tracking labor market demands. Analyzing the regularity of these assessments (e.g., annual vs. biannual) will provide insights into how proactively institutions adapt their programs to evolving industry requirements.

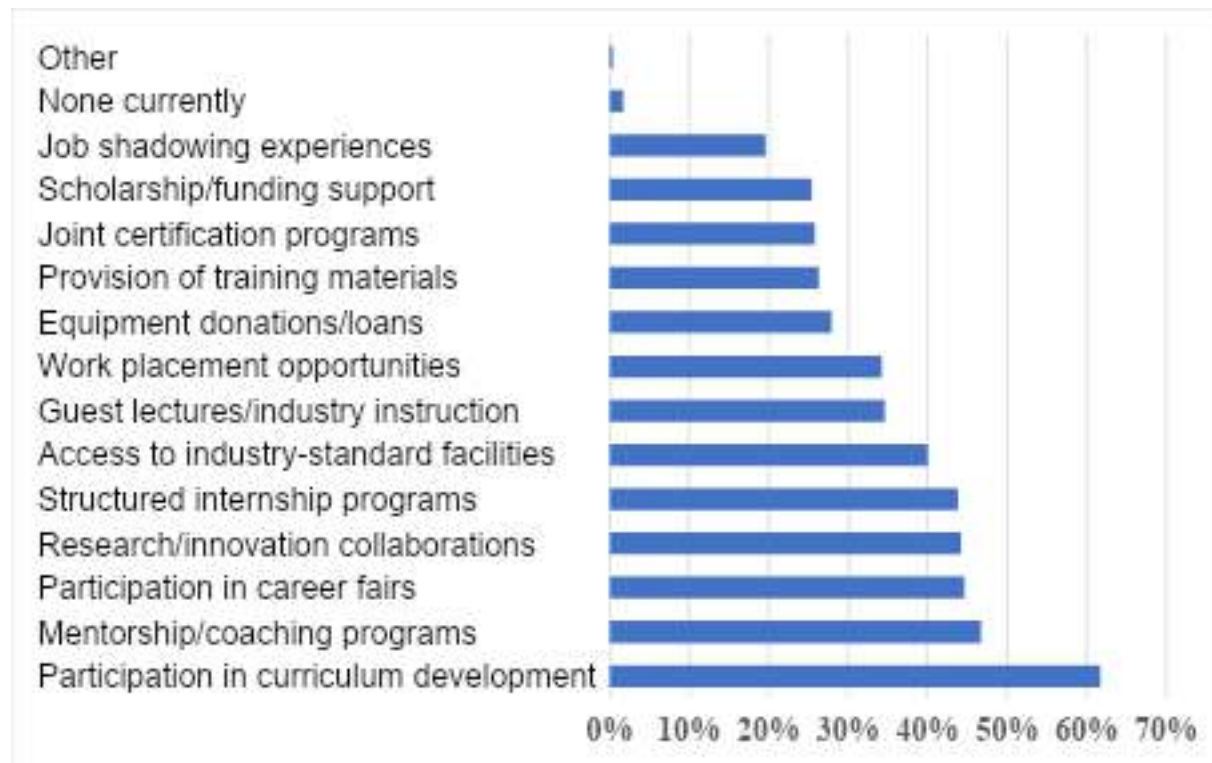


Figure 4 Most Common Support Type

Industry support for Kenyan TVET institutions primarily focuses on collaborative educational development, with curriculum participation emerging as the most common form of partnership (62%). This aligns with national efforts to enhance curriculum relevance through direct industry input. Mentorship programs (47%) and career fair participation (45%) follow closely, indicating strong industry engagement in student professional development. Nearly half of institutions benefit from research collaborations (44%), reflecting growing recognition of TVET's role in innovation. Hands-on learning opportunities are well-represented, with structured internships (44%) and work placements (34%) providing practical experience. However, job shadowing remains relatively limited (20%), suggesting potential for expansion in observational learning formats.

Material support shows moderate adoption, with access to industry-standard facilities (40%) being most prevalent, while equipment donations (28%) and training materials provision (26%) are less common. This may indicate resource constraints among industry partners or mismatched expectations between institutions and businesses. Notably, financial support mechanisms including scholarships (25%) and joint certification programs (26%) appear underutilized compared to knowledge-sharing collaborations. Only 2% of institutions reported no industry support, demonstrating widespread partnership adoption across Kenyan TVETs.

3.2 Effectiveness of industry linkages

A Mann-Whitney U test revealed a significant difference between STEM and non-STEM programs in perceptions of industry linkages' impact on employability ($U = 5,531$, $p = .043$), with Non-

STEM respondents reporting stronger agreement (M rank = 131.72) than STEM respondents (M rank = 114.79). The results of the Mann-Whitney U test indicate a statistically significant difference ($p = .043$) in how STEM and non-STEM program stakeholders perceive the effectiveness of industry linkages in improving graduate employability outcomes.

The test statistic ($U = 5,531$) and the associated Z-score (-2.023) demonstrate that Non-STEM respondents (Mean Rank = 131.72) expressed significantly stronger agreement about the positive impact of industry partnerships compared to their STEM counterparts (Mean Rank = 114.79). This suggests that industry-academia collaborations may be perceived as more beneficial or visible in non-STEM fields. These findings highlight the need for tailored approaches to industry engagement. While non-STEM programs appear to have more effective linkages, STEM programs may require more structured, sector-specific partnerships to bridge the perceived gap in employability outcomes. Further research could explore qualitative differences in these partnerships to identify best practices for both domains.

The correlation analysis reveals a statistically significant, though weak, positive relationship (Spearman's $\rho = 0.172$, $p = 0.008$) between the effectiveness of partnerships with industry bodies (e.g., KAM, KEPSA) and the percentage of graduates securing employment or self-employment. This suggests that industry engagement has a measurable, albeit modest, influence on the effectiveness of STEM-CBET programs, particularly in improving graduate employability outcomes.

Table 7 Correlation between Partnership Effectiveness and Graduate Employment Rates

		Partnerships effectiveness	Graduate employment rates
partnerships effectiveness	Correlation Coefficient	1	.172
	Sig. (2-tailed)	.	0.008
	N	240	240
Graduate Employment Rates	Correlation Coefficient	.172	1
	Sig. (2-tailed)	0.008	.
	N	240	240

The significance of this finding lies in its alignment with Competency-Based Education and Training (CBET) principles, which emphasize industry collaboration to ensure curricula meet labor market demands. While the weak correlation indicates that industry partnerships alone are not the sole determinant of program success, they contribute to bridging the skills gap and enhancing the relevance of training. The positive association implies that institutions with stronger industry linkages may better align program design (e.g., curriculum development), delivery (e.g., practical

training), and assessment (e.g., competency evaluations) with employer needs, thereby improving graduate outcomes.

However, the low coefficient suggests that other factors such as institutional resources, learner preparedness, or macroeconomic conditions also play critical roles. To maximize the impact of industry engagement, STEM-CBET programs should adopt a multifaceted approach, integrating partnerships with work-based learning, employer feedback mechanisms, and continuous curriculum updates.

In conclusion, industry engagement does influence STEM-CBET effectiveness, but its impact is partial. Strengthening and diversifying collaborations could further enhance program outcomes, ensuring graduates are both job-ready and adaptable to evolving industry demands.

3.2.1 Industry-Academia Collaboration Models in TVET

This study examines the relationship between industry-academia collaboration models and competency acquisition in STEM-based Competency-Based Education and Training (CBET) programs in Kenyan TVET institutions. Despite policy emphasis on industry linked training, concerns persist about graduates' workforce readiness, with only 20.77% completing programs successfully. The null hypothesis (H_0) posits no significant relationship between collaboration models (e.g., curriculum co-design, internships) and competency outcomes. Testing this hypothesis is critical to determine whether structured partnerships enhance skills alignment with Industry demands or if systemic gaps undermine their effectiveness.

Table 8 : Regression Model Summary

Model	R	R ²	Adjusted R ²	Std. Error	R ² Change	F Change	df1	df2	p-value
1	0.411	0.169	0.155	28.741	0.169	11.954	4	235	<.001
Predictors: (Constant), Industry Support Forms, Engagement Frequency, KNQF Alignment, Partnership Effectiveness									

Table 9 : ANOVA Results

Source	SS	df	MS	F	p-value
Regression	39,498.94	4	9,874.74	11.954	<.001
Residual	194,123.46	235	826.06		
Total	233,622.40	239			

Table 10 Regression Analysis of Industry Collaboration Factors on Graduate Employment Rates

Predictor Variable	B (Unstandardized)	Std. Error	β (Standardized)	t-value	p-value	Tolerance	VIF
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Constant	16.485	8.05 3	-	2.04 7	.042	-	-
Curriculum alignment with KNQF	10.177	8.83 7	0.072	1.15 2	0.251	0.907	1.102
Frequency of industry engagement	13.238	5.08 6	0.162	2.60 3	.010	0.917	1.091
Forms of industry support	0.354	0.06 2	0.35	5.73 5	.000	0.95	1.053
Partnership effectiveness	11.459	6.65 2	0.103	1.72 3	0.086	0.994	1.006

The regression analysis Table 8;9 and10 examining the relationship between industry academia collaboration models and competency acquisition levels (proxied by graduate employment rates) reveals statistically significant findings that lead to the rejection of the null hypothesis (H_{01}). The model explains 16.9% of the variance ($R^2 = 0.169$, $p < 0.001$) in employment outcomes, indicating a modest but meaningful influence of industry engagement on program effectiveness. Key predictors include the frequency of industry engagement ($\beta = 0.162$, $p = 0.010$) and forms of industry support ($\beta = 0.350$, $p < 0.001$), both of which demonstrate positive and significant associations with graduate employment. This suggests that active, multifaceted collaboration such as curriculum input and tangible support (e.g., internships, equipment) enhances competency acquisition.

However, the perceived effectiveness of partnerships shows a marginal positive trend ($\beta = 0.103$, $p = 0.086$), implying that institutional perceptions may not fully align with measurable outcomes. Surprisingly, curriculum alignment with KNQF is non-significant ($p = 0.251$), indicating that formal compliance with national frameworks does not necessarily translate into better employment results without industry integration. The model's F-statistic ($F = 11.954$, $p < 0.001$) confirms overall significance, though the moderate R^2 suggests other unmeasured factors (e.g., student preparedness, economic conditions) also play critical roles.

Industry-academia collaboration significantly impacts STEM-CBET outcomes, particularly when involving frequent engagement and concrete support. However, the limited variance explained underscores the need for holistic strategies beyond formal partnerships. Institutions should prioritize actionable industry involvement over bureaucratic compliance to maximize graduate employability. Further research could explore qualitative dimensions of collaboration to refine these models.

3.3 Curriculum alignment

The chi-square analysis reveals statistically significant differences in perceptions of curriculum alignment with KNQF standards between STEM and non-STEM programs ($\chi^2=22.30$, $df=4$,

$p < .001$). STEM programs demonstrated notably stronger agreement with the alignment statement, with 86% of respondents agreeing or strongly agreeing compared to 78% in non-STEM programs. More concerning is the higher level of disagreement among non-STEM respondents, where 11% expressed some degree of disagreement versus only 4% in STEM programs, including a notable 6% strong disagreement in non-STEM that was virtually absent in STEM programs ($< 1\%$). The moderate effect size ($\phi = .305$, Cramer's $V = .305$) suggests that program type accounts for approximately 9% of the variance in alignment perceptions, indicating that while the relationship is meaningful, other factors also influence these perceptions.

Table 11 Chi-Square Test Results for Curriculum Alignment by Program Type

Test Statistic	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	22.299a	4	0
Likelihood Ratio	22.212	4	0
Linear-by-Linear Association	0.012	1	0.912
N of Valid Cases	240		

These findings suggest STEM programs are generally more successful in implementing KNQF-aligned curricula, while non-STEM programs face greater challenges in achieving perceived alignment. The substantial disagreement in non-STEM programs, particularly the strong disagreement responses, points to specific institutional or programmatic issues that warrant further investigation.

To address these findings, several actions are recommended: First, qualitative research should be conducted with non-STEM institutions showing disagreement to identify specific implementation challenges. Second, KNQF implementation guidelines for non-STEM fields should be reviewed and potentially revised. Finally, targeted professional development for non-STEM educators on competency-based curriculum design may help improve alignment perceptions. These results highlight the need for differentiated support approaches across program types to ensure successful KNQF implementation throughout Kenya's TVET system.

3.3.1 Challenges in Curriculum Alignment

Despite notable progress in aligning TVET curricula with industry demands and the KNQF, several persistent challenges continue to hinder full and effective implementation. As outlined in Table 8, the most frequently cited challenge was the lack of communication between academia and industry, reported by 65% of respondents. This significant disconnect limits the integration of real-time labor market intelligence into curriculum development and reduces the relevance of training programs. Limited resources and funding for curriculum updates (55%) further exacerbate the problem, restricting institutions' ability to revise or modernize their offerings in response to industry shifts

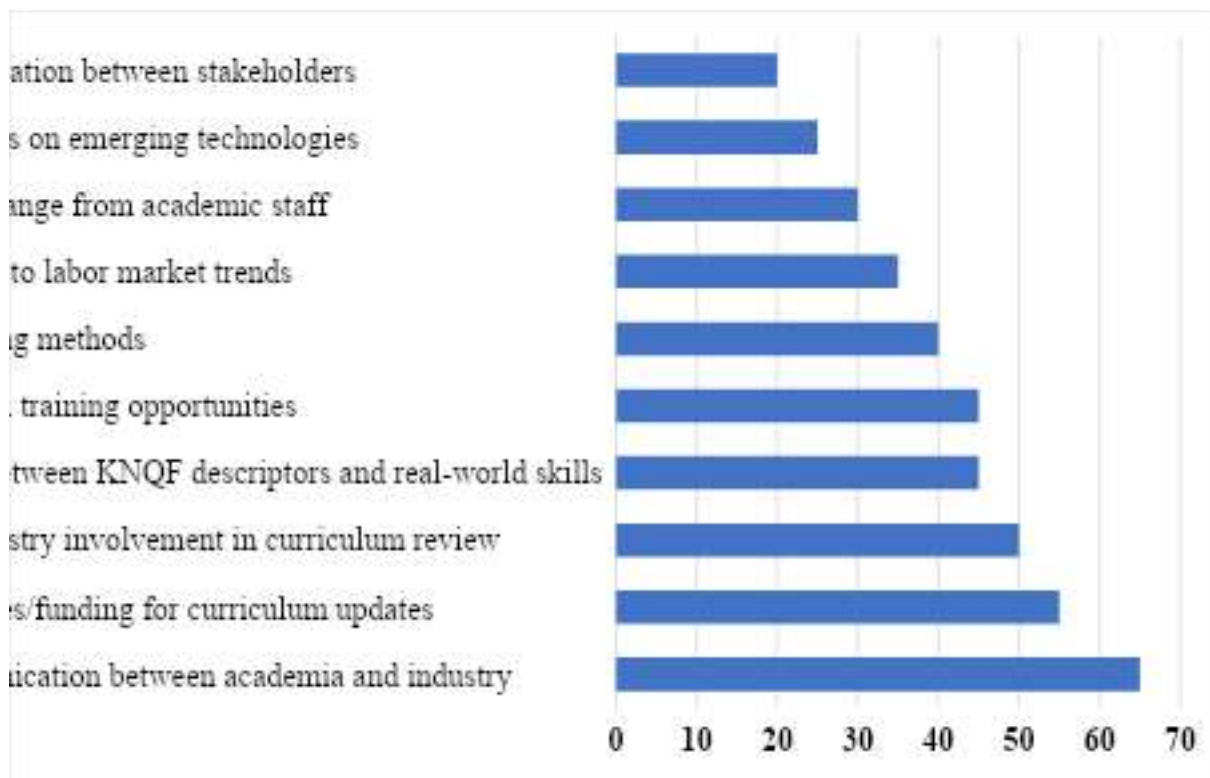


Figure 5 Challenges in Curriculum Alignment

The findings reveal systemic challenges in Kenya's TVET curriculum alignment, with half of respondents reporting insufficient industry involvement in curriculum reviews, leading to a disconnect between education and labor market needs. Key issues include misalignment between KNQF descriptors and actual job competencies (45%), lack of practical training (45%), outdated teaching methods (40%), and slow adaptation to labor market changes (35%). Additional barriers include staff resistance to change (30%), inadequate focus on emerging technologies (25%), and limited stakeholder collaboration (20%). These interconnected challenges highlight structural deficiencies in communication, funding, and industry engagement that require comprehensive reforms.

3.4 Conclusion

This study highlights the critical role of industry-academia collaboration in enhancing the effectiveness of STEM-based Competency-Based Education and Training (CBET) programs in Kenyan TVET institutions. The findings reveal that while curriculum alignment with the Kenya National Qualifications Framework (KNQF) is widely implemented, its impact on graduate employability is limited without active industry engagement. Regression analysis confirmed that frequent industry interactions ($\beta = 0.162$, $p = 0.010$) and tangible support, such as internships and equipment donations ($\beta = 0.350$, $p < 0.001$), significantly improve employment outcomes. However, the model explains only 16.9% of employment variance, suggesting that other factors

such as institutional resources, economic conditions, and learner preparedness also play crucial roles.

A notable disparity exists between STEM and non-STEM programs, with STEM institutions demonstrating stronger curriculum alignment (86% agreement vs. 78% in non-STEM) while non-STEM programs report higher industry linkage effectiveness in employability perceptions ($U = 5,531, p = 0.043$). This indicates that structured, sector-specific partnerships are essential for STEM fields to bridge the skills gap. Challenges such as poor academia-industry communication (65%), inadequate funding (55%), and outdated teaching methods (40%) further hinder curriculum relevance.

3.5 Recommendations for Strengthening STEM-TVET in Kenya

1. Modernize STEM Curriculum & Training Approaches

- Align STEM programs comprehensively with Industry 4.0 technologies by integrating emerging fields such as artificial intelligence, robotics, IoT, across all STEM disciplines.
- Develop micro-credentials focusing on high-demand digital skills like automation and data analytics to enhance learner employability and flexible skill acquisition.
- Strengthen practical training infrastructure by equipping STEM labs with industry-standard equipment through public-private partnerships.
- Implement virtual and simulation-based training solutions to safely teach expensive or hazardous technical processes.

2. Improve STEM Teaching Capacity

- Establish industry-led certification programs to professionalize and standardize STEM trainer qualifications.
- Recruit part-time practitioner-trainers from engineering and technology sectors by offering flexible employment terms and appropriate incentives.

3. Strengthen Labor Market Linkages

- Develop a dynamic STEM skills forecasting system jointly managed with KEPSA and KAM member firms to conduct quarterly skills anticipation surveys.
- Create a STEM Graduate Employability Dashboard that tracks employment outcomes by discipline and specialization and publicly ranks institutions based on graduate employment performance.
- Establish a responsive curriculum adjustment mechanism informed by labor market data to rapidly incorporate technological advancements.

4. Policy & Funding Recommendations

- Establish a dedicated STEM-TVET Development Fund with at least 30% allocation of the TVET budget earmarked for STEM infrastructure, innovation, and capacity building.

- Offer tax incentives to companies that invest in STEM training equipment and infrastructure.

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DECOLONIZING STEM CURRICULA: CENTERING AFRICAN KNOWLEDGE SYSTEMS AND SUSTAINABLE PRACTICES

¹Maradonah Sichilenge , ² Sibeso Mubukwanu

¹sichilengem@gmailcom, ² sibeso@aims.ac.tz

¹Shampande Day Secondary School, ² Monze Boarding secondary school

Abstract

Science, Technology, Engineering and mathematics (STEM) education across Africa has been shaped by colonial legacies that privilege Eurocentric knowledge systems and pedagogies. This paper argues that centering African Knowledge Systems and sustainable practices within STEM curricula can transform learning into a culturally resonant, socially just, and environmentally responsible endeavor. Using a conceptual and comparative approach, and drawing on cases from Zambia, South Africa, Uganda, and Zimbabwe, the paper examines policy frameworks, classroom practices, and teacher readiness. It highlights how traditional agricultural science, indigenous engineering, and local ecological knowledge can be mobilized to enrich STEM learning. A framework for decolonizing STEM is proposed, emphasizing epistemic pluralism, community partnership, teacher capacity, and sustainability orientation. Recommendations are offered for policymakers, teacher educators, and curriculum developers. The paper contributes to ongoing debates about knowledge sovereignty, curricular justice, and the role of STEM in advancing the Sustainable Development Goals (SDGs) in Africa.

Keywords: Decolonization, STEM education, African Knowledge Systems, sustainability, Zambia

1. Introduction

African nations have expanded science, technology, engineering and mathematics education since independence to foster innovation and socio-economic development. Yet most science, technology, engineering and mathematics curricula remain modelled on colonial frameworks that transmit Western knowledge without adaptation to local realities. This mismatch limits learners' engagement, discourages context-specific innovation, and marginalizes African epistemologies.

Zambia's current secondary school science syllabus, for instance, is rich in global content but light on local agricultural and environmental practices familiar to learners in rural districts. Similar patterns exist across the continent. At the same time, African communities possess rich reservoirs of scientific knowledge in soil management, medicinal plants, hydrology, architecture, and energy conservation that are rarely formalized in classrooms.

This paper explores how to decolonize STEM curricula by integrating African knowledge systems and sustainable practices. Specifically, it seeks to (1) analyse how colonial legacies shape STEM education, (2) present African examples of indigenous knowledge integration, and (3) propose a framework for curriculum transformation aligned with the SDGs.

2. Literature Review and Theoretical Framework

2.1 Colonial Legacy and Curriculum Gaps

Scholars such as Le Grange (2016) and Odora Hoppers (2002) show how colonial education systems exported Western epistemologies to African classrooms, treating local knowledge as peripheral. Standardized examinations reinforce this bias, discouraging teachers from contextualizing content.

2.2 African Knowledge Systems and Sustainability

African knowledge systems include cumulative local expertise in agriculture, environmental stewardship, engineering, and health. They are often holistic, relational, and sustainable. UNESCO (2019) and the African Union's Continental Education Strategy (CESA 2016–2025) both advocate integration of indigenous knowledge for relevance and sustainability.

2.3 Theoretical Lenses

Decolonial theory urges dismantling epistemic hierarchies; culturally responsive pedagogy emphasizes aligning teaching with learners' sociocultural backgrounds; and education for sustainable development (ESD) connects learning to ecological and social responsibility. These three lenses provide a basis for curriculum transformation.

3. Methodological Approach

This paper uses a qualitative, conceptual approach supported by documentary analysis and secondary data. We reviewed:

- i. National curriculum documents in Zambia, South Africa, Uganda, and Zimbabwe;
- ii. Recent empirical studies on African knowledge systems integration in STEM classrooms;
- iii. Teacher training policy documents and pilot initiatives in culturally responsive STEM education.

Cases were selected for geographical diversity, policy context, and evidence of indigenous knowledge integration.

4. Findings: Illustrative Cases

4.1 Zambia: Local Agriculture and Water Management

Although Zambia's science syllabus lists "environmental conservation" as a theme, it rarely names indigenous soil and water conservation methods. Yet communities in Southern Province use planting basins, contour ridges, and traditional weather prediction based on animal behavior. These could be used to teach concepts in soil science, meteorology, and climate change adaptation, making lessons more authentic for learners.

4.2 South Africa: Mathematics through Cultural Artifacts

A study in the Eastern Cape showed how teachers used local beadwork patterns and indigenous games to teach geometry and probability. Learners displayed greater problem-solving ability and enthusiasm than in traditional lessons (Gula & Jojob, 2024).

4.3 Uganda: Indigenous Materials and ICT in STEM

In the Rwenzori region, teachers combined indigenous materials (local plants for experiments, traditional measuring tools) with ICT to demonstrate scientific principles. Professional development improved teacher confidence, though infrastructure constraints remained (Ndungo et al., 2025).

4.4 Zimbabwe: Indigenous Agricultural Knowledge Systems

Analysis of the agriculture syllabus revealed partial inclusion of indigenous seed selection and pest control methods but little recognition of local climate indicators or agro-forestry practices (Pedzisai, 2020). Integrating these practices would enhance relevance and sustainability.

5. Discussion

The cases show that integration of African knowledge systems is possible and beneficial but inconsistent. Key insights include:

- i. Teacher capacity is decisive. Teachers need both content knowledge of African knowledge systems and pedagogical strategies for integration.
- ii. Policy support legitimizes local knowledge. Where national curricula or teacher standards explicitly mention African knowledge systems, teachers feel empowered to innovate.
- iii. Community partnership enriches STEM. Elders, artisans, and farmers can co-teach, provide materials, and contextualize concepts.
- iv. Sustainability is strengthened. Lessons based on local conservation practices connect learners to environmental ethics and climate adaptation.

However, obstacles persist: rigid examination systems, limited culturally relevant resources, lack of training, and language barriers (many African knowledge systems are embedded in indigenous languages). Without addressing these constraints, integration will remain ad hoc.

6. Towards a Framework for Decolonizing STEM Curricula

Drawing from literature and practice, we propose six interlocking components:

Component	Operationalization
Epistemic Pluralism	Treat African Knowledge Systems as valid knowledge, not anecdotes illustrating Western science.
Teacher Preparation	Embed African Knowledge Systems and culturally responsive pedagogy in pre-service and in-service training; provide resource kits.
Flexible Curriculum Design	Allow regional adaptation and local content selection within national standards.
Community Knowledge Partnerships	Develop structured mechanisms for elders and local experts to contribute to lessons.
Experiential Learning	Use fieldwork, school gardens, community labs, and local technologies as teaching sites.

Assessment Reform	Align examinations with problem-solving and contextual understanding rather than rote recall.
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This framework aligns with Zambia’s Vision 2030 and the SDGs, positioning STEM as a driver of sustainable, locally grounded development.

7. Conclusion

Science, technology, engineering and mathematics curricula in Africa need not be a mirror of foreign epistemologies. By centering African knowledge systems and sustainable practices, educators can cultivate scientifically literate, culturally rooted, and environmentally conscious graduates capable of innovating for local and global challenges. The proposed framework offers a roadmap for policymakers, teacher educators, and curriculum developers to actualize this vision.

8. Recommendations

1. Policy makers: Mandate African Knowledge Systems integration in syllabi and allocate funds for teacher training and resource development.
2. Teacher training institutions: Develop modules on indigenous knowledge, sustainability, and culturally responsive STEM pedagogy.
3. Schools: Establish partnerships with local communities and knowledge holders; pilot place-based STEM projects.
4. Assessment bodies: Redesign examinations to value contextual problem-solving and indigenous knowledge application.
5. Researchers: Conduct longitudinal studies on learning outcomes of decolonized STEM curricula; develop metrics for African Knowledge Systems integration.

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Article 6

Leveraging Technological Innovations to Overcome Shortage of Laboratory Facilities for teaching and Learning Mathematics and Science in Rwandan Secondary Schools

Faustin Nduwayezu¹, Ezechiel Nsabayezi¹, Jeannette Muterampundu¹, Pheneas Nkundabakura²,
Theophile Nsengimana², Eugenie Uwamariya³

nfaustinhoo@gmail.com

¹African Centre of Excellence for Innovative Teaching and Learning Mathematics and Science (ACEITLMS), University of Rwanda-College of Education (UR-CE), Kayonza, Rwanda

²University of Rwanda-College of Education (UR-CE), Kayonza, Rwanda

³Rwanda Basic Education Board, Kigali, Rwanda

Abstract

Practical laboratory experience plays a vital role in developing learners' conceptual understanding and scientific reasoning in Mathematics and Science education. However, many Rwandan secondary schools face persistent challenges in establishing and sustaining fully equipped laboratories due to financial and infrastructural constraints. To address this gap, the 30 Virtual Mathematics and Science Laboratories (VMSLs) were developed by University of Rwanda-College of Education (UR-CE) in partnership with Rwanda Basic Education Board. These tools complement the PhET interactive simulations in offering an innovative and cost-effective solution by simulating real experiments and enhancing experiential learning opportunities. This study, framed within a Design-Based Research methodology, investigated teachers' and learners' perceptions, participation, and engagement with VMSLs in Rwandan secondary schools. These education tools were embedded into structured lessons aligned with Rwanda's Competence-Based Curriculum (CBC). For capturing both quantitative and qualitative data on the implementation of these tools, data were collected from 200 students and 8 teachers by using Likert-scale questionnaires, semi-structured interviews, and classroom observations. Findings revealed overwhelmingly positive perceptions among teachers and learners. Majority of students (93%) and

teachers reported that VMSLs improve lesson clarity, foster learner-centered participation, and enhance engagement at behavioral, emotional, and cognitive levels. Challenges like limited ICT infrastructure, varying levels of teacher readiness, and technical disruptions were identified. However, participants expressed optimism about overcoming these barriers. The study recommends strategic investment in digital infrastructure, continuous professional development for teachers, and policies to ensure equitable access. Overall, VMSLs present a transformative pathway for modernizing STEM education in Rwanda and similar resource-constrained contexts.

Keywords: Virtual Mathematics and Science Laboratories, STEM education, Competence-Based Curriculum, perceptions, engagement, Rwanda.

Introduction

Practical laboratory experiences are foundational to developing scientific reasoning and conceptual understanding in Science, Technology, Engineering, and Mathematics (STEM) education. Laboratories offer learners opportunities to observe, manipulate, and apply theoretical concepts, fostering inquiry-based learning and creativity. However, many Rwandan secondary schools struggle to establish and maintain adequately equipped laboratories due to limited financial and infrastructural capacity.

The Rwandan government has prioritized STEM education through its Competence-Based Curriculum (CBC), aiming to nurture problem-solving, innovation, and technological literacy. Yet, implementation has been hindered by inadequate laboratory facilities, particularly in rural schools. To bridge this gap, the University of Rwanda–College of Education (UR-CE), in partnership with the Rwanda Basic Education Board (REB), developed 30 Virtual Mathematics and Science Laboratories (VMSLs) digital tools designed to simulate real experiments and provide interactive, cost-effective alternatives to physical laboratories.

Research objectives:

1. To explore the teachers and learners' perception on the use of Virtual Mathematics and Science Laboratories (VMSLs) in enhancing the teaching and learning Mathematics and Science in the Rwandan secondary schools
2. To determine the level of teachers' and learners' participation and engagement when integrating the VMSLs into Competence-Based Curriculum Lessons
3. To examine the challenges and enabling conditions influencing the effective implementation of VMSLs in resources-constrained secondary schools' environments.

Literature Review

The role of laboratory work in science and mathematics education

Laboratory activities have long been regarded as vital in promoting experiential learning, problem-solving skills, and scientific reasoning (Hofstein & Lunetta, 2004). In mathematics and science, virtual manipulatives enhance conceptual understanding and abstract reasoning (Moyer-Packenham & Westenskow, 2013). Through laboratory experiments, students plan investigations, use scientific reasoning, manipulate equipment, record data, analyze, present and discuss their findings, and come up with conclusions (Sahim & Sasmaz, 2022). The critical thinking, analytical, and problem solving skills are also developed through laboratory experiments (Malik & Setiawan, 2016).

Laboratory experiments encourage students' curiosity through the discoveries then use facts for building concepts, theories, and laws. They also train them to think creatively, critically, analytically, and having the divergent ideas towards any given biological phenomenon (Suryanda, Rusdi, & Kusumawati, 2017). Different laboratory experiment approaches including the real, virtual and blended laboratory experiments could be used in carrying out scientific experiments. In real laboratory experiments (RLE), students get opportunities of interacting with physical materials that help them to develop the motor skills through the hands on activities (Zacharias & Georgios, 2011). Through real laboratory experiments, students are involved in handling laboratory materials and experimenting practices that promote critical thinking and problem-solving skills which are important in the 21st century. However, different difficulties were identified in using real laboratory experiments. These include the expensive equipment and materials, dangerous nature of some chemicals, as well as difficulties in observing some complex phenomena (Scalise, Timms, Moorjani, Clark, Holtermann & Irvin, 2011).

Technological innovations in STEM education

Various studies advocate the use of virtual laboratory experiments as an alternate approach of responding to the laboratory material deficit. Virtual laboratories are computer-based platforms that replicate traditional physical lab experiments through simulations, animations, and interactive tools (Aljuhani et al., 2018). They give students the opportunity to undertake experiments that might otherwise be difficult owing to financial, safety, or logistical limitations. According to

Alneyadi (2019), virtual labs promote active learning by allowing students to alter variables and see real-time scientific processes. Virtual laboratories offer an interactive and cost-effective way to perform experiments in schools with limited resources (Nyiramukama, 2024). According to Dođru et al. (2023), interactive movies greatly improve science learning outcomes. They are used to supplement hands-on activities by carrying out laboratory experiments that would otherwise be impossible due to a lack of laboratory materials. They are also employed during laboratory preparation sessions to ensure that the actual laboratory investigations are effective (Ma'arop, 2016). Digital technologies like Virtual Labs, PhET Simulations, and Augmented Reality tools provide scalable alternatives to traditional laboratories. According to research, virtual experiments can provide learning outcomes that are equivalent to, if not better than, those obtained from physical trials.

For responding to the shortage of laboratory materials, different studies recommend the use of virtual laboratory experiments as alternative means. The virtual laboratories are computer-based platforms replicating the traditional physical lab experiments using simulations, animations, and interactive tools (Aljuhani, Sonbul, Althabiti, & Meccawy, 2018). They provide students with opportunities to conduct experiments that may otherwise be difficult due to financial, safety, or logistical constraints. According to Alneyadi, (2019) virtual labs foster active learning by allowing students to manipulate variables and observe real-time scientific processes. Virtual laboratories provide an interactive and cost-effective method for conducting experiments in schools with limited resources (Nyiramukama, 2024). Dođru, et al., (2023) states that interactive videos significantly contributed to the overall learning in science. They are used in complementing the hands-on activities experiments through the performance of some laboratory experiments that are not possible due to the shortage of laboratory materials. They are also used in laboratory preparation sessions so that the real laboratory experiments be effective (Ma'arop, 2016). Digital technologies such as Virtual Labs, PhET Simulations, and Augmented Reality tools offer scalable alternatives to traditional labs. Research suggests that virtual experiments can produce learning outcomes comparable to or even surpassing physical experiments (Zacharia & Olympiou, 2011). Virtual experiments have been found to enhance scientific inquiry abilities and conceptual understanding. According to a study by Gambari et al. (2018), instruction based in virtual labs encourages students' engagement and enthusiasm for their studies. According to the study, students can enhance their practical skills by using virtual laboratories to handle materials and equipment,

collect data, and conduct interactive experiments. Additionally, it enables students to carry out experiments that were thought to be challenging in actual labs (Nicol, Gakuba & Habinshuti, 2022). Furthermore, studies show that using virtual labs allows students to conduct scientific investigations in a variety of settings, which can increase authenticity and stimulate their interest in pursuing professions in science (Falode, 2018). The results demonstrated that an animation-based learning module in biology successfully promoted conceptual comprehension of meiosis, which may help students learn outside of the classroom (Goff et al., 2017).

According to Uwitonze and Nizeyimana (2022), virtual laboratory experiments provide several advantages for science education, such as improving students' conceptual comprehension and making laboratory experiments more accessible and affordable. Additionally, they boost students' critical thinking and analytical abilities (Wolf, 2009) and encourage their enthusiasm and involvement (Nyiramukama, 2024, Byukusenge, Nsanganuwmana & Tarmo, 2023). According to Niyigena & Nzabalarwa's (2022) study, pupils who participated in computer simulations showed superior conceptual retention in biology compared to those who only learned from textbooks.

In a similar vein, virtual labs offer another way to reduce expenses related to laboratory supplies, equipment, and upkeep (Tüysüz, 2010). Given the dearth of fully functional science labs in low-resource environments like Rwandan schools, this could be a significant answer (Byukusenge et al., 2022). Additionally, these platforms facilitate self-paced learning by enabling students to conduct experiments at any time and location (Alkhaldi et al., 2016). According to (Azizah & Aloysius, 2021), students who used virtual biology labs showed greater enthusiasm and interest in science subjects than those who used traditional physical laboratories, which helped to boost the students' engagement and motivation. With this method, some studies are carried out as games that enhance the learning process.

The science education in the Rwandan context

Rwanda's CBC promotes learner-centered pedagogy and technology-enhanced learning (REB, 2015). However, disparities in infrastructure and teacher ICT readiness remain challenges (Twizeyimana, 2021). The VMSL initiative aims to align with CBC goals by integrating simulation-based inquiry into regular classroom practice.

To enhance the teaching and learning process, several modifications were implemented in the Rwandan educational system. As stated in the Competence Based Curriculum (CBC), the most

recent change was the application of a learner-centered approach to enhance teaching and learning (REB, 2015). However, it was claimed that the CBC was not successfully applied in the teaching of biology in many lower secondary schools (Bizimana, Mutangana & Mwesigye, 2023). In Rwandan secondary schools, biology instruction was primarily teacher-centered (Ndikumana, Mugabo & Nsabimana, 2024). The scarcity of teaching and learning resources (Mbonimpaye, Nsengimana, & Nsengimana, 2021) and laboratory materials (Mukagihana et al., 2021) was found to be linked to the predominance of teacher-centered biology instruction.

In the journey of providing alternative solution, the RQBEHCD project developed virtual biology laboratory tools for helping both teachers and students in teaching and learning genetics among other Biology topics. After developing and using this resource, a survey-based research was used to evaluate the effectiveness of this tool in enhancing the conceptual understanding and how it increases students' motivation in their learning genetics.

Research methodology

Research design

This research used a survey-based research approach with sequential explanatory research design where teachers and students were asked to fill the questionnaires on how the VMSLs is used in teaching and learning mathematics and science. Classroom observation was also conducted to assess how developed VMSLs were explored by students, how teachers facilitated students in performing different virtual experiments and the challenges faced while exploring these tools. Furthermore, an interview was conducted with some randomly selected mathematics and science teachers for having more insights on the usability of VMSLs, challenges faced while using these tools and their recommendations for its effective use. In this research, both quantitative and qualitative data were collected to be complemented. The approach of collecting both qualitative and quantitative data is based on fact that only one type of data cannot provide opportunities of exploring all information needed (Creswell, 2014, p30-31).

Data collection tools

Different data collection tools were used to obtain data related to the use of VMSLs experiments in teaching different topics from different mathematics and science topics. Among these data collection tools include, Likert scale questionnaire, classroom observation checklist, and semi-structured interview protocol.

Likert scale questionnaire

A Likert scale questionnaire was used to collect data related to the teachers and students' perception on the use of VMSLs in enhancing the teaching and learning mathematics and science in the Rwandan secondary schools. This Likert scale questionnaire consisted of 15 items arranged in two sections (see annex 1). The first section consists of 7 items exploring how the VMSLs was pedagogically effective in teaching and learning mathematics and science while the second one consists of 8 questions on students' attitudes towards the use of VMSLs in learning Mathematics and science. The Likert scale questionnaire was also used to evaluate the challenges and enabling conditions for making use of these innovative tools effective. In collecting these data, the Kobo-Tool box was preferred as it was found to be easy collecting data, saving and managing the collected data. It is also good in collecting data of different formats like numerical and descriptive that was important in this research (Wayan, et al., 2020). On the other side, this tool provides students with freedom and privacy in responding as their teachers could not access the provided answers.

Classroom observation

For authenticity, the classroom observation was conducted by researcher to see how students were interacting with the VMSL tools. During this process, two virtual laboratory sessions (each of 80minutes) in each sampled school were observed to see how students were interacting with the tools, how they were motivated by performing laboratory activities planned and the challenges that might be faced by students in this regards. Two researchers in every laboratory session took note on everything observed during the process based on the observation protocol (see the table 1). Each observation protocol had 6 dimensions rated using a **5-point scale (1–5)** based on different pre-determined indicators (**1: Poor, 2: fair, 3: Good, 4: Very good, 5: Excellent**).

Table 1: VMSL experiment observation protocol

Dimension	Description	Example Indicators
Teacher Participation	Degree of teacher involvement in VMSL activity	Provides guidance, interacts with students, demonstrates lab tasks
Learner Engagement	Active participation of students	Asking questions, doing tasks, collaborating

Dimension	Description	Example Indicators
Use of VMSL Tools	Extent to which virtual labs were used effectively	Frequency and purpose of use
Collaboration and Interaction	Student–student and teacher–student collaboration	Group work, peer discussion
Classroom Management	Effective organization during virtual activities	Handling transitions, maintaining attention
Lesson Alignment	Integration of VMSL with competence-based curriculum goals	Activities aligned with CBC learning outcomes

Semi-structured interview protocol

The semi-structured interview with teachers was used to collect data from mathematics and science teachers on how the VMSLs were effective in improving Mathematics and science teaching, challenges in using these tools and the enabling factors for their effective use. This semi-structured interview was conducted with 8 purposefully selected mathematics and science teachers from 8 schools to provide their feedbacks on how the VMSLs tool were effective in teaching and learning mathematics and science, challenges faced in the use of these tools, and their views on how the tool could be effectively used in the teaching and learning mathematics and science.

Validity and reliability of data collection tools

Before being administered, the face and content validity of the research questionnaires were evaluated by the research experts from the University of Rwanda College of Education (URCE). Within this context, the staff from URCE evaluated each asked question to see if it is linked with the Rwandan competence based curriculum and integration of ICT in education. The reliability of questionnaire was also evaluated through the Cronbach Alpha test ($\alpha=.83$) as presented in the table below.

Table 2. Internal consistence of data collection tool

Sub-Dimension	Number of Items	Cronbach's Alpha (α)	Interpretation
Teachers and learners' perception on the use of Virtual Mathematics and Science Laboratories	7	0.8	Good reliability

Sub-Dimension	Number of Items	Cronbach's Alpha (α)	Interpretation
(VMSLs) in enhancing the teaching and learning Mathematics and Science in the Rwandan secondary schools			
The level of teachers' and learners' participation and engagement when integrating the VMSLs into Competence-Based Curriculum Lessons	4	0.91	Good reliability
The challenges and enabling conditions influencing the effective implementation of VMSLs in resources-constrained secondary schools' environments.	10	0.8	Good reliability
Average	21	.83	Acceptable reliability

Based on the findings in the table 2, the research questionnaire was effective ($\alpha=.83$) for data collection

Research participants and data collection procedure

During this research both teachers and students were involved in different activities related to the use of VMSL in the teaching mathematics and science. Data were collected from 200 ordinary level students and 8 teachers purposively selected from different schools in 4 districts. The schools were selected from 4 rural districts in the 4 provinces on the fact that they had teachers who were trained and used the developed VMSLs for teaching and learning mathematics and science. They have been selected from the rural schools as most of these schools present the shortage of laboratory facilities. After being trained on the use of VMSLs in the teaching and learning different topics in mathematics and science, then they were requested to go in their home schools for using these tools.

Availability of virtual mathematics and science laboratory experiments

Students in senior two and senior three were provided with the link (<https://csmis.reb.rw/vsl/>) available from the Rwanda Basic Education Board (REB) platform. This link contains the VMSLs (mathematics, biology, chemistry and physics) developed by University of Rwanda-College of Education experts through the RQBEHCD project, evaluated and validated by REB. On the other side, other VMSLs are available from the PhET platform (<https://phet.colorado.edu>). For exploring the VMSLs, students were guided on how to access the experiments from different platforms and how to explore different materials and protocols for each experiment.



Figure1. VMSLs available from the REB and PhET platforms

Data analysis

After collecting the required data, they were analyzed by using both excel 16 and python software. From these data, percentage, mean and standard deviation of teachers and students were computed respectively. On the other side, data on classroom observation for students' motivation and engagement was analyzed and findings presented in the table of the percentage and explanation of observed indicators. Response from interview with selected mathematics and science teachers were also thematically analyzed for complementing quantitative data to get more insight on the perception of students on the effectiveness of VMSLs in teaching and learning mathematics and science as well as the challenges encountered during the use of these tools.

Ethical issues consideration

Before all activities related to this program, approval letters were obtained from the research committee of the University of Rwanda-College of Education. The permission of carrying out the training was also abstained from Ministry of Education through the Rwanda Basic Education Board and Districts Director Education (DDEs) from the districts with the schools under which the research was conducted. Before data collection, both teachers and students were explained that participation was voluntary and no effect will be resulted from refusing or withdrawing from the participation. They were also explained that the provided answers were private and they should not be accessed by unauthorized personnel.

Research findings

Teachers and students' perception on the effectiveness of VMSLs in the teaching and learning mathematics and science

During this research, both teachers and students were asked on the effectiveness of the VMSLs, and how they were effective in promoting the effective teaching and learning mathematics and science. The findings are presented in the table 3 below.

Table 3. Effectiveness of VMSLs

Theme	Teachers		Learners	
	Mean	SD	Mean	SD
Usefulness	3.936	.803	3.046	.809
Ease of Use	3.516	.816	3.706	.772
Pedagogical Impact	3.058	.77	3.987	.848
Motivation	3.64	.853	3.829	.845
Average	3.5	.81	3.6	.82

Based on the findings presented in the table 3, teachers were generally found to have a less average mean (3.5) compared to the learners (3.6). This shows that students have more positive perception on the importance of VMSLs in their learning compared to their teachers. Within this context, students show higher positive perception in ease to use (3.706), pedagogical impact (3.9), and motivation

aspect (3.8) of the VMSLs. On the other side, teachers showed the higher positive perception in usefulness of VMSLs (3.9), motivation aspect (3.6), and ease to use (3.5).

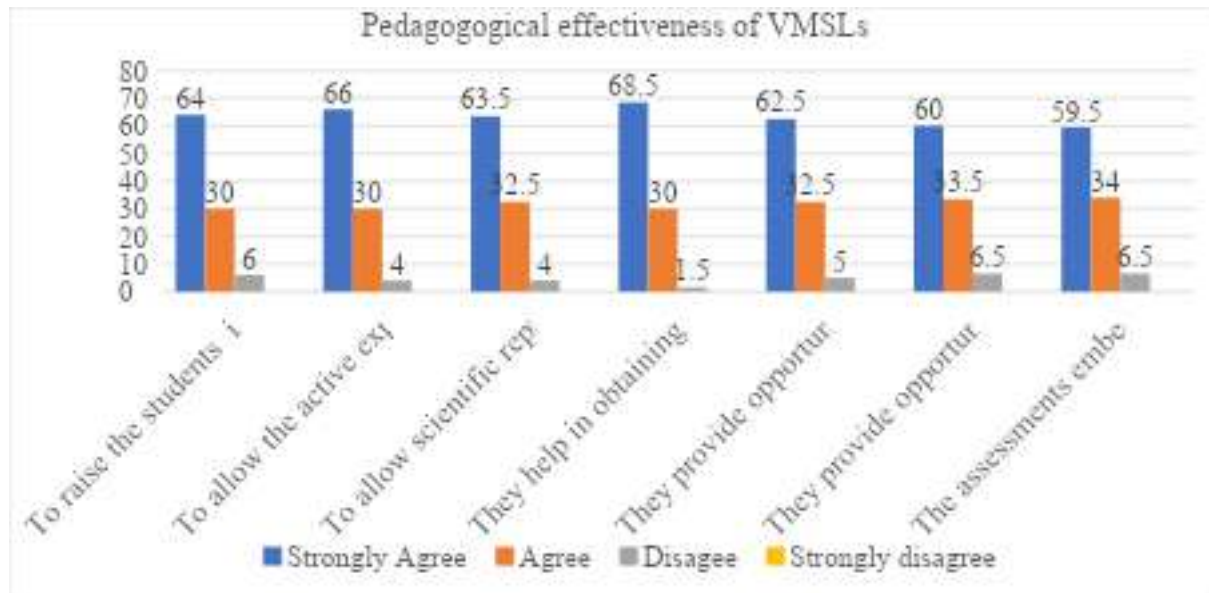


Figure 2. Effectiveness of VMSLs in the teaching and learning mathematics and science

From the graph, it is evident that the VMSLs were highly effective in providing the accurate information to support the presented concepts in mathematics and science (98.5 %) and in allowing the active exploration of mathematics and science concepts (96%). On the other side, the results presented in the *figure 2* showed that majority (94%) of students acknowledged that VMSLs raise students' curiosity to learn mathematics and science while 95% agreed that the VMSLs are effective for providing opportunity of applying the concepts from mathematics and science in forming and testing new hypothesis. The effectiveness of these innovative tools could be the catalyst for positive attitudes of teachers on adopting and using them in teaching and learning process. The findings on teachers' attitudes towards the use of VMSLs are presented in the figure 3 below.

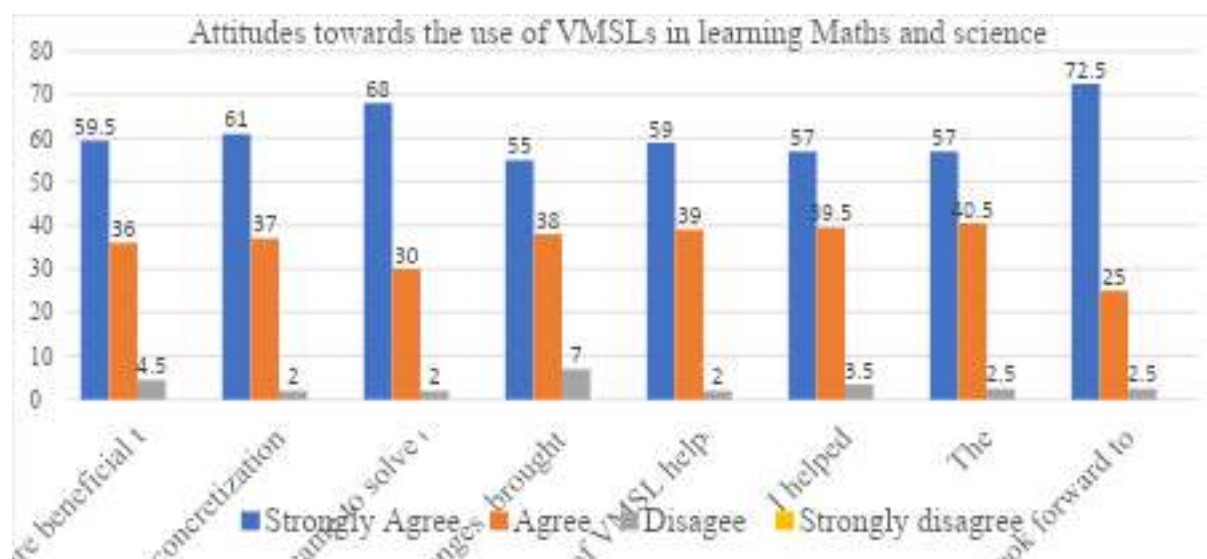


Figure 3. Teachers' attitudes on using VMSLs

Based on the findings presented in the figure 3, more than half of the respondents (students) strongly agreed that VMSLs are beneficial with the highest agreement in most of statements used like supporting that used the VMSLs in their learning activities (72.5% strongly agree and 25% agree), helped them to overcome learning challenges (68% strongly agree and 30% agree) and making mathematics and science concepts easier to concretize and explore (61% strongly agree and 37% agree). Similarly, 55% strongly agreed and 38% agreed that VMSLs enhance understanding through concept clarification and visualization while 57% strongly agree and 39.5% agreed that they help their classmates in using VMSLs.

Classroom observation

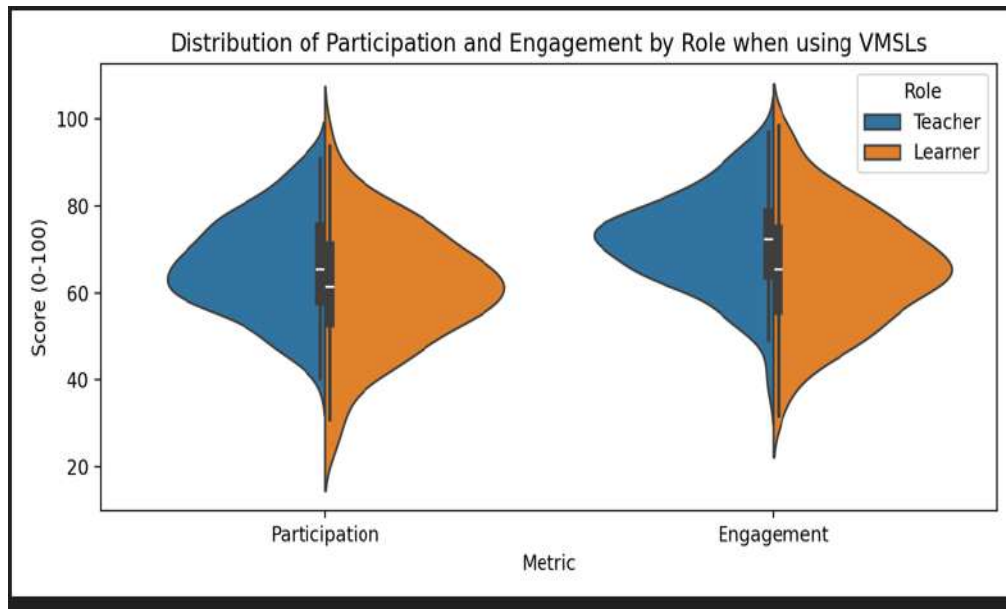


Figure 4. Level of teachers and students' participation and engagement during the use of VMSLs

Looking on the figure 4, the level of teachers and students' participation and engagement in using the VMSLs is significant (more than 60%). In this context, teachers tend to have slightly higher central tendencies for both participation and engagement, with moderately tight spread. This is highlighted by the mean (white line) of teacher which is in higher position compared to the position of mean in the students. Most of teachers are concentrated on the close position, showing that they have the close level of using VMSLs. On the other side, the learners exhibit broader dispersion, indicating more variability in how they participate and engage when VMSLs are used. Data presented in the figure 4, are resulted from the observation of different activities performed by teachers and students in planning and exploring the tools as presented in the table 4 below.

Table 4: Teachers and students use of VMSLs

Dimension	Level of implementation	Observed Indicators
Learner Engagement	93%	Most of students asked relevant questions, performed the provided tasks and collaborate each other
Teachers' Use of VMSL Tools	90%	Teachers use the tools appropriately and on the right topics

Dimension	Level of implementation	Observed Indicators
Students Collaboration and Interaction	88%	Most of students participated in the group discussion while exploring the VMSL platform
Teachers' Classroom Management	86%	Majority of teachers moved around different groups of students exploring the VMSLs for providing the extra-support
Lesson Alignment	95%	Teachers link the VMSLs activities with CBC learning outcomes
Average	90.4%	

Based on the findings presented in the table 4, the VMSLs were effectively used by both teachers and students (90.4%). Within this context, 93% were engaged in different activities of VMSLs, where most of them asked the important questions and performed different tasks planned in VMSLs. While looking on the alignment with the CBC, majority (95%) of observed teachers used different examples linking the VMSLs activities with the learner-centered approach. Moreover, 90% were observe using the VMSLs appropriately.

Challenges preventing the effective implementation of VMSLs in resource-constrained secondary school environments

Despite of VMSLs' importance, several barriers were highlighted as the challenges to the full implementation, particularly in schools with limited resources and infrastructure.

Table 5: The challenges in using the VMSLs for effective teaching and learning Mathematics and science

Challenge Category	Description	Frequency (%)
Limited ICT Infrastructure	Insufficient computers, unstable power supply, and weak internet connectivity.	68.5

Lack of Teacher Technical Skills	Some teachers lacked digital navigation and software integration skills.	61.0
Inadequate Training Opportunities	Few workshops and limited mentorship restricted confidence.	54.5
Time Constraints in Lesson Delivery	CBC lessons are time-limited, making simulation setup difficult.	47.0
Low Learner Digital Literacy	Many learners, especially in lower grades, lacked digital fluency.	42.5
Maintenance and Technical Support Issues	Schools lacked ICT technicians for troubleshooting systems.	38.0
Lack of administrative Support	Lack of encouragement from head teachers and time scheduling promoted VMSL use	48.0
Curriculum Alignment and Relevance	When VMSL activities are not aligned well with CBC competencies, engagement do not improve significantly.	67.0

Looking for the findings in the table 5, it is evidenced that different conditions are needed for making the use of VMSLs effective. Among the factors enabling the effective use of VMSLs in teaching and learning mathematics and science, the important ones include, curriculum alignment and relevance (67%), teachers' training and digital pedagogy (62.5%) and availability of ICT resources (54.5%).

Teacher opinions

During this research, mathematics and science teachers acknowledged that the VMSLs were effective in concretizing different mathematics and sciences concepts that are otherwise difficult to explain theoretically. When asked how these tools improved teaching and learning of mathematics and science subjects, teachers shared the following insights:

Teacher A stated: *“in the VMSLs, are important in teaching and learning mathematics and science by making some difficult content to be easy and understood. Like in Biology, the dominant, recessive and codominant alleles are simulated to show how they combine to produce organisms with dominant or codominant traits. This allows students to visualize and understand how organisms with different features arise. For example, we observed that the purple allele (for purple flower color) dominates over the white allele (for white flower color) producing only purple flowers in the F1 generation. In contrast, crossing chickens with white feathers) and black feathers resulted in codominance, where both colors appeared in the F1 generation”*. On the other side, the teacher B of physics, highlighted that VMSLs play an important role in teaching and learning linear motion. Teacher C added: *“Most students understood how to make translation and rotation of different geometrical figures by using VMSLs. By measuring and moving different points from one place to another, students understand more how to make a rotation and translation of an object.”* He emphasized that this approach also enhanced students’ interest and motivation in learning different mathematics and science concepts.

Discussion

The findings of this study showed that the use VMSLs is effective in enhancing the teaching and learning mathematics and science, particularly by concretizing abstract concepts. This aligns with the study of Byukusenge, Nsanganwimana & Tarmo (2023), which reported that the VSL can serve as an alternative solution to the shortage of physical laboratory facilities in Rwandan secondary schools. Similarly, the shortage of laboratory materials for teaching and learning mathematics and science in Rwanda was highlighted by Mbonimpaye, Nsengimana & Nsengimana (2021).

In this study, the majority of students (98.5%) acknowledged that the VMSLs was pedagogically effective in providing the accurate information to support the presented concepts in mathematics and science, confirmed that the tools were motivating particularly for topics usually taught theoretically in most schools. They also confirmed that these tools allow the active exploration of mathematics and

science concepts (96%) and raise students' curiosity to learn mathematics and science (94%). Supporting this, Teacher D stated: *"within the explored VMSL, different activities allow students to reflect on each process, which improves understanding and develops critical thinking, a key 21st century skill"*. These findings are consistent with the previous studies showing that animated-based learning enhance conceptual understanding in topics like meiosis (Goff et al., 2017).

The study also revealed the positive attitudes of students toward the use of VMSLs. About 97.6% of students reported that they used VMSLs in their learning activities, 98% confirmed that the VMSL helped them to overcome learning challenges while 93% agreed that VMSLs enhance mathematics and science understanding through concept clarification and visualization. To this end, 96.5% of selected students agreed that they help their classmates in using VMSLs.

During teachers' interviews, most educators emphasized that VMSLs fill gaps in laboratory resources and increase student motivation, allowing learners to work independently and at their own pace. Teacher F stated: *"VMSL are especially valuable when laboratory materials are scarce. Students can conduct experiments safely, learn independently, and perform experiments anywhere, anytime which provide flexibility in learning."* He added that could use these innovative tools to conducts different laboratory experiments and practices which are not possible in real laboratory setting.

Regardless of the positive impact of developed tools toward effective teaching and learning biology, some challenges were reported. Many teachers highlighted insufficient ICT skills among teachers and students (61%) as well as shortage of ICT infrastructure (68%) in some schools. The lack of adequate training opportunities was also highlighted (54.5%). Within this context, the teacher F explained: *"although the tool is effective for explaining different mathematics and sciences concepts, our school has only 25 computers for 100 students in year 3. This limits the effectiveness of ICT based teaching and learning, as one computer is shared by multiple students. Some students also need continuous support due to limited computer skills, and teachers may lack sufficient ICT experience too."* These challenges align with findings from Nyiramukama, (2024), which noted that limited ICT infrastructure and skills can hinder effective use of virtual laboratories both for students and teachers. Based on the shortage of computers, the Teacher G emphasized *the need more funds in ICT tools distribution for increasing the accessibility to students and investing in teacher's ICT related trainings.*

Conclusion and recommendation

This study explored the use of technological innovations to overcome the shortage of laboratory facilities for teaching and learning mathematics and science in Rwandan secondary schools. It evaluated the pedagogical effectiveness of the tools, as well as teachers and students' motivation and engagements in using these innovative tools. on teacher and student motivation. Additionally, the study examined the barriers to the effective use of these tools.

The findings revealed that majority of teachers and students appreciated the contribution of the VMSLs in improving teaching and learning of mathematics and science. Teachers reported that the VMSLs concretize complex mathematics and science concepts and phenomena, which are difficult or impossible to demonstrate through traditional teaching methods or real laboratory experiments. Both teachers and students indicated that the tool enhanced motivation toward learning genetics. However, some challenges were noted, including technical difficulties, limited computer availability in some schools, and inadequate ICT skills among certain teachers and students.

To increase accessibility of VMSLs, addressing the shortage of computers issues and investing in continuous professional developments for teachers on the use of ICT tools were recommended.

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Declaration of conflicting interests

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Nurturing Competence and Creativity in Large Early Learning Classes: Insights from Learning the Concept of Patterns in a Grade 1 Zambian Classroom

Lessly Malambo¹ and Chiponamaku Sakala²

lesslymalambo009@gmail.com, chiponamaku@gmail.com

Kazulabowa Primary School, Katete¹, Ministry of Education, Directorate of National Science
Centre, Lusaka²

Abstract

Large class sizes remain a persistent challenge in many Zambian early learning environments, limiting opportunities for creativity, exploration, and competence development. This study examined how a Grade 1 Creative and Technology Studies lesson on the concept of patterns was facilitated to promote engagement, collaboration, and creativity among learners in a double class of seventy-eight (78) pupils. A mixed methods action research design was used, enabling the teacher researcher to implement a learning sequence, observe learner responses, and refine practice. Qualitative observations and learner artefacts were analysed alongside simple quantitative participation measures. The results indicate that contextualised, hands on, and culturally relevant learning experiences supported by flexible outdoor learning spaces enabled learners to demonstrate high levels of pattern identification at seventy percent and moderate levels of independent creative pattern production at forty percent. The study offers practical guidance on how competence-based learning can be achieved in resource constrained and large class contexts.

1. Introduction

Zambia's Competence Based Curriculum seeks to promote learner centred, experiential, and collaborative approaches to classroom instruction. However, many teachers encounter difficulties when attempting to implement these pedagogical expectations in overcrowded and under resourced learning environments. Large class sizes, limited space, and inadequate teaching materials often constrain opportunities for creativity, exploration, and practical engagement among early grade learners. This study arose from a practical teaching situation in which a Grade 1 teacher was required to facilitate a competence based CTS lesson on patterns in a double class of seventy-eight learners. Despite the challenges associated with size and limited resources, the teacher sought innovative strategies for encouraging creativity, collaboration, and active participation. The study

therefore provides insights into how competence-based learning can be implemented authentically in real Zambian learning environments that fall short of ideal standards.

1.1. Purpose of the Study

The purpose of the study was to identify learner engagement strategies that promote creativity and collaboration in large class conditions; in order to inform how early grade teachers can facilitate competence-based learning within Zambia's Competence Based Curriculum.

2. Literature Review

Competence Based Education emphasises performance in authentic contexts through the integration of knowledge, skills, and values. Studies in early learning environments affirm that exploratory, tactile, and creative activities support learners in developing foundational competences that foster curiosity, reasoning, and imagination. The CTS learning area combines elements of craft, design, and technology, offering opportunities for young learners to create artefacts that reflect personal expression and practical problem solving. However, large class sizes present considerable instructional challenges, particularly in sub-Saharan Africa where staffing and infrastructure shortages are widespread. Research indicates that such conditions reduce opportunities for individualised feedback and meaningful learner teacher interaction. Nonetheless, several studies highlight that peer learning structures, the use of local materials, and flexible learning spaces can mitigate the effects of overcrowding. Social constructivist perspectives, particularly Vygotsky's theory of mediated learning, further argue that interaction among learners facilitates cognitive growth and shared construction of knowledge. The current study contributes context specific evidence on how creativity and competence can be nurtured within the constraints of large class teaching through practical and culturally grounded CTS tasks.

3. Methodology

This study employed a mixed methods action research design which enabled the teacher researcher to plan, implement, observe, and reflect on instructional practice in a real classroom setting. Action research was appropriate because it allowed the teacher to investigate pedagogical strategies while simultaneously improving the teaching and learning process. The study focused on a Grade 1 class comprising seventy-eight learners and one teacher who also served as the researcher. The class included twenty-five boys and fifty-three girls and represented a typical large class in a government school in Eastern Zambia. The learning activities were conducted outdoors in an open shaded area of the school due to limited space in the conventional classroom. This environment permitted freer movement, visibility of materials, and adequate interaction among learners. The outdoor space was used consistently from nine o'clock to ten fifteen hours during the three days of the learning sequence. Data collection involved systematic observation of learner behaviour and interaction, analysis of learner produced artefacts, and documentation of participation levels. The observations focused on indicators of engagement, collaboration, creativity, and competence demonstration. Artefacts were categorised based on type, material used, and number of learners involved. Descriptive statistics were used to summarise outcomes related to pattern identification and

creation, while qualitative data were analysed thematically to identify emerging instructional and behavioural patterns.

4. Results

4.1. Lesson Implementation

The CTS lesson on patterns was taught over three consecutive days. The first day focused on concept exploration as learners examined artefacts such as baskets, mats, traditional cloth, and hairstyles to identify repeating shapes and colours. The teacher demonstrated rope making using fibres, which helped learners to visualise repeated sequences. Learners displayed curiosity and asked questions about designs and repetitions. The second day emphasised preparation and inquiry. Learners identified materials available in their homes such as reeds, fibres, bottle lids, elastic bands, and paper. They engaged in group discussions to plan the types of patterns they intended to create. The activity promoted initiative and organisation as learners coordinated material sourcing. The third day involved practical creation and exhibition. Learners worked outdoors to produce ropes, reed mats, finger rings, wristbands, paper fans, and hair plaits. They later presented their artefacts and explained the logic of the patterns. The activity generated high levels of participation and excitement, with notable peer mentoring and creativity across groups. Table 1 indicates the CTS lesson on patterns taught over three consecutive days.

Table 1: CTS lesson on patterns taught over three consecutive days

Day	Focus of Learning	Key Activities	Engagement Indicators
Day 1 – Concept Exploration	Understanding the meaning of a <i>pattern</i>	Teacher used real artifacts (baskets, mats, chitenge, hairstyles) to illustrate repetition and design. Demonstrated rope-making using fibres. Learners observed and assisted.	Curiosity, questioning, observation of repeated shapes and colours.
Day 2 – Preparation and Inquiry	Material sourcing and idea generation	Learners discussed possible patterns, identified materials from home (reeds, fibres, bottle lids, paper), and planned group work.	Initiative, collaborative discussion, material organization.

Day 3 – Practical Creation and Display	Making and exhibiting simple patterns	Outdoor practical session: learners created ropes, reed mats, wristbands, paper fans, and plaits using local materials. Groups presented artifacts and explained pattern logic.	High participation, peer mentoring, creativity, joy in production.
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To further illustrate the high levels of learner engagement observed during the outdoor practical session, Figure 1 presents a visual example of learners collaboratively exploring and constructing patterned artefacts using locally available materials.



Figure 1: Learners engaged in outdoor activities

As part of the practical creation process, learners produced a range of artefacts using locally available materials. Table 2 presents the distribution of artefacts created by learners, highlighting the variety of outputs and levels of participation.

Table 2: Learner Output by Category

Category	Artifact Type	Materials Used	Number of Learners
1	Ropes	Fibres, plastic seals, strings	18
2	Reed mats	Reeds, threads	15
3	Finger rings	Plastic seals	11
4	Wristbands	Elastic bands, coloured lids	8
5	Paper fans	Paper sheets	7
6	Hair plaits	Threads, real hair	6
7	Observers only	–	6
8	Absent	–	7

4.2. Quantitative Findings

Quantitative analysis focused on two competence indicators: pattern identification and pattern creation. Seventy percent of the learners demonstrated competence in pattern identification, reflecting a strong understanding of repeated sequences when presented with familiar and culturally relevant artefacts. Forty percent of the learners successfully created their own patterned artefacts,

indicating emerging but still developing competence in independently applying the concept through practical tasks. Additionally, six learners remained observers during the practical session and seven were absent. These results are summarised in Table 3.

Table 3: Overall Competence Performance

Indicator	Percentage	Interpretation
Pattern identification	70%	Learners were able to recognise repeated designs from examples and artefacts.
Pattern creation	40%	Learners independently or collaboratively designed and produced their own unique patterns.

Seventy percent of the learners demonstrated competence in pattern identification, indicating a strong grasp of the concept. Forty percent successfully created their own patterned artefacts, showing emerging creativity and application of skills. Six learners remained observers during the practical session and seven were absent.

5. Discussion

The results of this study reveal several important insights into how competence and creativity can be meaningfully developed in large early-learning classes when instruction is grounded in contextualised, hands-on, and socially mediated activities. The high levels of engagement observed across the three-day CTS lesson indicate that class size alone does not determine learning quality; rather, the organisation of learning experiences, the relevance of materials, and the nature of teacher facilitation play decisive roles in shaping learner outcomes.



Figure 2: Teacher facilitation strategies

This finding aligns with Blatchford et al. (2011), who argue that while overcrowding can hinder individualised instruction, it does not inevitably result in diminished engagement when teachers adopt interactive pedagogical approaches. Teacher facilitation strategies were pivotal in transforming a potentially passive large class into a community of active learners.

The lesson structure itself demonstrates the value of experiential learning in supporting young learners' conceptual understanding. Kolb's (1984) experiential learning cycle is reflected within the progression from exploration (Day 1), to inquiry (Day 2), to practical creation (Day 3). The first day's activities, which required learners to examine familiar artefacts such as baskets, mats, and hairstyles, provided an immediate sensory and cultural entry point into the concept of patterns. This approach echoes UNESCO's (2015) emphasis on learning that emerges from culturally grounded experience, enabling children to connect new knowledge with their lived realities. By beginning with objects from the local environment, the teacher created what Mulenga and

Kabombwe (2019) describe as an “authentic learning context,” which is essential for competence-based education.

The second day’s focus on material sourcing and planning further supported competence development by shifting agency to the learners. Their active involvement in defining the materials, organising group roles, and envisioning potential outputs created space for ownership and collaboration. These behaviours align with Runco and Jaeger’s (2012) assertion that creativity thrives when learners exercise autonomy and engage in open-ended tasks. Even in a large class, the opportunity to generate ideas collectively enabled learners to refine their thinking through peer dialogue, demonstrating the collaborative nature of competence formation in early primary settings.

The third day, which centred on artefact creation and exhibition, provided explicit evidence of how social interaction mediates learning. Learners worked in groups, imitated peers, offered guidance, and demonstrated patterned logic through physical manipulation of materials. These behaviours reflect Vygotsky’s (1978) view that cognitive development is fundamentally social, occurring through guided participation and peer-supported activity. The distribution of artefacts in Table 2 confirms that learners were not passive recipients of instruction; rather, they actively engaged in producing creative outputs that required sequencing, reasoning, and symbolic interpretation.

The quantitative findings also deepen the interpretation of competence development. That seventy percent of learners achieved pattern identification suggests strong conceptual comprehension when learning is presented through culturally familiar and visually rich examples. Pattern identification relies heavily on recognition and observation, which aligns well with the exploratory tasks of Day 1. By contrast, only forty percent achieved pattern creation competence. This gap indicates that while learners could recognise patterns with relative ease, independently generating patterns required a higher level of cognitive integration, combining fine motor skills, planning, and creativity. This distinction reflects Akinyemi and Adeyinka’s (2022) observation that creativity in large classes is best developed through structured support, as learners benefit from modelling and scaffolding before they can fully internalise and reproduce complex concepts.

The presence of observers, who did not actively create artefacts, further underscores the role of differentiated facilitation in large-class settings. Such learners may require targeted questioning, extended modelling, or scaffolded roles to draw them into active participation. This finding aligns with the general caution noted by Blatchford et al. (2011) regarding the risk of disengagement in large groups when learners do not receive personalised support.

The outdoor learning environment itself appears to have been a critical enabler of competence development. By shifting the class outside, the teacher expanded physical space for movement and collaboration, mitigating one of the structural limitations associated with large class sizes. Outdoor learning not only fostered visibility and accessibility but also allowed learners to engage in tactile manipulation of materials in ways that would have been impractical in a crowded indoor classroom. This resonates with UNESCO’s (2015) recognition of flexible learning spaces as essential for early childhood pedagogy.

Overall, this demonstrates that competence-based learning in large early learning classes depends more on **instructional design**, **material relevance**, and **peer-supported processes** than on class size itself. When learners are provided with culturally meaningful artefacts, opportunities for exploration, and collaborative spaces for creation, they develop both conceptual understanding and creative competence. The findings therefore reinforce Mulenga and Kabombwe’s (2019) argument

that effective competence-based education must be grounded in practice-rich, participatory approaches rather than theoretical exposition alone

6. Conclusion

This study demonstrates that competence and creativity can be effectively nurtured even in large early-learning classes when instructional practices are deliberately structured to be experiential, contextualised, and socially mediated. The three-day CTS lesson on patterns revealed that learners responded positively to activities that integrated culturally familiar artefacts, collaborative problem solving, and hands-on creation. The high proportion of learners who achieved competence in pattern identification confirms that foundational understanding is strengthened when abstract concepts are anchored in authentic, relatable objects. Although fewer learners successfully created their own patterned artefacts, this outcome highlights the developmental complexity of creative production and underscores the need for structured scaffolding, guided modelling, and sustained peer interaction.

The findings reinforce theoretical perspectives from experiential learning and social constructivism, demonstrating that learning occurs most meaningfully when learners actively manipulate materials, observe demonstrations, engage in dialogue, and receive guided support from both teachers and peers. Outdoor learning spaces and flexible grouping strategies played a critical role in mitigating the challenges of a large class size, allowing learners to move, explore, and collaborate freely. At the same time, the presence of learners who remained observers suggests the continued need for differentiated facilitation to ensure that all learners benefit equitably from practical competence-based experiences.

Overall, the study supports the argument that competence-based education in Zambia can be successfully implemented under real-world constraints when teachers adopt innovative, context-sensitive approaches that prioritise participation, creativity, and hands-on engagement. These insights contribute to the growing body of evidence that large classes, while challenging, can still serve as productive environments for meaningful learning when instructional design is intentional and grounded in learner-centred pedagogy.

7. Recommendations

Teachers should make deliberate use of outdoor and flexible spaces to accommodate large CTS classes. Collaborative learning structures should be strengthened to enhance peer support and engagement. Continuous professional development should incorporate competence-based facilitation and action research methods. Additionally, schools should maintain resource collections of local and recyclable materials to support practical learning activities.

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Building a Teachers' Learning Platform for Fostering Reflective Practitioners: A Case Study of a Knowledge Co-Creation Programme in Zambia

Yumi Sekiguchi Maguchi

Japan International Cooperation Agency / Ministry of Education

Lusaka, Zambia

yumi.sekiguchi.1234@gmail.com

Abstract

In the past, teacher trainings conducted under international educational cooperation schemes placed little emphasis on each teacher's life experiences, his educational views on learners, or the individual belief as an educator. Cascade training, for example, offers the advantage of training large numbers of teachers in a short period and continues to be implemented worldwide. Zambia, the case study country in this research, also has implemented cascade trainings. However, it had faced some challenges. The termination of support from the international aid organizations made it difficult to continue the training, and the training contents were not effectively reflected in school settings. Consequently, from 2005, Zambia began pursuing a different approach to teacher training by introducing Lesson Study, aiming to enable teachers to recognise their own challenges, accept them, and become change agents for educational improvement. To share this insight—that collaborative Lesson Study promotes teaching improvement—within Africa, Zambia has been running Third-Country Training Programmes (TCTP) for African educators since 2016. From the beginning, these programmes have prioritized the process of trainees continuously reflecting and finding their own solutions, using “collaboration” and “co-creation” as key concepts. Therefore, this study focuses on the TCTP held in July 2025, and analyses its training process from perspectives of reflective practitioner theory and adult learning theory. Finally, it discusses the essence of teacher training that builds a collaborative learning platform enabling trainees to develop as reflective practitioners.

Keywords: Reflective practitioner, Adult learning theory, Collaboration

Sub-theme: 1. Decolonizing STEM Curricula: Centring African Knowledge Systems and Sustainable Practices.

1. Problem Statement

In the 1990s, the World Bank (1995) clearly mentioned the economic benefits of investing in education, heightening international interest in expanding educational access in developing countries. Since 2000, international educational cooperation has been significantly influenced by global trends such as the Millennium Development Goals (MDGs) and Sustainable Development Goals (SDGs) (Kuroda et al. 2019: 23). In 2018, the World Bank published the “World Development Report 2018”, sounding the alarm that millions of children remain unable to read, write, or perform basic arithmetic despite attending school for years. This fostered a trend in international educational cooperation focused on improving educational quality (World Bank 2018).

International educational cooperation represents approaches to improve education. Despite the fact that educational quality is influenced by the individual values (Yamada 2004: 3), critical examination of the nature of international educational cooperation itself from pedagogical or individual teacher's perspectives has been largely absent (Hashimoto 2021). For example, an educational method deemed effective in Country A is generalised to facilitate nationwide implementation across schools and then transferred to Country B using models and manuals (Ono 2019, Kishi 2021). In such cases, the training themes are often set around “how-to” style solutions for visible urgent challenges from the outside, such as promoting ICT education or inclusive education. Knowledge and techniques are transferred through cascade-style training, a method of information dissemination. The teaching methods and theories acquired through such training often achieve immediate results. Thus, teachers actively incorporate new approaches, and pupils become increasingly engaged in lessons. However, as the same teaching methods are repeated, the expected effects may diminish (Miwa 2023: 11-12, Aoyama et al. 2019: 129). Such training tends to overlook the complex and rich processes of education, treating it as if input automatically produces output (Kuroda 2023: 60). As a result, the policies lack reference to national or regional contexts. If the country names were removed, they would become indistinguishable from other countries' policies (Furukawa 2021: 193).

In Zambia, the introduction of Lesson Study – where teachers collaborate within schools or among peers to improve teaching – began in 2005 as one method of teacher training (Baba & Nakai 2009). At that time, Zambia faced challenges with its traditional cascade training model: the termination of donor support made continuing the training difficult, and high teacher turnover meant training content failed to take root in schools. Therefore, Zambia decided to develop a Zambian-style teacher training programme through introducing Lesson Study. In the Lesson Study, teachers were required to identify challenges, embrace them, and become change agents for educational improvement (Baba & Nakai 2009, JICA 2023a: 21-22, 29, JICA 2023b: 89-90). To share insights gained from such activities within Africa, Zambia has, with Japan International Cooperation Agency (JICA) support, been conducting TCTP for African educators since 2016 (NSC 2025a:3). The TCTP is a capacity development training programme conducted by a developing country

possessing comparative advantages in relevant knowledge and skills, inviting trainees from neighbouring developing countries (Ministry of Foreign Affairs 2011: 39-40). However, Zambia's TCTP is unique in that it involves not only trainees from neighbouring African countries, but also many Zambian teachers and educator participating as trainees (JICA 2023a: 46-47). This reflects the vision of the implementing agency, the National Science Centre (NSC), to create a platform for mutual learning rather than a vertical structure where Zambian trainers manage and instruct international trainees. It focuses on the process of solving problems through interaction among trainers and trainees by talking and listening together (JICA 2023b: 84-85, 96). Thus, the programme is called the "Knowledge Co-Creation Programme (KCCP)" rather than the TCTP, and will be referred to as KCCP throughout this paper.

In the field of teacher education, since the late 1980s, the importance of the abilities as reflective practitioner has been increasingly emphasised internationally. In other words, it involves teachers, within the complex and uncertain environment of the actual educational setting, formulating their own questions and advancing their inquiry and research through interaction with learners, colleagues, and others (Kaneko et al. 2022, Shon: 1984, Miwa 2023:25). In African educational research, while some studies emphasise the importance of teachers as reflective practitioners, there is limited research focusing on the process of teachers' growth as reflective practitioners within training programmes (Yebach, A. et al. 2024, Mpodu, J. 2013). Moreover, in Zambia, to the best of my knowledge, research examining the practical processes of INSET (in-service teacher training) from the perspective of adult learning theory is limited (Phiri, D. et al. 2023). Therefore, this paper examines how Zambia's KCCP functions as a learning platform for African educators to develop as reflective practitioners utilising adult learning theory.

2. Research Purpose and Research Questions

The purpose of this study is to examine the current state and challenges of conventional teacher training (cascade-type training, and short-term training conducted by JICA in Japan) within international educational cooperation from the perspective of reflective practitioner theory. Next, using the Zambia KCCP implemented in July 2025 as a case study, the study clarifies whether the KCCP functions as a learning platform that promotes educators' growth as reflective practitioners. To achieve this purpose, the following research questions are set.

【RQ1】 To clarify the characteristics of reflective practitioners and adult learning theory in teacher education, and establish analytical frameworks for the teacher trainings.

【RQ2】 To clarify the characteristics of the Zambia KCCP by analysing cascade training, JICA's short-term training and the Zambia KCCP from the perspective of reflective practitioner theory and adult learning theory.

【RQ3】 To examine what abilities the trainees demonstrated through the training by analysing the learning process of the Zambia KCCP.

3. Research Theories

This Chapter addresses “Research Question 1” by reviewing prior researches and establishing three analytical frameworks.

3-1. Reflective Practitioner Theory

It was once thought that teachers could be trained by obtaining universal knowledge concerning lesson design and teaching methods at higher educational institutions. However, following the publication of D. Schon's book “The Reflective Practitioner” in 1984, the field of teacher education gradually began to emphasize not merely technique, but also engaging in education proactively based on practice and reflection (Mishina 2024: 7). Schon termed those who applied such techniques to solve problems in school settings as “technical experts”, while referring to the latter as “reflective practitioners” (Schon 1984). Today, the theory of reflective practitioners has been adopted as the fundamental philosophy underpinning teacher education policy in many countries (Mishina 2024: 7, Sato 2011: 52). It is considered crucial to cultivate the abilities of teachers as reflective practitioners who, within the complex and intricate school environment, set their own questions and advance their inquiry and research through interactions with learners, colleagues, and others (Schon 1984, Miwa 2023: 25). This perspective is required not only of teachers, but also of those responsible for teacher training, such as university/college lecturers and Ministry of Education officials (Moriya 2022: 2). Figure 1 illustrates the difference in the roles of trainers between the technical expert model and the reflective practitioner model, under teacher training.

The technical experts observe the group of participating teachers (hereafter referred to as “trainees”) from a high hard ground, and partially understand the local situation of target area. They identify problems based on their observations, and make effective use of existing pedagogical methods to derive solutions. On the other hand, the reflective practitioners chose to place themselves alongside the trainees in a swampy lowland where the confusing situation arises. They seek to understand the complexity and ambiguity of the situation. They then set an appropriate problem and facilitate the trainees in finding solutions themselves. The trainers never become the principal party responsible for resolving problems (Miwa 2023).

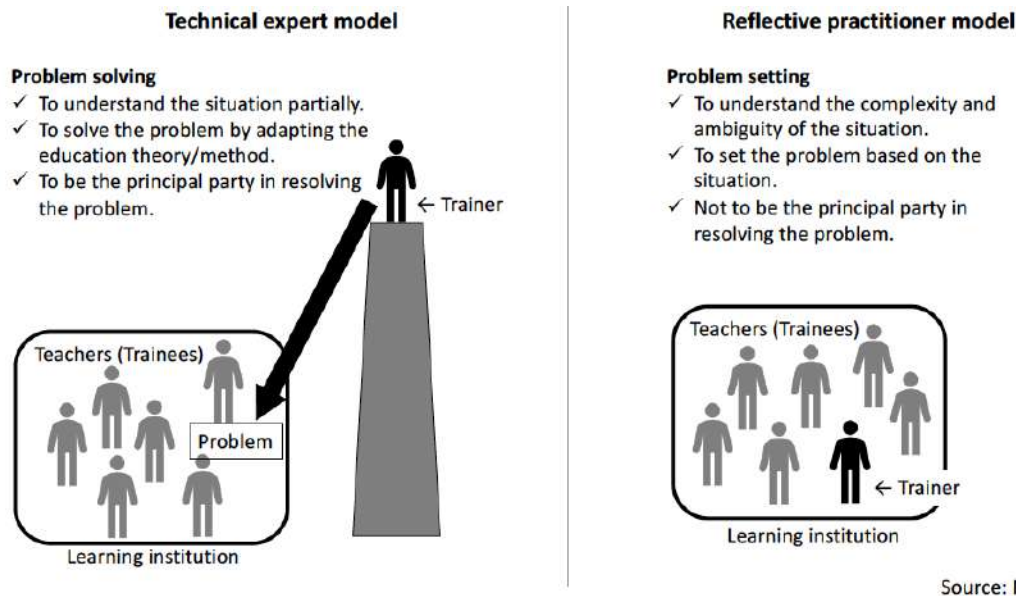


Figure 1. The difference in the roles of trainers between the technical expert model and the reflective practitioner model

3-2. Adult Learning Theory

The educational work is perpetually steeped in complexity and uncertainty; absolute knowledge or theory does not exist. So, teachers are required to be conscious of their own fixed frameworks, evolving and deepening their existing acquired knowledge within practical situations, and then to generate new knowledge (Kaneko et al. 2022: 401). In this way, teachers continue to learn about their professional work as adults. This adult learning is called “andragogy” and is distinguished from “pedagogy”, which deals with children's education (Miwa 2023: 33). The characteristics of adult learning are summarised in table 1. It addresses only the three elements covered in this study. (Knowles et al. 1998, Miwa 2023).

Table 1. Key Elements of Adult Learning Theory

Key elements of Adult Learning Theory	Descriptions
The trainee's self-concept and self-directed learning	The trainees are responsible for their own role. While demonstrating autonomy as teachers at the school environment, they tend to adopt a dependent stance as passive learners during teacher trainings. To foster self-directed learning, trainees must gradually develop their own learning practices. The trainers support trainees in gradually developing autonomy, enabling them to recognise their own learning needs and establish a cycle of learning.

The role of the trainee's experience	The trainees' life and teaching experiences have great importance and should be utilised as learning resources. The trainers have an attitude of learning from trainees' rich experiences and work collaboratively with trainees to select appropriate training methods. They can employ experiential methods such as discussion, problem-based learning, and field studies to support trainees in the process of making meaning of their own experiences.
Transformative learning	The trainees become aware of the somewhat narrow values and fixed thinking patterns they have developed during their lives, reflect on them, and acquire alternative cognitive frameworks. The trainers support the learning process so that trainees can recognize the fundamental beliefs and values underlying their own learning. This is to guide them towards learning that extends beyond mere problem-solving techniques. Specifically, they engage through questioning and inquiry rather than correction.

Source: Knowles et al. (1998), Miwa (2023)

3-3. Six Abilities of Human Relationship Specialists

There are professions termed “specialists” which possess advanced specialised knowledge and skills, public accountability, professional bodies, and training systems. Miwa et al. (2023) specifically distinguish those working in occupations centred on interpersonal relationships as “Human Relationship Specialists” (Imazu 2012: 54, Miwa 2023: 2-3). For example, teachers working with pupils, nurses engaging with patients, and NGO/NPO staff working with local community are all considered Human Relationship Specialists. Human Relationship Specialists must continue learning not only to acquire specialised knowledge and skills, but also to foster collaboration and cooperation with diverse stakeholders (Miwa 2023: 2, 8).

Miwa (2019, 2023: 9) developed upon the prior research of Imazu (2012), classifying the abilities of Human Relationship Specialists into six categories (see table 2). They are A) Problem-solving & clearance of tasks, B) Guidance and advice to students regarding specific subjects, C) School and classroom management, D) Interpersonal relationship, E) Improvement of educational beliefs, and F) Inquiring mind for personal growth.

In teacher education, abilities A to C are frequently found in the evaluation criteria for both PRESET (Pre-service teacher training) and INSET. This is because they are easy to acquire through “how-to” style workshops, and their outcomes are clearly observable. However, the direct application of these practical techniques and skills (A to C) within the school setting is merely the work of technical experts (Miwa 2023). Rather, what is required of the Human Relationship Specialists is to consider the meaning of relationship with pupils, colleagues and guardians (D), and their own educational beliefs as educational specialists (E). In addition, it is precisely because they possess an inquiring mind (F) that they can connect every opportunity – informal exchanges,

chance encounters, or other unexpected occurrences – to their own growth. On the other hand, if this inquiring mind (F) is neglected, there is a risk that all aspects from A to E may be compromised (Miwa 2019, 2023).

Table 2. Six Abilities of Human-Relationship-Specialists

Abilities	Definition	Remarks
A. Problem-solving & clearance of tasks	Problem-solving Skills within one's specialised field, and the skills to accomplish the various tasks assigned by institutions.	They are easy to acquire through “how-to” style workshops, and their outcomes are clearly observable. They are frequently found in the evaluation criteria of teacher education.
B. Guidance and advice to students regarding specific subjects	Knowledge and skills to give guidance and advice to students and colleagues.	
C. School and classroom management	Knowledge and skills to manage school and classroom as head teacher or classroom teacher.	
D. Interpersonal relationship	Communication skills to interact with pupils, colleagues and guardians.	It is difficult to observe and evaluate them from the outside. They form the foundation of the specialists' work.
E. Improvement of educational beliefs	Reflecting on and refining the educational beliefs and values. i.g., views on learners, views on teaching.	
F. Inquiring mind for personal growth	Inquiring mind as the fundamental source underpinning abilities A to E.	

Source: Miwa (2019, 2023)

4. Analytical Method

This study first employs the analytical frameworks for “the role of trainers” and “key elements of adult learning theory” outlined in Chapter 3 to compare cascade training, JICA short-term training, and the Zambia KCCP, thereby clarifying the features of each training design. For cascade training and JICA short-term training, the analysis is primarily done based on literature review; for the Zambia KCCP, it utilises the NSC implementation report and the JICA expert's report as sources.

Next, regarding the Zambia KCCP, a narrative analysis is conducted using the analytical framework of “Six abilities of Human Relationship Specialists”. This analysis is based on interview results with trainees and their statements during the training to examine what abilities the trainees demonstrated and developed.

5. Results and Discussion

5-1. Conventional Training Design

This section examines the cascade training model and JICA's short-term training programmes as the conventional training approaches, in response to “Research Question 2”.

5-1-1. Analysis Results

Firstly, the cascade training has been utilised worldwide as a practical method for introducing new subjects and new teaching methods nationwide, as it enables the training of numerous teachers within a short period (Ngeze et al. 2018, British Council 2018, Kawakami 2015). Here, efficiency is prioritised, with master trainers at the centre of the training. They identify common challenges across various settings, generalise solutions into models or manuals, and transfer this information to trainees. However, challenges are noted in this cascade-style transmission of information: Information often becomes diluted as it is passed down from each level to the next, and generalised teaching methods may not be suitable for specific individual problems encountered in the field (British Council 2018, Kishi 2021, etc.). Furthermore, the teaching methods recommended in training are often highly simplified and standardised (Ogisu 2013: 87-88), and do not necessarily correspond to the trainees' own life and professional experiences. Consequently, trainees frequently cannot utilise their own experiences as learning resources. As a result, trainees are required to faithfully carry out the tasks assigned by their trainers (Ogisu 2013: 88). This inevitably leads to passive learning and, in some cases, may result in the complete rejection of introduced methods when they conflict with the trainee's own educational values (Sekiguchi 2023).

Next, we shall examine the short-term training programmes conducted in Japan for educators from developing countries, which are one of JICA's technical cooperation schemes. These programmes aim to convey Japan's administrative systems, institutional frameworks, technologies, and development experience to developing countries, thereby supporting human resource development. In basic education trainings, the trainees are expected to learn the latest information, knowledge, and techniques from Japan through lectures by Japanese university faculty and government officials, as well as through lesson observation sessions conducted by Japanese school teachers. They are then expected to adapt and utilise these knowledge and skills within their local contexts (JICA 2009: 4-6). Trainees tend to seek immediate solutions for school settings or workplaces, and acquiring knowledge about new educational methods in such trainings align with their needs. However, challenges remain: trainees from countries with different social backgrounds and histories often find it difficult to understand the context underlying Japanese experiences and knowledge, or to directly apply what they have learn in Japan to their home countries (JICA 2009: 4-6).

5-1-2. Discussion

Both the cascade training and the JICA short-term training predominantly employ a vertical facilitation approach. Under this approach, the trainers identify issues and provide appropriate solutions, which trainees then receive and implement within their own workplaces (Baba & Nakai 2009: 110, Ogisu 2013). Here, the trainers act as “technical experts”, looking down from the high hard ground onto the school setting, generalising its challenges, and providing the trainees with several educational methods as solutions. The educational methods and theories acquired through such trainings may yield immediate results, but as the same teaching methods are repeated, they

may become unsuitable for specific individual problems in school environment, and gradually losing their effectiveness (Miwa 2023: 11-12, Aoyama et al. 2019: 129, British Council 2018). In such cases, the trainees must acquire new teaching methods through further training (Aoyama et al. 2019), making it difficult for them to develop autonomy and sustain self-directed learning.

5-2. New Training Design at the Zambia KCCP

This section examines the Zambia KCCP as the new training approach, in response to “Research Question 2”.

5-2-1. Overview of the Zambia KCCP

In response to the challenges with conventional training designs, Zambia has been exploring ways to build learning platforms through teacher training, with “collaboration” and “co-creation”. Rather than promoting exemplary Zambian educational practices as models, the Zambia KCCP presents ordinary Zambian schools and lessons as they are. It prioritises a process of “collaboration” and “co-creation”, where Zambian trainers, Zambian trainees and international trainees work together. Using Zambian schools as case studies, the trainees identify common educational challenges across Africa and jointly devise solutions.

The following outlines the KCCP implemented in July 2025.

1) Theme and Objectives of the KCCP 2025

In previous years, training tasks were given separately for each subject group. However, for the KCCP 2025, with the aim of having all subject teachers demonstrate their expertise and collaborate while recognising each other's strengths, the entire trainees worked together on a single task under the common theme of “developing STEM-focused learning environments”, as shown in table 3.

Table 3. Theme and Objectives of the KCCP 2025

Theme	Enhancing Understanding and Development of a Learning Environment: Accelerating STEM Learning Competences in Africa
Main objective	Enable trainees to understand, design, and develop STEM-focused learning environments while applying pedagogical strategies that foster competence acquisition among learners in African contexts.
Sub-Objectives	1. To understand and identify foundational learning environments that foster scientific literacy and STEM Education 2. To design and construct engaging STEM-focused learning spaces (especially for Hospitality and Agriculture STEM education) 3. To trial STEM learning environments in actual lesson settings

2) Activity Log of the KCCP 2025

At the KCCP, detailed programmes were not distributed; instead, the training programme was flexibly adjusted based on the trainees' progress. Consequently, table 4 shows the activity logs for

the KCCP conducted in July 2025, based on the JICA expert's report and photographic documentation.

Table 4. Activity Log of KCCP 2025

	Date	Timing stage	Activities		Date	Timing stage	Activities
Day 1	Jun-29	S	Arrival of KCCP participants, Orientation	Day 10	Jul-08	T	Sharing progress of each group
Day 2	Jun-30	M	Welcome remarks	Day 11	Jul-09	W	Planning the learning environment
			Report on activities after KCCP 2024 by each subject panel	Day 12	Jul-10	T	Constructing the learning environment
Day 3	Jul-01	T	School visits in Lusaka, Sharing impression of school visits	Day 13	Jul-11	F	Constructing the learning environment
			Presentation of pre-course assignment	Day 14	Jul-12	S	Constructing the learning environment
			Lecture 1 'Human thinking modes'	Day 15	Jul-13	S	Constructing the learning environment
			Sharing daily reflection	Day 16	Jul-14	M	Constructing the learning environment
Day 4	Jul-02	W	Lecture 2 'Generation divide'	Day 17	Jul-15	T	Constructing the learning environment
			Lecture 3 'Boxed education'	Day 18	Jul-16	W	Constructing the learning environment
			Lecture 4 'Learning environment for age 10-16'	Day 19	Jul-17	T	Constructing the learning environment
			NSC tour including ECE/primary learning environment	Day 20	Jul-18	F	Constructing the learning environment
Day 5	Jul-03	T	Brainstorming on planning of learning environment (group)	Day 21	Jul-19	S	Constructing the learning environment
			Planning the learning environment (group)	Day 22	Jul-20	S	Constructing the learning environment
Day 6	Jul-04	F	Sharing progress of each group	Day 23	Jul-21	M	Constructing the learning environment
			Planning the learning environment	Day 24	Jul-22	T	Constructing the learning environment
Day 7	Jul-05	S	Feedback from NSC	Day 25	Jul-23	W	Constructing the learning environment
Day 8	Jul-06	S	Planning the learning environment				Cleaning up the learning environment
Day 9	Jul-07	M	Lecture and Feedback from NSC	Day 26	Jul-24	T	Closing ceremony
			Planning the learning environment	Day 27	Jul-25	F	Report on the findings of the participants' daily reflections by the NSC director
				Day 28	Jul-26	S	Way-forward (The NSC had individual meetings with each country)
							Farewell party at the developed learning environment
							Departure of KCCP participants

*Trainees are required to fill in daily reflection on online LMP (Learning Management Platform)

3) Participants of the KCCP 2025

This training programme was an advanced course aimed at further developing the capacities of previous KCCP participants. In July, KCCP 2025 had 31 international trainees from 16 countries, and 47 participants from Zambia. The majority of them were school teachers, followed by teacher trainers, educational officials, college lecturers, and others. The breakdown by subject and specialised field is as follows.

Table 5. Number of KCCP Participants in July 2025

	Internationals		Zambian			Total
Upper Primary Level	Mathematics, Chemistry, Science, Design & Technology.	15	Mathematics, Chemistry, Agriculture	Biology, Physics, Science,	15	30
Secondary Level	Mathematics, Chemistry, Physics.	16	Computer Design & Technology, Home Economics & Hospitality.	Science,	32	48
Overall Total	31		47			78

Source: Administrative Report for 2025 Knowledge Co-Creation Programme Zambia (NSC 2025b)

5-2-2. Analysis Results

The training design of the Zambia KCCP was examined from the perspective of the trainer's role and adult learning theory. The analysis was divided into the following three sub-objectives.

Sub-Objective 1: To understand and identify foundational learning environments that foster scientific literacy and STEM Education

Sub-Objective 2: To design and construct engaging DTEM-focused learning spaces

Sub-Objective 3: To trial STEM learning environments in actual lesson settings

1) Results of Sub-Objective 1

In the 2025 training programme, the focus was on trainees identifying the real root of the problem, with nine days devoted to school visits and activity planning. Throughout this planning stage, the trainers continually posed questions designed to draw out insights rather than providing immediate answers. This approach ensured that all trainees recognised educational problems as their own personal issues and progressed to the next stage with conviction. The activities conducted from the second to the ninth day of the training are outlined below (Source: JICA expert's report).

Day 2:

At the beginning, the trainees considered that resource shortages are the one of the causes of poor-quality education in Africa. They did not consider the problem to lie with themselves. The trainer then asked the trainees to reflect on the past year and present what activities they had undertaken. The trainees reported on activities over the year, from the completion of the previous KCCP to the present. It was revealed that only two subjects' panels out of 15 are holding regular meetings. After that, the trainer encouraged trainees to honestly acknowledge their current situation and weakness without making excuses such as poor internet connection and unavailable materials. The trainees gradually began to confront themselves.

Day 3:

After school visits in Lusaka, the trainees were aware that the available resources were not being fully utilised at schools.

Day 4:

After a series of lectures by the trainer, the trainees asked a lot to the presenter. However, the trainers avoided answering directly, instead encouraging them to keep thinking. They began to consider how learning in a high school classroom is disconnected from the real world and to understand the meaning of the KCCP theme "Enhancing Understanding and Development of a Learning Environment: Accelerating STEM Learning Competences in Africa".

Day 5-7:

The trainees conducted land surveys within the NSC premises and designed the learning environment for Hospitality and Agriculture STEM education. The trainers accompanied them to the activity site, observed their activities, and offered advice where necessary.

Day 6:

The trainer provided critical feedback on the land survey results done by the trainees, citing issues with measurement accuracy and land mapping. Subsequently, the trainees recognised the importance of precision and carefully re-surveyed the land using appropriate tools.

Day 8:

The trainees finalized the design of the learning environment with guidance from the trainers. The trainees presented their proposals for designing the learning environment based on conventional thinking. Among the trainees, the concept of learning environments within the African context had not yet been clearly established. Therefore, the trainers introduced them to new insights by exploring locally available resources and seeking innovative designs through social media.

Day 9:

The trainees used CAD (Computer-Aided Design) software to create accurate land maps. The trainers acknowledged the trainees' learning process.

The trainees refined their proposals aiming to create learning environments that would attract visitors and learners by utilising local resources.

2) Results of Sub-Objective 2

During problem-solving stages, the trainers worked alongside trainees to develop learning environments related to the training tasks of Hospitality and Agriculture STEM education. The trainees gradually enhanced their knowledge and skills through activities. The activities from the 11th to the 16th days of the training are described below (Source: the JICA expert's report).

Day 11-16

The trainees commenced construction of buildings to serve as kitchen and eating areas for developing the learning environment for the Hospitality.

Many trainees were novices to construction work. However, they gradually mastered the use of drills, the execution of foundation work, and the construction of block walls and so on under the guidance of the trainers.

As the daily construction work continued, both the trainees and the trainers gradually lost sight of the original objective of the KCCP. Therefore, the trainers and trainees engaged in discussion and self-reflection regarding how STEM subjects relate to this construction process. Through these experiences and reflections, they gradually develop the image of the STEM learning and its competences.

3) Results of Sub-Objective 3

For the trial in actual lesson settings, Zambian secondary school learners were invited to Hospitality and Agriculture learning spaces and experienced the CBE from the day 17. Despite the absence of a detailed lesson plan, the participants facilitated learners by utilising their own experiences as learning resources. First, they built relationships with learners regardless of nationality. Then, they posed questions to learners from the perspective of their specialised subjects, and offered advice on how to conduct activities effectively. Finally, the trainees discovered that the learners enjoyed practical activities, taught each other, and gradually increased what they could do each day. The activities from the 17th to the 26th days of the training are described below (Source: the JICA expert's report).

Day 17-26:

The trainees worked together and transferred their knowledge and skills to the learners.

The trainees observed what competences the learners were developing.

The trainees encouraged learners to think about the meanings and scientific reasons behind processes and products.

Day 23-26:

By the time a week had passed, the trainees and some learners built a good relationship with each other.

For intentional reflection, the trainers asked learners and trainees what they have learned at learning environments.

4) Analysis Results of Trainees' Voices

This sub-section analyses the feedback provided by participants in the Zambia KCCP programme regarding the leaning and impressions of their learning gained during their training, as responses to "Research Question 3".

As described in table 6, the trainees reflected on their training process. Their comments focused particularly on interpersonal relationship (D) and educational beliefs (E), rather than specific teaching techniques such as Ability A to C (Source: the trainees' voices).

Table 6. Examples of Trainees' Voices

Abilities	The trainees' voices
A. Problem-solving & clearance of tasks	<i>One method of pest control is to plant with bitter-tasting leaves. These are well known to our Nigerian colleagues (Trainee A).</i> <i>We continue to ask even now. I ask them every day. Why this? Why that?</i>
B. Guidance and advice to	<i>Why that? (Trainee A)</i>

students regarding specific subjects	
C. School and classroom management	N/A
D. Interpersonal relationship	<i>So, whatever we have, we are those coming from physics part, mathematics part, biology, and... All those are placed together, which is actually happened here. (Trainee B)</i> <i>We understand the skill of collaboration. The skill of collaboration was there. Now, two groups here. But you cannot identify the groups. (Trainee D)</i> <i>Where we sat together from different subjects, were able to realise that from each of this subject area. (Trainee E)</i> <i>To the head teachers and learners of following schools. For grounding our work in authentic community engagement. Because if we didn't have you with us, it will be got a different story all together. (Trainee E)</i>
E. Improvement of educational beliefs	Views on teaching <i>Teachers support the learners to keep thinking and keep acting and questioning. (Trainee A)</i> <i>We cannot create competence without doing it. (Trainee E)</i> Views on teaching and learning materials <i>Now, from Zambian perspective, what is actually needed is that we have a lot of resources, we proud of what we have, so we get something which how we manage and develop our country and also African continent. We realised that there was enough in Lusaka and we had to look around and get materials nearby secondary school. (Trainee B)</i> <i>We have everything we need. (Trainee C)</i> <i>We are being carried out true true competence-based training. (Trainee C)</i> Views on learning <i>Every pathway, every structure, every learner experiences, must embody the spirits of competence-based education. This is the shift from delivering contents to cultivating deep-thinking, collaboration, innovation, and learner's agency. (Trainee E)</i> Views on learners <i>...asked learners what are you learn here. He said 'I leant how to get the measure of cement, how to measure sand, how to measure other to build the house.' (Trainee C)</i> <i>it became very clear that this was not just a training. It was a mindset shift. (Trainee E)</i> Views on training <i>Each and every one of us have very rich experiences from the difference intentional ecosystems. (Trainee E)</i>

F. Inquiring mind for personal growth	<i>It likely took over a week to break through, and we found that suitable materials we needed now for constructions (Trainee B).</i>
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5-2-3. Discussion

Initially, the trainees believed that the lack of appropriate resources such as curricula, textbooks, and teaching aids was the cause of low quality of education. However, when they visited the school, they realised that the teaching materials and school environment were not being used effectively. They came to understand that their own understanding had remained superficial. And they posed questions to the trainer—such as how to build a better learning environment, what practical methods or solutions exist—seeking immediate and concise answers. At that stage, it appeared that the problem had not yet become a personal matter, and its resolution seemed to depend on others.

Subsequently, the trainees commenced surveying the land as preparation for their training task on improving the learning environment. The provided land was not rectangular, and they struggled to measure it accurately. The trainees became acutely aware of their own lack of knowledge and skills. Simultaneously, through repeated discussions among themselves, they gradually began to utilise their own experience and expertise to autonomously find solutions.

Finally, the trainees could accept the educational problems as their own responsibility rather than blaming others, setting the problems for themselves. As they realised, they could solve these problems themselves, they felt their own growth. During the training process, they began to exercise self-directed learning, transforming their perspective on the training. This process influenced their educational beliefs. Furthermore, through tackling challenges collaboratively with fellow trainees, they came to grasp the true meaning of “collaboration” and “co-creation”, acquiring a different framework for thinking.

At the KCCP 2025, the trainees, as adult learners, tackled the tasks of developing STEM learning environments through practical application by drawing on their own life experiences and professional backgrounds. The NSC trainers themselves were constantly mindful not to become the problem solvers themselves, intentionally withholding answers to encourage the trainees to think for themselves. However, rather than leaving the trainees to work independently, the trainers participated alongside them in activities, demonstrating through their own actions and attitudes that they were essential members in building the collaborative learning platform. In this way, a horizontal relationship was established between the trainers and the trainees, they seem sustain the inquiring mind (Ability F). This is thought to be one reason why collaborative learning platform via social networking services (SNS) has continued actively from the end of the training programme to the present day.

6. Conclusion

This study discussed the nature of teacher training that aims to create collaborative learning platforms for educators to grow as reflective practitioners. Teacher training often relies on methods such as observing well-prepared model lessons or visiting exemplary schools to learn outstanding practices and advanced teaching methods. In contrast, the Zambia KCCP is trialling a new approach to teacher training. This involves observing the everyday reality of schools, re-evaluating the value and challenges of the current learning environment, and then tackling these challenges collaboratively, with both trainees and trainers working together.

This training may not yield the clear solutions to immediate educational challenges or the knowledge and techniques for teaching methods ready for immediate classroom use that traditional teacher training often provides. However, the trainees reflected on their beliefs and values as educators (Ability E), enhanced their communication skills (Ability D) through experiencing “collaboration” and “co-creation”, and honed their inquiring mind for personal growth (Ability F) to continue learning alongside their fellows. The particular emphasis on the inquiring mind (Ability F) is expected to ensure the continuous professional development, and is also considered to contribute greatly to the acquisition of knowledge and technical skills: Problem-solving & clearance of tasks (Ability A), Guidance and advice to students regarding specific subjects (Ability B), and School and classroom management (Ability C) (Miwa 2023).

7. Prospects for the Future

It is necessary for trainers to update their “views on training” by reflecting on what they have learnt from KCCP 2025 and discussing this among themselves. Furthermore, to grow as reflective practitioners themselves, the trainers must also maintain the inquiring mind (Ability F). This inquiring mind can connect all aspects of one's surroundings – including informal events, chance encounters, and other opportunities – to personal growth (Miwa 2023). It fosters our holistic development and enables each individual to become a unique being. This, in turn, leads to organising a diverse group of trainers for our learning platform.

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Balancing Formative and Summative Assessment for Competence Development in African STEM Education

Benson Banda¹, George Kwabena Kwakye², Marrio Chongo³, Cleopatra Songolo⁴

¹Ministry of Education, Directorate of National Science Centre, Zambia

²Ghana Education Service, Science Unit, Ghana

³St Clements Secondary School, Zambia

⁴Solwezi Skills Training Centre, Zambia

Correspondence: bensonbanda2003@yahoo.co.uk

Abstract

Competence-Based Curriculum (CBC) reform in African STEM education seeks a workable balance between formative assessment—which nurtures competence through continuous feedback—and summative assessment—which certifies achievement. This qualitative study, drawing on the AfriSTEM WhatsApp dialogue (5–10 October 2025) moderated by the author, explores educator perspectives on the formative–summative balance in CBC systems. Thematic analysis reveals broad agreement that formative assessment is central to competence development, yet its credibility depends on strong moderation structures and alignment with national policy. Participants proposed an 80/20 formative–summative weighting model, continuous teacher capacity-building, and continental frameworks to ensure equivalence of assessment practices. Key recommendations include establishing national policies that prioritise formative evidence, creating moderation hubs to strengthen reliability, and re-conceptualising summative examinations as authentic demonstrations of competence rather than recall-based tests. Overall, the findings reaffirm that competence grows within feedback-rich ecosystems—not in examination halls.

Keywords: formative assessment, summative assessment, competency-based curriculum, assessment balance, moderation

BACKGROUND

Introduction

Assessment practices in African education systems have historically been shaped by colonial examination models that prioritised high-stakes, recall-based testing as the primary measure of learner achievement. These summative-dominated systems entrenched a culture where passing examinations overshadowed deeper learning and practical competence.

Contemporary perspectives within African education reveal a gradual but significant shift. Policymakers, curriculum developers, and many educators now acknowledge that traditional examinations alone cannot measure the breadth of competencies required in modern STEM fields.

Growing consensus suggests that assessment must evolve to support skills such as problem-solving, experimentation, communication, and innovation—skills that demand continuous feedback rather than end-point judgment.

Yet, tension persists. Many teachers still perceive assessment primarily as grading, due partly to limited professional development, high workloads, and systemic pressure to produce exam results. Communities and parents often equate examination scores with academic success, reinforcing summative dominance.

Recent CBC reforms across countries such as Kenya, Zambia, Rwanda, Ghana, and Namibia reflect a shift in perspective toward holistic, learning-oriented assessment. CBC frameworks emphasise application, performance, and real-world tasks—competencies that rely heavily on formative assessment. International scholarship also supports this paradigm: balanced systems where formative assessment drives learning and summative assessment verifies mastery produce higher-quality learning, improved equity, and stronger learner engagement (Black & Wiliam, 1998; Harlen, 2005).

Despite policy momentum, practical challenges remain. Teachers struggle to integrate formative strategies such as peer assessment, observation, reflective journaling, and feedback loops due to limited resources or training. Without supportive structures—such as moderation hubs, digital tools, and standardisation frameworks—formative assessment can be inconsistent or untrusted.

These evolving perspectives among teachers, policymakers, and stakeholders underscore the importance of examining how educators conceptualise the balance between formative and summative assessment in CBC-driven STEM classrooms.

Problem Statement

Although CBC frameworks advocate formative assessment, summative examinations continue to dominate instructional practices and certification systems, limiting authentic competence evaluation and constraining formative feedback.

Objectives

This study aims to:

1. Document educators' perspectives on balancing formative and summative assessments in CBC.
2. Identify effective models for integrating formative and summative assessment.
3. Propose mechanisms to strengthen the reliability and validity of formative assessment.
4. Examine the role of digital technologies in enhancing STEM assessment practices.

Research Questions

1. How do educators conceptualise the formative–summative balance in CBC?
2. What structures support reliable teacher-led formative assessment?
3. How can summative assessment be reframed to authentically verify competencies?
4. What role can technology play in strengthening assessment practices?

Literature Review

Formative Assessment

Formative assessment is widely recognised as a core driver of learning in competency-based systems. Black and Wiliam (1998) describe it as all activities that generate evidence of learning to be used as feedback by teachers and learners to adjust teaching and learning in real time. Their review showed that feedback-rich formative practices—such as questioning, feedback cycles, and peer/self-assessment—produce substantial learning gains, especially for low-achieving learners.

Subsequent work has refined this view, emphasising that formative assessment is not a set of tools but a *process* embedded in instruction: clarifying learning intentions and success criteria, engineering effective discussions, activating peer- and self-assessment, and using evidence to adapt teaching (Trumbull & Lash, 2013; Wiliam, 2022, as synthesised in recent evidence summaries). In CBC-oriented STEM classrooms, this means using tasks that surface conceptual understanding, procedural fluency, and problem-solving strategies rather than only checking recall.

Within African CBC reforms, formative assessment is also framed as a mechanism for equity—helping teachers notice and respond to diverse learner needs, language backgrounds, and prior experiences (UNESCO, 2021). However, studies note that many teachers still equate assessment with marks and grading, and they often lack sustained professional development in formative approaches, limiting the depth of implementation.

Summative Assessment

Summative assessment traditionally refers to assessments “of learning” conducted at the end of a unit, term, or programme for purposes such as certification, selection, and accountability. Wiggins (1998) argues that summative assessment in standards-based systems should be *educative*: tasks ought to mirror real-world performance, require transfer of learning, and provide meaningful feedback rather than simply ranking students.

Recent scholarship on balanced assessment systems has reinforced that summative assessments should be tightly aligned with curriculum and modern conceptions of learning, and designed to support equity and ambitious teaching rather than narrow test-preparation cultures (Marion, 2019; Marion et al., 2024). This implies rethinking national high-stakes examinations in STEM from primarily recall-oriented items towards authentic tasks—projects, investigations, design challenges, and practical problem-solving—that can validly evidence competence.

In CBC reforms, summative assessments are increasingly conceptualised as *confirmation* of competences that have already been nurtured and demonstrated through ongoing formative processes, rather than as the sole or primary driver of learning. National frameworks such as Kenya’s Competency-Based Assessment Framework explicitly present summative assessment as one component within a broader, continuous assessment system.

Balanced Assessment Systems

The notion of a **balanced assessment system** responds to the recognition that no single assessment type can meet all purposes. Stiggins (2004, 2006) proposes that high-quality systems deliberately integrate assessment *for* learning (formative), assessment *as* learning (student self-regulation), and assessment *of* learning (summative), with classroom assessment playing a central role. FAME+1 In such systems, formative evidence is used to guide instruction and support learner agency, while summative data provide defensible judgments for reporting and certification.

Recent analyses highlight that “balance” is not simply a numerical split of test types, but a matter of **coherence**—alignment of curriculum, instruction, and assessment across levels of the system, from classroom to national policy (Marion et al., 2024). Balanced systems foreground classroom-based, curriculum-embedded assessment, supported (rather than crowded out) by large-scale tests. They also emphasise equity, cultural responsiveness, and the need for clear theories of action showing how different assessment components collectively support learning.

Within CBC in Africa, this conversation has taken on a distinctly contextual dimension. Emerging continental debates argue that balanced systems must recognise the realities of large classes, resource constraints, multilingual classrooms, and pressures from high-stakes examinations, while still moving towards feedback-rich, learner-centred assessment cultures (Ruth, 2019; Wawire et al., 2025). The 80/20 formative–summative model discussed in AfriSTEM dialogues reflects this effort to operationalise balance in a way that structurally privileges formative evidence while maintaining credible summative verification.

African Context: CBC, Assessment, and Moderation

Competency-based curriculum reforms have expanded across many African countries, including Kenya, Rwanda, Zambia, Namibia, Ghana, and Tanzania. A growing body of work documents both the promise and the challenges of these reforms. Ruth (2019) argues that CBC must be “Africanized” to reflect local socio-economic realities, resource constraints, and cultural expectations about teaching, learning, and authority, rather than merely copying models from high-income contexts.

A recent scoping review of CBC implementation in African classrooms by Wawire et al. (2025) synthesises evidence from multiple countries. It finds that while CBC policies emphasise learner-centred pedagogy and continuous assessment, classrooms often remain dominated by teacher-centred, exam-driven practices. Teachers report difficulties with large classes, limited materials, and insufficient training in designing and using performance-based assessments. Systemic barriers include misalignment between CBC policy documents, high-stakes examination formats, and available support structures for teachers. Scribd

Reports from regional initiatives and webinar series on CBC in Africa similarly highlight tensions between competence-oriented rhetoric and exam-centric realities. They note that high-stakes summative examinations continue to drive teaching, while school-based formative assessment is

often under-valued, inconsistently moderated, and weakly integrated into national certification frameworks. Consequently, strengthening **moderation**—through cluster-based teacher communities, district moderation hubs, and national/continental guidelines—is increasingly seen as essential to ensure the credibility and comparability of teacher-led formative assessment evidence.

Recent African commentary on CBC also reframes assessment reform as a process of *perpetual improvement*: systems must continuously refine criteria, tools, and professional learning structures so that assessment keeps pace with evolving curricular aims and labour-market needs (Mykuras, 2025).Kurasa Africa This view aligns with the AfriSTEM recommendation that formative assessment should carry greater weight (e.g., 80%) but must be anchored in robust moderation, teacher capacity-building, and policy coherence.

Technology-Enhanced Assessment in STEM

Digital technologies are reshaping how formative and summative assessments are designed, documented, and moderated in both school and higher-education STEM contexts. During and after the COVID-19 pandemic, e-portfolios and online platforms became key tools for documenting continuous learning, supporting reflection, and providing feedback. A 2024 systematic review of e-portfolio use during the pandemic concludes that e-portfolios can strengthen self-regulation, collaboration, and evidence-based assessment when accompanied by clear rubrics and scaffolding (Zhang & Tur, 2024).Open Praxis

In African contexts, research on mobile and online tools shows how low-cost technologies such as WhatsApp groups, learning management systems, and web-based e-portfolios can support continuous assessment, peer interaction, and mentoring, particularly in STEM teacher education and postgraduate programmes (Singh-Pillay, 2023; Modise, 2021, as cited in Zhang & Tur, 2024). Studies of virtual or hybrid teacher education programmes also describe how formative virtual assessments and digital portfolios help sustain feedback loops and track competence development in resource-constrained environments.

For CBC-oriented STEM education in Africa, these findings suggest that technology can:

- ✓ make formative evidence more **visible and portable** (through digital portfolios, photos, videos, and logged tasks);
- ✓ support **remote moderation** and peer review among teachers across schools, districts, and countries; and
- ✓ enable **richer, multimodal summative tasks** that capture experimentation, design, and collaboration rather than solely written responses.

However, digital divides, infrastructure gaps, and limited digital assessment literacy among teachers and students remain significant constraints, underlining the need for investment and targeted professional development.

Methodology

A qualitative thematic analysis was conducted on an AfriSTEM WhatsApp discussion held from 5–10 October 2025. Participants included educators from Zambia, Nigeria, Kenya, Uganda, Ghana, Namibia, Lesotho, Malawi, Mozambique, and Cameroon. Open coding generated themes relating to formative practice, summative roles, moderation, and policy alignment.

Findings

Theme 1: Formative Assessment as the Heart of CBC

Participants consistently described formative assessment as the core of competence development.

Theme 2: Preference for an 80/20 Formative–Summative Weighting

Educators recommended that formative evidence contribute 80% of learning evaluation, with summative assessments contributing 20%, supported by continuous professional development.

Theme 3: Reliability Through Moderation and Policy

Concerns regarding teacher reliability highlighted the need for moderation hubs and continental standardisation to maintain credibility.

Discussion

The findings align with global research supporting formative assessment as central to effective learning (Black & Wiliam, 1998). The 80/20 weighting reflects a shift toward learning-oriented assessment, while ensuring summative verification remains meaningful. However, successful implementation depends on supportive systems—moderation, policy alignment, digital tools, and teacher capacity-building.

Recommendations and Implications

Policy

- Institutionalise an 80/20 formative–summative model.
- Establish national moderation hubs.
- Support continental frameworks such as CAF-Africa.

Practice

- Use diverse evidence sources, including portfolios, artefacts, and reflections.
- Redesign summative tasks as authentic performance demonstrations.
- Integrate digital tools for efficient documentation and feedback.

Capacity Building

- Provide continuous CPD in formative assessment.
- Allocate time for collaborative moderation.
- Build teacher competence in digital assessment methods.

Implications

- Improved depth, equity, and relevance of learning.
- Enhanced trust in school-based assessment.
- Stronger feedback ecosystems supported by digital innovation.

Conclusion

A balanced assessment system requires formative assessment to guide instruction and support competence development, while summative assessments verify mastery authentically. Strengthening moderation, policies, and technological integration will transform African education from an examination-driven culture to a learning-oriented, feedback-rich ecosystem.

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The Impact of Technology in Tertiary Education. A case study of Midlands State University (MSU) Bioinformatics students.

Munashe K.F. Chakamanga, Tom Muzenda and Luckmore Furidze

frankchakamanga@gmail.com

Midlands State University, Zimbabwe

Abstract

The integration of technology in tertiary education has revolutionized teaching and learning, offering innovative approaches to curriculum delivery, student engagement, and academic success. This study examined the impact of technology on the academic experiences of bioinformatics students at Midlands State University (MSU). Using a mixed-methods approach, the research explored how tools such as virtual learning environments, online resources, and specialized bioinformatics software enhance learning outcomes, promote collaborative work, and address challenges unique to this interdisciplinary field. The study highlighted the benefits of technology in fostering critical skills, including data analysis and computational proficiency, while identifying barriers such as access disparities, inadequate infrastructure, and the need for faculty training. Findings suggest that while technology has significantly enriched the bioinformatics program at MSU, strategic investments and policies are essential to optimize its potential. This case study contributes to the broader discourse on technology adoption in higher education and its implications for advancing STEM disciplines.

Introduction and Literature Review

The landscape of tertiary education has undergone a remarkable transformation in recent decades, driven by the rapid advancements in technology. The integration of various digital tools, platforms, and pedagogical approaches has revolutionized the way students learn, engage with course content, and collaborate with their peers and instructors. This technological revolution has permeated across diverse academic disciplines, including the field of bioinformatics. The rapid advancements in technology have significantly transformed the landscape of higher education, including the field of bioinformatics. The integration of technology-driven pedagogical approaches has the potential to enhance student engagement, improve learning outcomes, and better prepare students for the demands of the modern workforce. However, the extent to which these technological interventions impact the educational experiences of bioinformatics students remains an area that requires in-depth investigation.

Background of the Study

The rapid evolution of technology has significantly transformed various sectors, including education. In the realm of higher education, technology has become a crucial tool for enhancing teaching and learning experiences. According to Huang, *et al.* (2020) tertiary institutions worldwide, including universities, are increasingly adopting digital tools and platforms to facilitate learning. This shift has enabled more interactive, flexible, and student-centered educational environments, while also posing new challenges for educators and students alike.

Midlands State University (MSU) is a prominent public institution of higher education located in the heart of the Midlands region of Zimbabwe. Established in the late 20th century, MSU has built a reputation for its innovative and forward-thinking approach to education, with a particular focus on preparing students for the technological advancements shaping the modern workforce (Kelley, *et al.* 2019). Midlands State University (MSU) has embraced this technological wave, particularly in the Bioinformatics program under the Department of Applied Biosciences and Biotechnology in the Faculty of Science and Technology. Bioinformatics, being a highly interdisciplinary field that combines biology, computer science, and data analysis, inherently relies on cutting-edge technologies (Kira, & Zeidner, 2013). The integration of online learning platforms, educational software, and computational tools has become essential for students pursuing degrees in this field.

However, the impact of these technologies on students' learning outcomes, engagement, and academic success remains under-researched, particularly in the context of MSU.

This dissertation focuses on assessing the impact of technology on tertiary education with a specific emphasis on Bioinformatics students at MSU. It explores how technology enhances or hinders the learning experience of these students and examines their attitudes, challenges, and benefits regarding technology in education.

The widespread integration of technology into tertiary education has reshaped the academic landscape. Bioinformatics is the intersection of biology, computer science, and information technology, it is a rapidly evolving field that heavily relies on the utilization of cutting-edge technologies. However, the extent to which these technological advancements benefit students' learning experiences is still uncertain. At MSU, Bioinformatics students depend heavily on technology for both theoretical learning and practical applications. In the context of tertiary education, the integration of technology in bioinformatics programs has become paramount. Bioinformatics students require proficiency in a wide range of computational tools, data analysis software, and online resources to effectively navigate the complexities of this interdisciplinary domain. The effective integration of technology not only enhances the learning experience but also prepares students for the technology-driven bioinformatics industry. Despite this dependency, there is limited research examining the actual impact of these tools on students' academic performance, engagement, and overall experience. This study addresses this gap by investigating how technology influences the educational outcomes of MSU Bioinformatics students. It focused on assessing whether the current technological tools and platforms used at the university are meeting the educational needs of the students and whether there are areas for improvement.

The primary purpose of this study was to evaluate the impact of technology on the learning experiences of Bioinformatics students at Midlands State University. This included understanding the effectiveness of different technological tools in improving student engagement, academic performance, and knowledge retention. Additionally, the study aimed to identify any challenges students face in using these technologies and explore potential strategies to optimize the use of digital tools in higher education.

Aim

To investigate the various technology-based learning tools and resources utilized in the Bioinformatics program at MSU.

Objectives

- To analyze the influence of technology integration on the academic performance, engagement, and overall learning experiences of Bioinformatics students at MSU.
- To identify the challenges and barriers faced by Bioinformatics students at MSU in effectively integrating technology into their learning processes.
- To provide recommendations for the Bioinformatics program at MSU and other educational institutions on the effective implementation of technology-driven pedagogical approaches.
- To measure and explore student's attitudes towards the use of technology in their learning process.

Research Questions

1. How does technology impact the academic performance of Bioinformatics students at MSU?
2. What challenges do Bioinformatics students face in using technology for their studies?
3. To what extent does technology enhance student engagement and participation in Bioinformatics courses?
4. What are the students' perceptions of the effectiveness of the technologies used in their learning?
5. How can the use of technology in Bioinformatics education be improved to better support student learning?

Significance of the Study

This research holds significance for several stakeholders within the university, including students, educators, and policy-makers. For Bioinformatics students, the findings will provide insights into how technology is shaping their educational journey, highlighting areas where it has been beneficial and where it may need improvement. For educators, this study offers a deeper understanding of how their teaching methods and tools can be enhanced to better meet student needs.

Additionally, university policy-makers and administrators can benefit from the findings by using them to inform decisions about investing in and implementing new technologies, particularly in STEM-related fields like Bioinformatics. In the broader context, this study contributes to the ongoing conversation about the role of technology in higher education and how it can be leveraged to create more effective learning environments.

Scope of the Study

This study was limited to Bioinformatics students at Midlands State University. It focused on their use of technology in academic settings, such as online learning platforms, computational tools, and software for bioinformatics analyses. While the study provides insights into the experiences of students within this specific discipline, the findings may also have broader implications for other fields within tertiary education.

Definition of Terms

- **Technology in Education:** Refers to the use of digital tools and platforms, such as e-learning systems, computational software, and other technologies, to facilitate teaching and learning.
- **Bioinformatics:** An interdisciplinary field that combines biology, computer science, and data analysis to interpret biological data, particularly in genomics and molecular biology.
- **Student Engagement:** The level of participation, interest, and interaction students exhibit in their learning activities, often enhanced by interactive technologies.
- **E-learning Platforms:** Online systems that provide access to educational resources, facilitate communication between students and teachers, and support the delivery of course materials.

Technology in Tertiary Education

Previous studies have extensively documented the growing reliance on technology in tertiary education. According to Garrison and Anderson (2011), the integration of technology into higher education has evolved from merely enhancing traditional teaching methods to fundamentally reshaping educational delivery. The adoption of e-learning platforms, such as Moodle, Blackboard, and Google Classroom, has enabled educators to offer flexible and personalized learning

environments, where students can access course materials, participate in discussions, and submit assignments remotely. This has led to a more student-centered approach to learning, with increased autonomy and self-regulation by students.

Moreover, research by Laurillard (2012) highlighted the advantages of blended learning, which combines face-to-face instruction with online learning tools, providing a balance between traditional and digital learning experiences. Blended learning has been shown to enhance students' engagement, motivation, and learning outcomes in various disciplines. The use of digital tools, such as simulations, multimedia content, and interactive quizzes, has also contributed to making learning more dynamic and interactive (Bonk & Graham, 2012).

However, not all studies reported positive outcomes from technology integration. Some researchers found that technological tools, when not appropriately designed or implemented, can lead to disengagement and confusion among students (Selwyn, 2016). Concerns about the "digital divide" have also been raised, as students from disadvantaged backgrounds may lack access to the necessary devices or internet connectivity required for online learning (Van Dijk, 2020). These findings indicate that while technology has the potential to enhance learning, careful consideration must be given to the challenges and limitations associated with its use.

Technology in Bioinformatics Education

Bioinformatics, an interdisciplinary field combining biology, computer science, and statistics, requires a robust understanding of both biological concepts and computational techniques. Studies indicate that technology is integral to bioinformatics education, enabling students to analyze large datasets, utilize computational tools, and engage in practical research (Baker *et al.*, 2018). The integration of technology into the curriculum is essential for preparing students for careers in bioinformatics and related fields. Recent literature highlights several key trends in the integration of technology in higher education, particularly in bioinformatics showcasing areas such as Online Learning Platforms. The rise of Massive Open Online Courses (MOOCs) and other online learning platforms provides students with flexible access to educational resources (Laurillard, 2018). Software applications for data analysis, such as R, Python, and specialized bioinformatics tools, are increasingly central to bioinformatics curricula (Kelley *et al.*, 2019). Digital platforms facilitate collaboration among students, enabling them to work on research projects and share knowledge across geographical boundaries (Dillenbourg, 2018). Flipped Classrooms model allows students to

engage with lecture materials at their own pace through online resources, reserving classroom time for interactive discussions and hands-on activities (Bishop & Verleger, 2013). Virtual Laboratories include Online simulations and virtual lab environments that provide students with opportunities to conduct experiments and analyze data in a risk-free setting, enhancing experiential learning (Rosenblatt *et al.*, 2020). Artificial Intelligence (AI) and Machine Learning include technologies that are increasingly used in bioinformatics to analyze large datasets and make predictions, necessitating corresponding educational frameworks to train students in these advanced methodologies (Kelley *et al.*, 2019).

Midlands State University and the Bioinformatics Program

Midlands State University (MSU) is a prominent public institution of higher education located in the heart of the Midlands region. Established in the late 20th century, MSU has built a reputation for its innovative and forward-thinking approach to education, with a particular focus on preparing students for the technological advancements shaping the modern workforce. As a comprehensive university, MSU offers a diverse range of academic programs across various disciplines, including the sciences, engineering, business, and the humanities. The university's commitment to excellence and its dedication to fostering a culture of innovation have been instrumental in its growth and recognition within the region and beyond.

Midlands State University (MSU), established in 2000 in Zimbabwe, has become a leading institution in higher education within the Southern African region. Known for its dedication to educational innovation, MSU has expanded its academic offerings to address the evolving demands of the modern workforce, especially within the fields of science and technology. As a response to the growing importance of computational approaches in biological research, MSU introduced a Bioinformatics program, which aligns with global trends emphasizing the interdisciplinary fusion of biology, computer science, and information technology (Mudavanhu & Dube, 2020).

The introduction of a Bioinformatics program at MSU is timely, as Zimbabwe and many African countries are experiencing a surge in biological data from genomics, proteomics, and biodiversity studies, necessitating specialized skills in data analysis. As highlighted by Nembaware *et al.* (2019), the African continent faces challenges with disease burden, agricultural sustainability, and biodiversity conservation, all of which can benefit from bioinformatics approaches. MSU's program thus addresses a critical need for skilled professionals capable of leveraging

bioinformatics tools to analyze biological data, fostering local expertise and reducing dependency on external resources.

The Bioinformatics program at MSU is designed to equip students with foundational and advanced knowledge in computational biology, genomics, and data science. The curriculum integrates modules covering genomic sequencing, data analysis, and software development, providing a balance between theoretical knowledge and practical skills. Key components of the program, such as Whole Genome Sequencing (WGS) and computational biology, reflect the latest advancements in the field. Additionally, students gain hands-on experience with essential tools and platforms like R, Python, and public biological databases, preparing them for various roles in academia, healthcare, and industry.

Research within MSU's Bioinformatics department aligns with pressing global issues, including health-related studies focusing on genomics and pathogen evolution. For example, research efforts at MSU have targeted genetic studies related to disease susceptibility and resistance, agricultural biotechnology, and environmental conservation (Chimusa *et al.*, 2021). This research focus has positioned the university as a key player in contributing data and insights relevant to regional health and ecological challenges, such as those arising from climate change and infectious diseases. The program also encourages collaborative projects and partnerships, allowing students to engage with real-world bioinformatics applications in both research and clinical settings.

Despite the success and growth of the Bioinformatics program at MSU, several challenges persist. Limited access to high-performance computing resources and financial constraints for laboratory equipment have posed difficulties in fully realizing the program's potential. However, recent partnerships with organizations like H3Africa and the African Society for Bioinformatics and Computational Biology (ASBCB) have provided avenues for resource sharing and funding opportunities (Nembaware & H3Africa Consortium, 2022). Looking forward, MSU's Bioinformatics program aims to further its research capabilities, expand its course offerings, and solidify its reputation as a hub for bioinformatics in Southern Africa.

Overview of the bioinformatics program

Within the vibrant academic environment of MSU, the Department of Biological Sciences offers a distinguished bioinformatics program. Launched over four years ago, the bioinformatics program at MSU has gained recognition for its comprehensive curriculum and strong emphasis on

integrating technology-driven approaches. The bioinformatics program at MSU comprises a well-structured curriculum that blends core biological sciences with a strong foundation in computer science, data analysis, and information technology. Students undertake a diverse range of courses including, molecular biology and genomics, computational biology and algorithms, biological database management, biostatistics and data visualization, biological sequence analysis and protein structure and function prediction

Integration of technology in the program

The bioinformatics program at MSU has been at the forefront of leveraging technological advancements to enhance the learning experience of its students. The program's curriculum and instructional methods are designed to seamlessly integrate various digital tools, platforms, and resources to provide access to online databases and bioinformatics software. The program also facilitates use of hands-on practical sessions with computational tools and enables data-driven research and project-based learning. It also encourages collaboration and knowledge-sharing through digital platforms thus help in preparing students for the technology-driven bioinformatics industry.

Impact on Student Engagement and Performance

Student engagement is considered a key predictor of academic success, and numerous studies have investigated the impact of technology on engagement in higher education. According to Kuh (2009), engaged students are more likely to achieve higher academic outcomes, as they actively participate in learning activities, interact with peers and instructors, and utilize available resources effectively. Technology, particularly through online learning platforms and digital communication tools, has been found to promote higher levels of student engagement by facilitating interaction and collaboration.

In a study by Al-Rahmi *et al.* (2015), the use of social media and online forums in university courses was shown to increase student participation and collaboration, contributing to improved learning outcomes. Similarly, Davies *et al.* (2013) found that students who used technology to interact with their peers and instructors outside of the classroom demonstrated higher levels of engagement and academic achievement.

However, some studies reported mixed results regarding the impact of technology on performance. For instance, Kirschner and Karpinski (2010) found that excessive use of social media and other digital distractions could negatively affect students' academic performance. The authors argued that while technology can enhance learning, it can also lead to multitasking and reduced focus, ultimately hindering academic success. Additionally, students' familiarity with technology and their digital literacy levels were found to influence how effectively they used educational technologies, with digitally literate students benefiting more from these tools (Bennett *et al.*, 2008).

The Role of Technology in Bioinformatics Education

Bioinformatics, an interdisciplinary field that combines biology, computer science, and data analysis, is inherently dependent on technology. The use of bioinformatics software, databases, and computational tools is central to the curriculum, enabling students to analyze biological data and solve complex problems in genomics, proteomics, and systems biology. As a result, the effective integration of technology into Bioinformatics education is crucial for student success.

Several studies have highlighted the unique challenges and opportunities associated with teaching Bioinformatics. According to Attwood *et al.* (2011), students in Bioinformatics programs must not only develop a deep understanding of biological concepts but also acquire strong computational and data analysis skills. This requires the use of specialized software, such as BLAST, ClustalW, and various genome browsers, which students must learn to use proficiently. Moreover, given the rapid advancements in the field, educators must continuously update their curricula to reflect the latest technological developments (Schneider *et al.*, 2010).

Studies have also shown that the use of technology in Bioinformatics education enhances student engagement and learning outcomes. For example, Petersen *et al.* (2013) found that the use of interactive bioinformatics tools and online databases in teaching resulted in improved student comprehension of complex biological data and increased confidence in conducting research. Additionally, virtual labs and simulations have been used effectively to teach bioinformatics concepts, allowing students to practice data analysis and experimental techniques in a virtual environment (Wood & Gebhardt, 2013).

Despite these advantages, there are also challenges associated with the use of technology in Bioinformatics education. Students often face steep learning curves when using specialized software, and the lack of sufficient training and support can lead to frustration and disengagement

(Attwood *et al.*, 2011). Furthermore, access to the necessary hardware and software can be a limiting factor, particularly in resource-constrained institutions (Machluf & Yarden, 2013).

Challenges of Technology Integration in Tertiary Education

While the benefits of technology in education are well-documented, several challenges persist in its integration, particularly in tertiary institutions in developing countries. One of the main challenges is the accessibility and availability of technological resources. According to Selwyn (2016), many universities in developing countries struggle to provide reliable internet access, up-to-date hardware, and software for their students. This digital divide exacerbates the disparities in education, as students from lower socio-economic backgrounds often lack access to the technological tools necessary for their studies.

Another challenge relates to the training and support for both students and educators. Research by Lawless and Pellegrino (2007) indicated that the successful implementation of technology in education requires adequate training for teachers to effectively incorporate digital tools into their teaching practices. Without proper training, educators may be reluctant to adopt new technologies, and students may not fully benefit from their potential.

Additionally, there are concerns about the over-reliance on technology in education. Some researchers have warned that excessive use of digital tools may detract from the development of critical thinking and problem-solving skills, as students may become passive consumers of information rather than active participants in the learning process (Carr, 2011).

Benefits of Technology in Bioinformatics Education

Research demonstrates several benefits of technology integration in bioinformatics education such as Enhanced Learning Outcomes. Studies indicate that students who engage with technology-driven curricula exhibit improved learning outcomes and a deeper understanding of complex concepts (Wang *et al.*, 2019). Technology equips students with essential skills for the bioinformatics workforce, including data analysis, programming, and computational thinking (Huang *et al.*, 2020). The use of interactive tools and multimedia resources enhances student engagement and motivation, making learning more enjoyable and effective (Dunleavy *et al.*, 2014).

Challenges of Technology Integration

Despite the advantages, several challenges impede the effective integration of technology in bioinformatics education such as, Resource Availability. Access to advanced technological resources can be limited, particularly in developing regions, affecting the quality of education (Zheng *et al.*, 2020). Lack of proper Training and Support would lead to Faculty and students requiring additional training to effectively utilize technological tools, posing a barrier to successful implementation (Kirkwood & Price, 2014). Ensuring that technology integration aligns with educational goals and outcomes can be challenging, necessitating ongoing evaluation and adaptation (Rogers, 2017).

Research Methodology

This study employed a mixed-methods research design that combined both quantitative and qualitative data collection approaches. A mixed-methods approach was chosen to allow for a more comprehensive understanding of the impact of technology on Bioinformatics education at MSU. The mixed-methods research design was included also to enrich the study's findings through the combination of quantitative and qualitative approaches. This design enabled a comprehensive exploration of the research questions. According to Creswell (2014), mixed-methods research is particularly useful in educational studies as it enables the collection of diverse types of data, leading to richer insights and stronger conclusions.

The quantitative component focused on gathering statistical data regarding student engagement, performance, and technology use. Surveys were used to collect numerical data on students experiences with technology in their Bioinformatics studies. Quantitative approach also helped in facilitating statistical analysis of trends and patterns in student perceptions regarding technology use in their education. This component was aimed at quantifying how technology impacts areas such as learning engagement, skill acquisition, and overall satisfaction.

On the other hand, qualitative data were gathered through interviews and open-ended survey questions, providing deeper insights into the students' perspectives on the challenges and benefits of technology in their learning experiences. In-depth interviews provided a platform for students and faculty to express their thoughts and experiences more openly. This qualitative approach was critical in uncovering the nuances behind the quantitative data, revealing deeper insights into how technology is perceived and utilized in the program.

Population and Sampling

The sample selection process was designed to ensure diverse representation among participants. The population for this study consisted of all Bioinformatics students at Midlands State University. As of the 2024 academic year, the Bioinformatics program at MSU had an enrollment of 120 students across various year levels. Given the relatively small size of this population, the study used stratified random sampling to ensure representation from different cohorts (e.g., first-year, second-year, and final-year students). Stratified random sampling, as argued by Trochim (2006), increases the accuracy of results by ensuring that all key subgroups within a population are adequately represented.

Thus, to survey participants, a stratified random sampling technique was utilized to select 70 students from different academic years within the bioinformatics program. This approach ensured inclusivity across various demographics, including gender, age, and academic performance, allowing for a richer analysis of the data.

For interview participants, the qualitative interviews, a purposive sampling method was employed to select 10 students and 5 faculty members. This selection was based on their direct experiences with technology in the bioinformatics curriculum. Participants were chosen to capture a range of perspectives, including those who had positive experiences and those who faced challenges.

Thus, in total a sample size of 70 students was deemed sufficient for this study, representing greater than 50% of the total Bioinformatics student population. This sample size was determined based on the recommendations of Cohen, Manion, and Morrison (2011), who suggested that in educational research, a sample size of at least 30% is necessary to obtain reliable results, especially when investigating smaller populations.

Data Collection Instruments

Data collection involved several key methods to ensure comprehensive coverage of the research questions, various data collection instruments were employed including a structured questionnaire for quantitative data collection and semi-structured interviews for qualitative data. For surveys, an online questionnaire was developed, consisting of both closed-ended and Likert scale items. The survey assessed various dimensions, such as perceived effectiveness with students rated how effectively they believe technology enhances their learning. Engagement levels used questions that

gauged the extent to which technology kept students engaged during their studies. Open-ended questions allowed students to detail any difficulties they encountered with technology integration. Semi-structured interviews were conducted to gather in-depth qualitative data. The interview guide included open-ended questions designed to explore personal experiences with technology in learning, perceptions of the effectiveness of specific tools and resources and suggestions for improvement in technology integration. The interviews were audio-recorded with participants consent, transcribed verbatim, and analyzed for key themes. The semi-structured interviews were conducted with 10 students selected from the sample to gain deeper qualitative insights. These interviews focused on the students experiences with specific technologies, such as bioinformatics software (e.g., BLAST, ClustalW), online learning platforms (e.g., Moodle), and communication tools (e.g., Google Classroom). Interviews were recorded and transcribed for analysis.

Also, a structured questionnaire was designed to gather quantitative data on students' experiences with technology. It included questions on the frequency of technology use in their studies. The types of technologies and software used and the perceived impact of technology on their learning outcomes. The questionnaire used a five-point Likert scale, ranging from "strongly disagree" to "strongly agree" to measure the students' attitudes and perceptions. Likert scales, as noted by Boone and Boone (2012), are effective in measuring subjective responses and provide easy-to-interpret data for statistical analysis.

Data Collection Procedure

Data collection was carried out over a period of three months from August to October 2024. The questionnaire was distributed both online via Google Forms and in paper format to ensure all students had the opportunity to participate. The online format allowed students to complete the survey at their convenience, and this was particularly important for those facing connectivity issues or difficulties attending in-person sessions.

Following the distribution of the questionnaire, interviews were scheduled with 10 students who had indicated willingness to participate further. These interviews were conducted both in person and via Zoom, depending on the preferences and availability of the students. Each interview lasted approximately 30 minutes, and the conversations were audio recorded with the consent of the participants.

Data Analysis

Quantitative Data Analysis

The analysis of collected data was performed in two distinct phases being quantitative analysis and qualitative analysis. Statistical software R Studio was used to analyze survey data. Descriptive statistics provided an overview of the responses, while inferential statistics (e.g., t-tests, ANOVA) helped identify significant differences between groups based on demographic factors. This quantitative analysis aimed to reveal patterns and correlations in student perceptions. For qualitative analysis, thematic analysis was applied to the interview transcripts. This process involved coding. This included identifying and labeling key phrases and concepts from the data and grouping codes into broader themes that reflected common experiences and perceptions related to technology use. R Studio software facilitated the organization and analysis of qualitative data, allowing for systematic exploration of themes. Descriptive statistics, including mean scores, standard deviations, and frequency distributions, were used to summarize the data. These measures helped in understanding the overall trends and patterns in the students use of technology and its impact on their learning.

Inferential statistics, specifically t-tests and ANOVA (Analysis of Variance), were applied to examine differences in the perceptions and experiences of students across different year levels. These tests were conducted using the R Studio software. According to Field (2013), inferential statistics are crucial for determining whether observed differences in the data are statistically significant or due to random variation.

Qualitative Data Analysis

The qualitative data collected from the interviews were analyzed thematically. Thematic analysis involves identifying recurring patterns or themes within the data (Braun & Clarke, 2006). Interview transcripts were read multiple times, and initial codes were generated based on students' responses. These codes were then grouped into themes such as benefits of using technology in Bioinformatics education, challenges related to technology access and usage and students recommendations for improving technology integration at MSU. The thematic analysis allowed for a nuanced understanding of the students experiences with technology and highlighted areas that quantitative data alone could not reveal.

Validity and Reliability

To ensure the validity and reliability of the research instruments, a pilot study was conducted before the full-scale data collection. The pilot study involved administering the questionnaire to 10 students from another department at MSU, and feedback was used to refine the questions. According to Drost (2011), pilot studies are important for identifying ambiguities and ensuring that the questions are clear and capable of measuring what they are intended to measure. Reliability was further ensured by using Cronbach's alpha to measure the internal consistency of the Likert scale items. A Cronbach's alpha value of 0.7 or higher is generally considered acceptable for educational research (Tavakol & Dennick, 2011). The reliability coefficient for the questionnaire was found to be 0.82, indicating good internal consistency.

Ethical Considerations

Ethics played a crucial role in the research process, guiding the treatment of participants and the handling of data. Ethical clearance was obtained from the Midlands State University Research Ethics Committee before the commencement of the study. The ethical principles were adhered to such as informed consent, confidentiality, right to withdraw and data protection. All participants were informed about the purpose of the study and their voluntary participation. They signed consent forms before participating in the surveys or interviews. Participants' identities were kept confidential, and any identifying information was anonymized in the final report. Participants were informed that they had the right to withdraw from the study at any time without penalty. All data collected were stored securely, and only the researcher had access to the data. After the analysis, all raw data were destroyed in accordance with university guidelines. Participation in the study was entirely voluntary, with participants informed of their right to withdraw at any stage without penalty.

Limitations of the Study

While a sample of 70 students was sufficient for the purposes of this research, a larger sample size might have provided more generalizable results. Some students may have had limited access to the internet or the necessary devices, which could have affected their participation in the online survey. The use of self-reported data in the questionnaires may have introduced bias, as students may have either overestimated or underestimated their use of technology. Given the rapid evolution of

technology, the findings may become less applicable over time as new tools and methodologies emerge within the field of bioinformatics.

Results

Quantitative Data Analysis

The quantitative data from the structured questionnaires were analyzed using descriptive and inferential statistics. The results are presented in tables and charts for ease of interpretation. The responses focused on students' experiences with technology, their perceptions of its impact on their learning, and the challenges they faced in accessing and using educational technology.

Survey Demographics

A total of 70 students participated in the online survey. The demographic breakdown is as follows:

Gender

Female: 60.9%

Male: 39.1%

Non-binary/Other: 0%

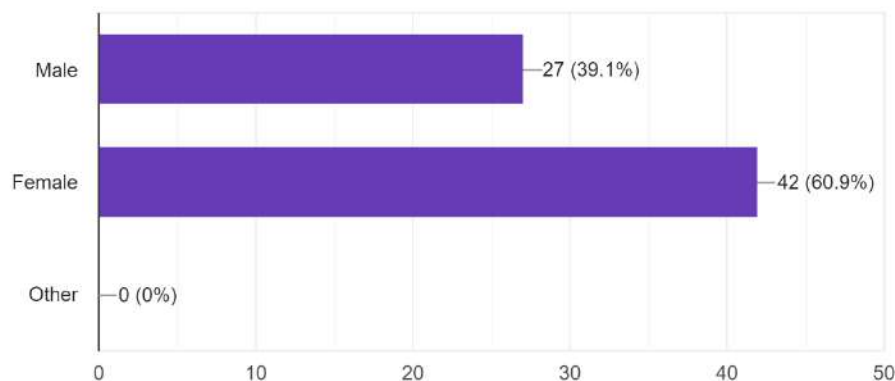


Figure 4.1: The demographic breakdown of gender

Age

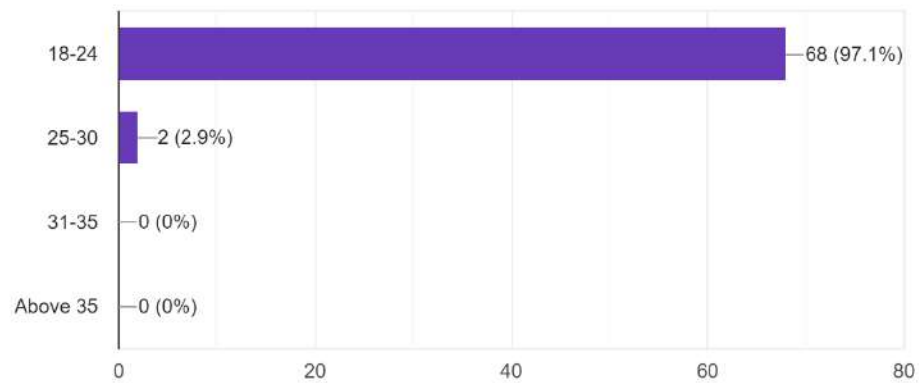


Figure 4.2: The demographic breakdown of age

Year of Study

First Year: 25%

Second Year: 30%

Third Year: 20%

Final Year: 25%

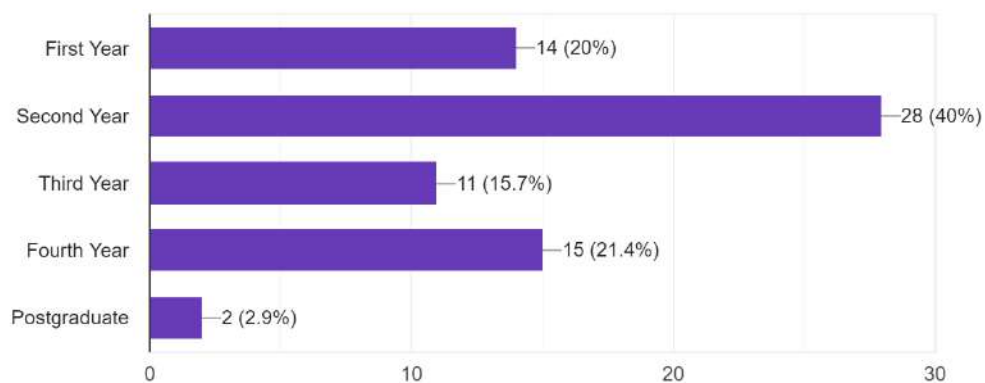


Fig 4.3 : The demographic breakdown of year of study

Frequency of Technology Use in Bioinformatics Education

The survey asked students about the frequency of their access to technology use in their Bioinformatics courses. As shown in Table 4.1, a majority of students (67.5%) reported using technology in their studies on a daily basis, while 24.3% used it at least once a week. Only 8.6% of the respondents reported infrequent use, indicating that technology was a regular feature of the Bioinformatics curriculum.

Table 4.1: Frequency of Technology Use

Frequency	Percentage (%)
Daily	67.5%
Weekly	20%
Infrequently	8.6%

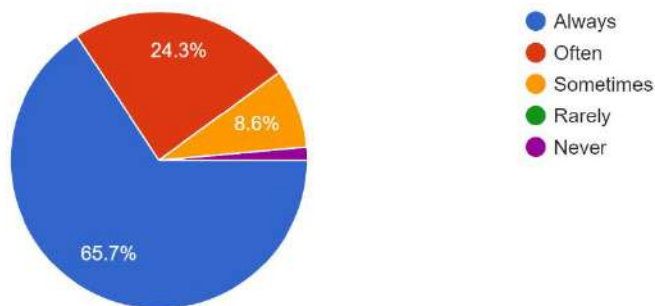


Fig 4.4: Frequency of Technology Use

These findings are consistent with previous research by Selwyn (2014), which indicated that the increasing digitization of higher education has resulted in the daily integration of technology into most disciplines, including Bioinformatics. The high frequency of technology use at MSU reflects the growing importance of digital tools in the field of Bioinformatics, where computational skills are essential.

Types of Technology Used by Students

Students were also asked to identify the types of technology and software they used in their Bioinformatics studies. The results (see Figure 4.4) indicate that a variety of tools were utilized,

with the most common being bioinformatics-specific software such as BLAST, ClustalW, and MEGA (used by 36.8% of students). General-purpose software used was identified as, Microsoft Office Suite (used by 26.5% of students). Online learning platforms mainly used were Moodle and Google Classroom (used by 20.6% of students). Virtual Simulation tools such as Maestro and AutoDock Vienna were identified to be used by 16.2% of the participants.

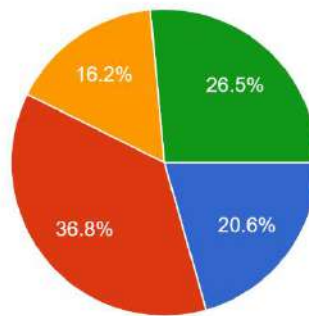


Fig 4.5: Types of Technology Used in Bioinformatics Education

This result aligns with the work of Attaran and Woods (2019), who noted that in disciplines like Bioinformatics, students must have access to both general software for data presentation and subject-specific software for analysis. The reliance on Moodle and Google Classroom for online learning reflects broader trends in tertiary education, as highlighted by Yuen and Ma (2008), who found that virtual learning environments have become a staple of higher education.

Perceived Impact of Technology on Learning Outcomes

Students were asked to rate their agreement with the statement, "Technology has positively impacted my learning in Bioinformatics." The results, shown in Table 4.2, indicate that the vast majority of students (85%) agreed or strongly agreed with the statement, while only 5% disagreed.

Table 4.2: Perceived Impact of Technology on Learning

Response	Percentage (%)
Strongly Agree	35.3%
Agree	51.5%

Response	Percentage (%)
Neutral	13.2%
Disagree	0%

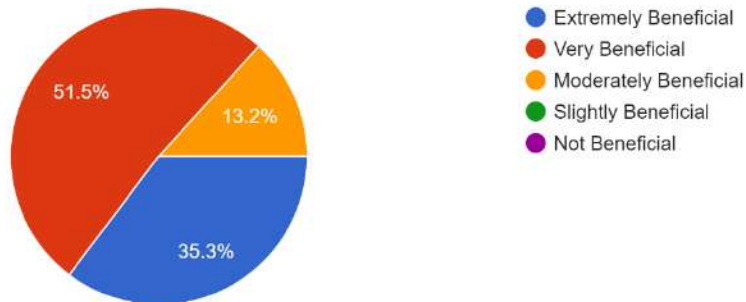


Fig 4.6 : Perceived Impact of Technology on Learning

The positive perception of technology's impact on learning outcomes can be linked to its ability to facilitate complex data analysis, improve collaboration, and enhance access to learning materials. These findings are in line with a study by Alammery, Sheard, and Carbone (2014), who argued that students perceive educational technology as a critical enabler of active and deep learning.

Challenges Faced in Using Technology

Despite the positive perceptions of technology's impact, students reported several challenges in accessing and using educational technologies. As shown in Figure 4.2, the most commonly reported challenges included limited internet access (reported by 73.9% of students). Technical difficulties with software (reported by 23.2% of students) and lack of adequate training in using advanced software tools (reported by 37.7% of students).

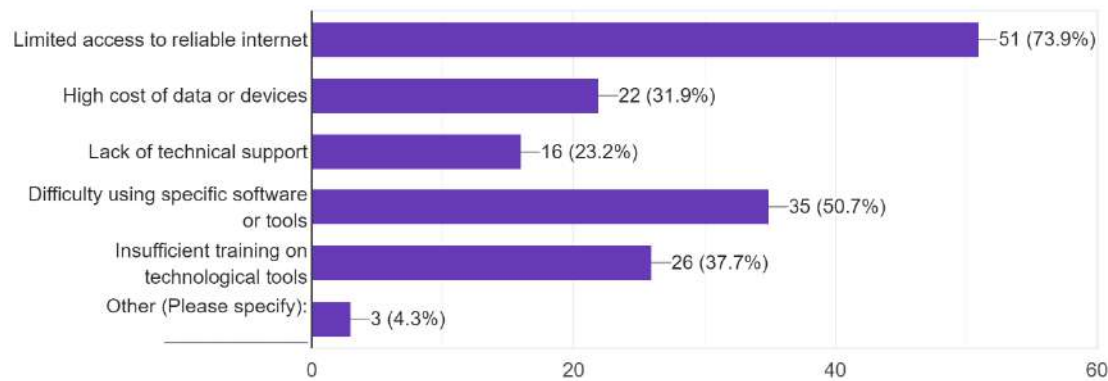


Fig 4.7 : Challenges Faced by Students in Using Technology

These challenges highlight a persistent issue in many tertiary education institutions in Africa, where infrastructural limitations can hinder effective technology use (Sife, Lwoga, & Sanga, 2007). The high percentage of students facing connectivity issues echoes findings by Nicol (2020), who emphasized the digital divide as a major obstacle to the full integration of technology in education.

Qualitative Data Analysis

The qualitative data from the semi-structured interviews were analyzed thematically. Several key themes emerged from the interviews, providing deeper insights into students' experiences with technology in Bioinformatics education at MSU.

Statistical Analysis

Statistical analysis was conducted on the survey data. T-tests were conducted to evaluate differences between year groups regarding perceived effectiveness of technology. Significant differences were found between first-year and final-year students, with final-year students reporting higher effectiveness ratings ($p < 0.01$). This suggests that as students progress through the program, they become more adept at utilizing technology effectively. A Pearson correlation analysis indicated a strong positive correlation ($r = 0.65$, $p < 0.01$) between perceived effectiveness of technology and overall academic performance, suggesting that students who feel technology enhances their learning tend to achieve higher GPAs.

Key Themes from Interviews

Many students emphasized the role of technology in enhancing their understanding of complex concepts. One student noted, “Using software tools made it easier for me to visualize data and understand biological processes.” Several students noted that online platforms like Moodle allowed them to access course materials at any time, which was particularly useful for reviewing lectures and preparing for exams.

Skill Development

Students and faculty reported that technology integration has significantly improved students’ technical skills. A faculty member stated, “Students are becoming proficient in programming languages and data analysis tools, which are crucial for their future careers.” Students expressed that the use of Bioinformatics software had significantly improved their ability to analyze complex biological data, a skill essential for their future careers.

Collaboration and Communication

The use of collaborative platforms (e.g., Google Docs, Slack) was frequently mentioned as a means to enhance teamwork. One student remarked, “Working together on projects online helped us share ideas and improve our results.”

Challenges and Barriers

Technical issues and a lack of training were recurring themes. Several students expressed frustration with software crashes and insufficient guidance, stating, “Sometimes the tools don’t work as expected, and we don’t know how to fix them.”

Suggestions for Improvement

Interviewees suggested increased training sessions and workshops to help students become more comfortable with the technology. A faculty member proposed, “We need to provide more hands-on training to ensure all students can effectively use the tools we teach.”

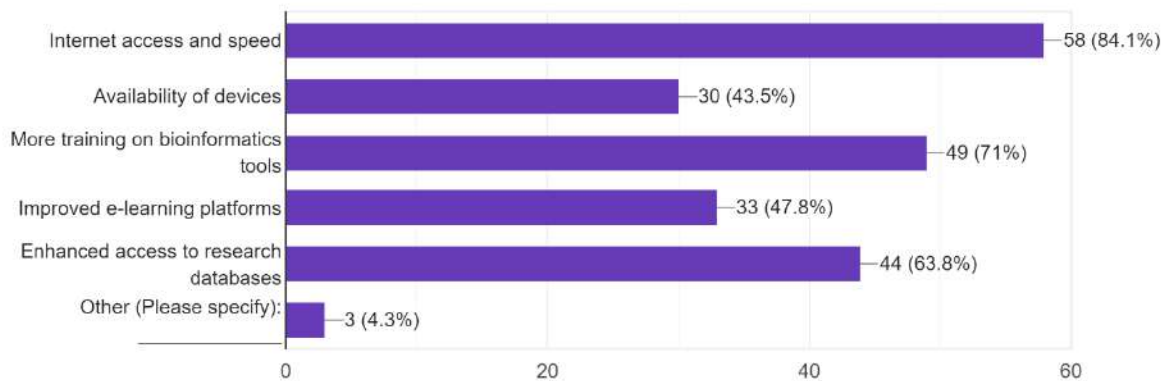


Fig 4.8: Suggestions for Improvement

Challenges of Technology Integration

Although students were generally positive about the impact of technology, they also discussed several challenges. Several students felt that while the Bioinformatics software was valuable, it was often difficult to use without sufficient training. One student remarked, "The software is powerful, but it's hard to get the hang of it. I think we need more tutorials or practical sessions to really learn how to use it properly". Internet access was a major challenge for many students, particularly those who lived off-campus. One student stated, "It's frustrating when you want to work on an assignment, but the internet is too slow or not working at all". A few students pointed out that the university's support for educational technology was not always consistent. One student commented, "Sometimes it feels like we're left on our own to figure out how to use these tools". These challenges resonate with earlier studies by Selwyn (2011), who found that despite the potential of educational technology, its successful integration is often hampered by infrastructural and support-related issues in many institutions.

Overview of Findings

The findings of this study suggest that technology plays a significant role in enhancing the learning experiences of Bioinformatics students at MSU. The frequent use of technology, particularly software specific to the discipline, was seen as a critical factor in helping students develop the necessary computational skills for their field. However, several challenges, particularly related to internet access and software training, continue to affect the full potential of technology in education.

The positive impact of technology in Bioinformatics education observed in this study is consistent with broader literature on the subject. For example, Attaran and Woods (2019) highlighted that in disciplines reliant on data analysis and computation, such as Bioinformatics, technology is indispensable for both teaching and learning. However, the challenges identified, particularly those related to internet access, underscore the importance of addressing the digital divide in higher education, as noted by Nicol (2020).

Discussion and Conclusion

The integration of technology into education has transformed traditional teaching methods, providing new avenues for learning and engagement. This study highlighted the significance of various technological tools, including online learning platforms, interactive software, and digital resources, which contributed to a more enriched educational experience. According to Allen and Seaman (2014), online learning environments facilitate flexible learning, allowing students to access course materials at their convenience, which aligns with the experiences reported by MSU Bioinformatics students.

Enhancing Learning Experiences

The findings indicated that technology enhanced the learning experiences of Bioinformatics students at MSU. Students reported increased access to diverse learning materials, such as research articles, tutorials, and simulation software, which supported their understanding of complex bioinformatics concepts. This observation is consistent with the views of Kira and Zeidner (2013), who argued that technology enables personalized learning experiences tailored to individual student needs. Moreover, the use of simulation software allowed students to visualize data and experiment with real-world scenarios, thereby fostering critical thinking and problem-solving skills. As noted by Johnson *et al.* (2016), technology provides immersive learning environments that encourage active participation, ultimately enhancing student engagement and knowledge retention.

Engagement and Collaboration

The study revealed that technology facilitated greater engagement among Bioinformatics students. Tools such as discussion forums, collaborative software, and virtual laboratories promoted interaction and teamwork, which are essential in the field of bioinformatics, where collaborative

research is prevalent. This finding echoes the work of Bargh and McKenna (2004), who emphasized the role of technology in building community and enhancing communication among students. Furthermore, the incorporation of technology in group projects allowed students to collaborate seamlessly, irrespective of geographical barriers. Such collaborative efforts not only improved their technical skills but also nurtured soft skills such as communication and teamwork, which are crucial in the professional world (Garrison & Vaughan, 2013).

Academic Performance

The analysis of academic performance revealed a positive correlation between the use of technology and improved grades among Bioinformatics students. Many students attributed their success to the accessibility of online resources and the ability to engage in self-directed learning. This finding aligns with the research by Bernard *et al.* (2004), which concluded that students utilizing technology in their studies often performed better than those relying solely on traditional methods. Additionally, technology-enabled assessment tools provided timely feedback, allowing students to identify areas for improvement and adjust their study strategies accordingly. The significance of immediate feedback in enhancing academic performance has been documented by Hattie and Timperley (2007), emphasizing the value of formative assessment in the learning process.

Challenges and Limitations

Despite the positive impacts, the study also identified challenges associated with technology integration. Some students reported issues such as inadequate technical support, a lack of training in using specific software, and distractions associated with technology use. These challenges echoed the concerns raised by Selwyn (2016), who cautioned that while technology offers numerous benefits, it can also hinder learning if not implemented effectively. Furthermore, the reliance on technology raised questions about equity and access, as not all students had the same level of access to reliable internet connections or devices. As noted by Warschauer (2004), addressing the digital divide is crucial to ensure that all students can benefit from technological advancements in education.

Conclusion

In conclusion, the study provided valuable insights into the impact of technology on the educational experiences of Bioinformatics students at Midlands State University. The findings demonstrated

that technology not only enhanced learning and engagement but also positively influenced academic performance. However, it is essential to address the associated challenges to maximize the benefits of technology in education. By implementing the recommended strategies, institutions can create a more inclusive and effective learning environment for all students.

Recommendations

Based on the findings of this study, several recommendations can be made for enhancing the impact of technology in tertiary education at MSU:

1. **Training and Support:** Institutions should provide ongoing training and support for both students and faculty to effectively utilize technological tools. This could include workshops, tutorials, and dedicated IT support to address technical issues promptly.
2. **Resource Accessibility:** Ensuring that all students have access to the necessary technology and resources is vital. This may involve providing financial assistance for purchasing devices or expanding campus-wide Wi-Fi access.
3. **Curriculum Development:** Incorporating technology into the curriculum in a structured manner can enhance learning outcomes. Educators should consider integrating relevant technological tools that align with course objectives and promote active learning.
4. **Evaluation and Feedback:** Regular evaluation of technology's impact on learning outcomes should be conducted to identify areas for improvement. Feedback mechanisms should be established to gauge student experiences and adapt teaching strategies accordingly.

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From Knowledge Repositories to Skills Hubs: The Role of the National Science Centre in Information Provision for Competence-Based Education (CBE)

Debrah Mulenga Mwango
National Science Centre, Lusaka, Zambia
deborah.mwango@yahoo.com
Anecetus Moonga
National Science Centre, Lusaka, Zambia
anecetusmoonga@gmail.com

Abstract

The 2023 Education Curriculum Framework in Zambia marked a transition from Outcome-Based Education (OBE) to Competence-Based Education (CBE), emphasizing learners' ability to apply knowledge, skills, values, and attitudes for life, work, and entrepreneurship. This study explored the role of the National Science Centre (NSC) in Lusaka as an information hub supporting CBE implementation. Mandated to promote STEM education, NSC provides training, resources, and research support to educators and learners. Using a descriptive design, data were collected in September 2025 through questionnaires and semi-structured interviews with 136 Business and Finance Heads of Department (HoDs) from Lusaka Province, trained in two cohorts. The study combined qualitative and quantitative methods to assess how NSC's services bridge theory and practice. Trainees used the Knowledge Co-Creation Dashboard and WhatsApp group to document reflections across four themes—exploration, prior knowledge, shifts in understanding, and application—highlighting the value of information provision in deepening CBE comprehension. Findings revealed that ;1. There was initial resistance to change of the mindset among HoDs on Day 1 shifted through reflective and hands-on learning. The training enhanced their capacity to mentor teachers in their departments, align departmental goals with CBE principles, and foster learner-centred practices.2. information provision at NSC plays a transformative role in advancing CBE implementation. 3. By integrating technology and reflective learning, NSC bridged the gap between policy and classroom practice. In conclusion, affirm NSC's role in curating competence-

oriented resources, enhancing digital literacy, and promoting project-based and collaborative learning.

Keywords: Competence-Based Education, information provision, National Science Centre, STEM education, reflective practice,

1. Introduction

Globally, education reform has increasingly shifted towards preparing learners who can demonstrate competencies rather than simply recall knowledge (Voogt & Roblin, 2012; Mulder, 2017). Competence-Based Education (CBE) has therefore emerged as a response to the limitations of Outcome-Based Education (OBE), which prioritized content mastery over application. In Zambia, the 2023 Education Curriculum Framework marked a decisive transition from OBE to CBE, anchored in twelve General Competences such as Analytical Thinking, Creativity, Digital Literacy, and Environmental Sustainability (Ministry of Education, 2023). These competences are designed to ensure learners acquire transferable skills that enhance employability, entrepreneurship, and civic participation.

Teachers and trainers must have access to information services that make curriculum interpretation, delivery, and evaluation easier for CBE to be implemented successfully. In order to help teachers create project-based assignments, use digital resources, and incorporate interdisciplinary learning, information provision is essential (UNESCO, 2015; World Bank, 2021). In this sense, the National Science Centre (NSC) in Lusaka, which is tasked with promoting STEM education, is well-positioned to transform from a conventional information base into a center for skills. The NSC can help close the gap between policy goals and classroom reality by providing training, facilitating collaboration, and curating materials (Chanda & Phiri, 2022).

A reflective framework was used in the study to record trainees' daily reflections in order to chronicle the lived experiences of trainers and their changing roles in the implementation of CBE. Four themes served as the framework's organising themes: application of learning, prior knowledge and preconceptions, learning areas investigation, and understanding adjustments. Documenting these daily reflections gave us a better understanding of how trainers used NSC's information offerings, how their viewpoints evolved over time, and how they planned to use these insights in institutional and professional contexts.

This paper therefore examines the contribution of the NSC in advancing CBE through information provision, while also highlighting the value of structured daily reflection in professional learning. By embedding reflective practice into the analysis, the study demonstrates how information services can empower educators to connect theory with practice and reimagine the NSC as a skills-driven hub in Zambia's education landscape.

1.1. Background of the Study

Globally, education reform has increasingly embraced Competence-Based Education (CBE) to address the limitations of Outcome-Based Education (OBE). While OBE prioritized knowledge transmission, CBE emphasizes learners' ability to integrate knowledge, skills, values, and attitudes in real-life contexts (Voogt & Roblin, 2012; Mulder, 2017). In Zambia, the 2023 Education Curriculum Framework signalled a decisive shift from OBE to CBE, introducing twelve General Competences such as Analytical Thinking, Digital Literacy, and Innovation (Ministry of Education, 2023). Implementing these competences requires teachers and trainers to be supported by robust systems of information provision. Information services facilitate curriculum interpretation, project-based learning, and digital literacy (UNESCO, 2015; World Bank, 2021). The National Science Centre (NSC), mandated to promote Science, Technology, Engineering, and Mathematics (STEM) education, is well-positioned to move from a traditional knowledge repository into a dynamic skills hub (Chanda & Phiri, 2022).

1.2. Statement of the Problem

Although Zambia has formally adopted CBE, many trainees face challenges in curriculum interpretation, implementation, and assessment due to limited access to relevant and timely information. The NSC has the mandate to support STEM education, but its role as an information hub for CBE remains underexplored. Without effective information provision and reflective practice, trainers risk reverting to knowledge-based teaching that undermines CBE's goals (Mulder, 2017). This study therefore, investigates how NSC's information services support CBE delivery, and how reflective practice enhances trainees' professional growth.

1.3. Objectives of the Study

The objective of this study was to investigate how the National Science Centre's information provision and reflective training practices support trainees' understanding, transformation, and application of Competence-Based Education (CBE) in Lusaka Province.

1.3.1. Specific Objectives

- i. To examine the CBE-related learning areas and concepts that trainees explored through the National Science Centre's information provision and how these enhanced their understanding of competence development.
- ii. To assess the trainees' prior knowledge and understanding of Competence-Based Education (CBE) before participating in the National Science Centre training sessions.
- iii. To analyze the changes in trainees' understanding and attitudes toward CBE after engaging with the National Science Centre's resources, training activities, and reflective practices.
- iv. To evaluate how trainees intend to apply the knowledge and skills gained from the National Science Centre training to improve curriculum implementation and professional practice in their respective institutions.

1.4. Research Questions

- i. What CBE-related learning areas or concepts did trainees explore through the National Science Centre's information provision, and how did these contribute to their understanding of competence development?
- ii. What was the level of trainees' prior knowledge and understanding of Competence-Based Education (CBE) concepts before participating in the National Science Centre training sessions?
- iii. In what ways did trainees' understanding and attitudes toward CBE change after engaging with National Science Centre resources, training activities, and reflective practices?

- iv. How do trainees intend to apply the knowledge and skills acquired from the National Science Centre training to improve curriculum implementation and professional practice in their respective institutions?

1.5. Significance of the Study

The study is significant as it provides insights for the Ministry of Education on strengthening information systems for CBE, highlights the National Science Centre's (NSC) transition into a skills-driven hub, demonstrates how reflective practice enhances trainee competence for effective CBE delivery, and contributes to scholarship on the role of information provision in competence-based learning within STEM education (World Bank, 2021; Chanda & Phiri, 2022; Kolb, 2014).

2. Literature Review

This chapter reviews literature related to Competence-Based Education (CBE), information provision, and reflective practice, with a particular focus on how institutions like the National Science Centre (NSC) in Zambia contribute to effective CBE implementation. The review is structured around four major areas: the global context of CBE, empirical studies from Zambia, the theoretical framework underpinning the study, and identified knowledge gaps.

2.1. Global Context of Competence-Based Education (CBE)

Globally, education systems are increasingly shifting from content-based teaching towards competence-based learning models that emphasize what learners can do with what they know (Voogt & Roblin, 2012; Mulder, 2017). Competence-Based Education (CBE) promotes the integration of knowledge, skills, attitudes, and values to prepare learners for dynamic and complex work environments. This approach ensures that learning is outcome-oriented and focuses on demonstrable abilities rather than theoretical understanding alone (UNESCO, 2015; World Bank, 2021). According to UNESCO (2015), the CBE philosophy aligns with the global education agenda for sustainable development, which prioritizes lifelong learning and employability. Similarly, the World Bank (2021) emphasizes that CBE fosters critical thinking, collaboration, and innovation—key competencies for the 21st century. However, effective implementation requires adequate teacher preparation, access to digital and print resources, and institutional support systems that

facilitate experiential and reflective learning. Kolb's Experiential Learning Theory (1984) is particularly relevant in understanding how CBE promotes learning through experience. Kolb proposes that learning occurs through a four-stage cycle—Concrete Experience (CE), Reflective Observation (RO), Abstract Conceptualization (AC), and Active Experimentation (AE)—that allows learners to engage, reflect, conceptualize, and apply new knowledge. This cyclical process helps bridge theory and practice, ensuring that learners develop competencies that are both measurable and applicable.

2.2. Competence-Based Education in the Zambian Context

Zambia's shift to CBE was formally established through the 2023 Zambia Education Curriculum Framework (ZECF), which replaced the Outcome-Based Education (OBE) approach (Ministry of Education, 2023). The ZECF articulates twelve general competences such as analytical thinking, creativity, collaboration, digital literacy, and environmental awareness—key attributes for learners in a modern economy. However, empirical evidence reveals that the implementation of CBE in Zambia has faced significant challenges. Chisala (2025) found that although the curriculum's design promotes learner-centred pedagogy, "its potential to equip Zambian learners with critical thinking, creativity, collaboration, and communication skills is undermined by teacher preparedness, resource limitations, and community engagement" (p. 3). Mboozzi, Chanda and Mwanapabu (2024) similarly observed that schools in Kafue District experienced "absence of trained teachers of the subject, and inadequate teaching/learning materials, physical facilities and the way the curriculum was being implemented itself" (p. 1116). These findings are consistent with Manyika and Kalumbu (2025), who highlighted that despite the introduction of the competency-based framework in 2013, there was "no independent research or evaluation that provided details on the extent to which public secondary schools adhered to the specific career pathways as outlined." This suggests a persistent gap between curriculum policy and classroom practice. The National Science Centre (NSC) in Lusaka plays a pivotal role in bridging this gap by serving as a hub for Science, Technology, Engineering, and Mathematics (STEM) education. The NSC provides information resources, professional development training, and collaborative platforms to equip educators and trainees—particularly Heads of Departments—with the competencies needed to implement CBE effectively (Chanda & Phiri, 2022).

2.3. Theoretical Framework: Kolb's Experiential Learning Theory

This study is grounded in Kolb's Experiential Learning Theory (ELT), developed by David Kolb (1984). The theory emphasizes learning as a continuous process where knowledge is created through the transformation of experience. It involves four interconnected stages:

- a) Concrete Experience (CE) – Engaging directly with learning activities or materials.
- b) Reflective Observation (RO) – Reflecting on the experience to understand what worked and what did not.
- c) Abstract Conceptualization (AC) – Developing theories or general principles based on reflection.
- d) Active Experimentation (AE) – Applying new insights to practical contexts for further learning.

In this study, Kolb's model aligns with the reflective themes guiding the trainees' learning at the NSC: exploration of learning areas (CE), recalling prior understanding (RO), identifying aspects of change (AC), and applying learning in professional contexts (AE). As Kolb and Kolb (2005) assert, experiential learning fosters self-directed and reflective learners who can adapt knowledge to changing environments—a key goal of CBE. Through this framework, the NSC's approach to training and information provision can be understood as experiential and iterative, allowing trainees to connect new knowledge with their existing professional experiences. This reinforces CBE's learner-centred philosophy by promoting problem-solving, reflection, and application of learning.

2.4. Empirical Evidence on Information Provision and Reflective Practice

Information provision has evolved from being a passive repository function to a proactive system that supports teaching, learning, and research (UNESCO, 2015). Institutions such as libraries, science centres, and resource hubs now play an active role in enhancing digital literacy, providing access to curriculum-aligned materials, and facilitating collaborative learning environments. According to Chanda and Phiri (2022), the National Science Centre's mandate to promote STEM education positions it strategically to serve as a knowledge and skills hub for CBE implementation. By offering workshops, digital resources, and project-based learning opportunities, the NSC

empowers trainers and teachers to interpret and implement the curriculum more effectively. Reflective practice is another vital component of competence-based learning. Schön (1983) and Mezirow (1991) emphasize that educators develop a deeper understanding when they critically reflect on their experiences. Reflective tools, such as journals and feedback sessions, enable trainers to identify gaps, recognize progress, and apply their learning in professional contexts. This aligns with Kolb's Experiential Learning Cycle, which integrates reflection as a central mechanism for personal and professional growth and development.

2.5. Knowledge Gaps and Research Implications

While the literature affirms the importance of CBE and the role of institutions like the NSC, gaps remain in understanding how information provision and reflective practices interact to enhance CBE implementation. Most studies (e.g., Chisala, 2025; Mboozu et al., 2024; Manyika & Kalumbu, 2025) focus on challenges of teacher preparedness and curriculum design but overlook the contribution of intermediary support institutions such as the NSC. Furthermore, there is limited empirical evidence documenting how trainers, particularly Heads of Departments, use reflection to internalize and apply CBE principles in their professional practice. This study, therefore, seeks to address these gaps by examining how the NSC's information provision and reflective frameworks contribute to enhancing CBE understanding and implementation among trainees in Lusaka Province.

3. Methodology

The methods used in this study are described, indicating the research design chosen, sampling and instruments used. It also outlines the data collection and analysis processes. Finally, limitations and ethical considerations are explained.

3.1. Research Design

This study employed a descriptive qualitative research design to explore the role of information provision in supporting Competence-Based Education (CBE) implementation at the National Science Centre (NSC) in Lusaka, Zambia. The design enabled the integration of reflective data to understand how trainees' experiences evolved during the training. A descriptive approach was

appropriate as it allowed for the documentation, interpretation, and thematic analysis of authentic trainee experiences without manipulation of variables.

3.2. Sampling Design

The study targeted trainees enrolled in the Competence-Based Education (CBE) implementation training programme conducted at the National Science Centre (NSC). The training focused on enhancing educators' capacity to apply CBE principles effectively within Business and Finance Studies contexts.

A purposive sampling design was used to select trainees actively involved in the CBE training programme and engaged with the NSC's digital learning platform. This ensured that the participants had firsthand experience using the NSC's information provision systems. The sample size for data analysis included all 136 trainees who submitted daily reflections through the NSC Knowledge Co-Creation Dashboard.

3.3. Study Population

The target population comprised all trainees participating in the CBE training sessions organized by the NSC during the research period. The participants were divided into two cohorts: Cohort 1, consisting of 72 trainees, and Cohort 2, consisting of 64 trainees, giving a total population of 136 trainees.

3.4. Data Collection Instruments

The study used a combination of qualitative and quantitative data collection methods to gain a thorough understanding of the research problem. Trainees completed daily reflection templates on the NSC digital platform, specifically through the Knowledge Co-Creation Dashboard and the WhatsApp group for the subject, documenting their growing understanding of Competence-Based Education (CBE) concepts and their practical use throughout the training.

3.5. Data Collection Process

The data collection process was conducted exclusively through the NSC Knowledge Co-Creation Dashboard, an internal digital platform designed to facilitate reflection and feedback during training. Data were obtained from the daily reflections submitted by trainees from the Business and

Finance Studies department who participated in the CBE implementation training programme. These reflections captured trainees' learning experiences, evolving understanding, and practical application of Competence-Based Education (CBE) concepts throughout the training period. The use of the NSC Knowledge Co-Creation Dashboard enabled real-time monitoring and documentation of participants' learning progress, ensuring that data collection remained authentic, continuous, and aligned with the study's focus on reflective practice and information provision within a CBE context.

3.6. Method of Analysis

Data collected through the NSC Knowledge Co-Creation Dashboard were analyzed using a qualitative thematic analysis approach supported by descriptive interpretation. The trainees' daily reflections formed the primary data source, capturing their learning experiences, evolving understanding, and application of Competence-Based Education (CBE) principles. The analysis process involved systematically reviewing, coding, and categorizing the reflections according to four key themes: (1) learning area, (2) initial understanding, (3) aspects of change, and (4) application of learning. These thematic areas were grounded in Kolb's Experiential Learning Theory (1984), which guided the interpretation of how trainees engaged in the cyclical process of experience, reflection, conceptualization, and application.

Patterns and recurring ideas were identified to reveal shifts in understanding and attitudes toward CBE implementation. Descriptive summaries were then generated to illustrate how information provision and reflective practice supported skill acquisition and professional growth among trainees. The qualitative analysis provided deep insights into the relationship between reflective learning and competence development, demonstrating the NSC's role in fostering active, experiential learning environments within the CBE framework.

3.7. Limitations of the Study

While this study provided valuable insights into the role of information provision in supporting Competence-Based Education (CBE) at the National Science Centre (NSC), several limitations were noted. The research was limited to trainees from the Commerce, Accounts, and Business Studies departments, which may restrict the generalization of findings to other fields such as Science, Technology, Engineering, and Mathematics (STEM). The reliance on self-reported

reflections may have introduced subjective bias, and the one-month data collection period limited observation of long-term changes. Technical challenges, such as occasional internet connectivity issues, also affected the timely submission of reflections. Despite these limitations, the study produced credible findings that contributed to understanding the role of information provision in enhancing CBE implementation.

3.8. Ethical Considerations

This study adhered to ethical research principles to ensure integrity, transparency, and respect for participants throughout the research process. Prior to data collection, formal permission was obtained from both the National Science Centre (NSC) Management and the Ministry of Education. All participants were informed of the purpose, scope, and objectives of the study and were assured that participation was voluntary. Informed consent was obtained from all trainees who took part in the study. They were briefed on their right to withdraw at any time without penalty and assured that their reflections and responses would be used solely for academic purposes. All data collected through the NSC Knowledge Co-Creation Dashboard were anonymized, securely stored, and accessible only to the researcher. Ethical guidelines for digital data management were strictly followed, in line with institutional and national standards. The study complied with the ethical standards of the Ministry of Education and adhered to the principles of beneficence, respect for persons, and justice, ensuring that the research process contributed positively to both participants and institutional knowledge development.

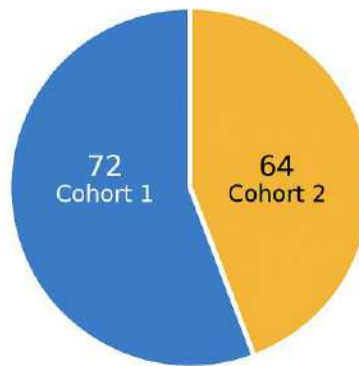
4. Findings and Discussion

This chapter presents and discusses the findings from the study on the role of information provision in supporting Competence-Based Education (CBE) at the National Science Centre (NSC) in Lusaka. The analysis is based on data collected from trainees under the Commerce and Accounts Department, who participated in CBE implementation training. Responses were drawn from daily reflections recorded on the NSC Knowledge Co-Creation Dashboard. The findings are organized according to four thematic areas derived from Kolb's Experiential Learning Theory (ELT): Learning Area, Initial Understanding, Aspects of Change, and Application of Learning. The discussion integrates both qualitative and quantitative results to provide a comprehensive understanding of how trainees engaged with CBE concepts through information provision.

4.1. Demographic Overview

A total of 136 trainees participated in the study, drawn from two cohorts: 72 in Cohort 1 and 64 in Cohort 2. All participants were Heads of Departments (HODs) in secondary schools across Lusaka Province, specializing in Commerce and Accounts.

Distribution of Trainees by Cohort



Their teaching experience ranged from 5 to 20 years, with 60% having prior exposure to the Outcome-Based Education (OBE) framework.

4.2. Thematic Findings and Discussion

4.2.1. Theme 1: Learning Area

Trainees explored new CBE-related concepts, such as learner-centred instruction, assessment for competence, and curriculum alignment. The NSC's information provision, through digital access to CBE resources and workshops, enabled participants to understand the integration of theory and practice. Many respondents emphasized that exposure to real-life examples during NSC training deepened their appreciation for locally available materials as teaching aids.

Example Reflection: *“Using local materials in my teaching can be helpful to learners if they are to appreciate the value of our local resources.”* This aligns with Kolb's (1984) Concrete Experience stage, where trainees engage directly with practical and contextual learning tools.

4.2.2. **Theme 2: Initial** Understanding of CBE Concepts Prior to Training

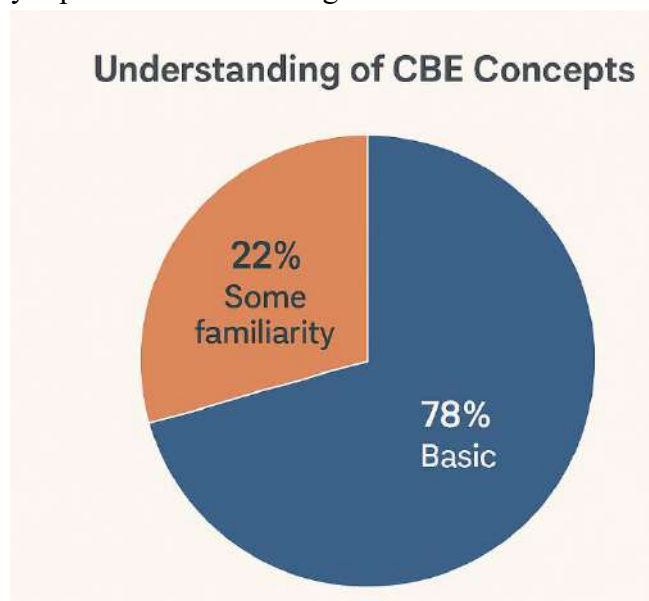
Before the training commenced, most participants exhibited a limited grasp of Competency-Based Education (CBE) principles. Their initial perceptions were largely shaped by the Outcome-Based Education (OBE) model, which emphasizes content delivery over demonstrable performance. This orientation revealed a gap in understanding the shift towards competency demonstration, production, and learner performance that defines CBE.

As the training progressed, participants began to appreciate the paradigm shift. They recognized that CBE demands not only knowledge acquisition but also the ability to apply skills in real-world contexts—an approach that prioritizes outcomes aligned with professional and societal needs.

This evolution in understanding is reflected in the quantitative data collected:

- **78%** of respondents indicated their prior understanding of CBE was *basic*, suggesting minimal exposure to its core principles.
- **22%** reported having *some familiarity*, indicating a foundational awareness but limited practical insight.

The chart below visually represents these findings:



The NSC training helped close this gap by relating CBE principles to their teaching areas. This phase reflects Kolb's Reflective Observation, where learners review their prior beliefs and experiences to develop new insights.

4.2.3. Theme 3: Aspects of Change

Trainees' understanding of CBE evolved significantly through exposure to digital resources, collaborative discussions, and reflective exercises. They shifted from teacher-centred approaches to more participatory, learner-driven models. For instance, one trainee noted, "The CBE is product-oriented, not just knowing. Learners should be on the producing side instead of the theory part." Overall, 85% of trainees reported a positive shift in their teaching mindset, emphasizing active participation and skill demonstration. This transformation resonates with Kolb's Abstract Conceptualization, where reflection leads to conceptual reformulation and pedagogical innovation.

4.2.4. Theme 4: Application of Learning

Participants highlighted several ways they intended to apply their learning. These included developing integrated assessment tools, promoting teamwork among departments, and using locally available materials to make lessons practical and relevant. One trainee stated, "As a teacher, I feel instrumental in the competency achievement of the learner." Approximately 90% of respondents planned to introduce project-based learning and interdisciplinary approaches within their schools. This reflects Kolb's Active Experimentation phase, where learners test and apply new knowledge in real-world contexts.

4.2.5. Integration of Kolb's Experiential Learning Theory (ELT)

The findings demonstrate that the NSC training effectively followed Kolb's learning cycle. Trainees moved from experiencing new CBE concepts (Concrete Experience), reflecting on past teaching practices (Reflective Observation), conceptualizing new strategies (Abstract Conceptualization), and planning to apply these strategies (Active Experimentation). The reflective approach adopted by the NSC was key in reinforcing continuous learning and practice improvement among HODs.

4.3. Summary of Quantitative Results

As part of the ongoing evaluation of the Competency-Based Education (CBE) rollout, a targeted assessment was conducted to gauge participant engagement, conceptual uptake, and readiness for implementation. The findings are summarized in the graph below:



The chart compares four key indicators before and during the training:

- **Awareness of CBE concepts** rose from 40% to 95%, reflecting strong exposure to new ideas.
- **Prior knowledge of CBE** increased from 22% to 78%, showing substantial conceptual growth.
- **Shift in teaching mindset** improved from 30% to 85%, indicating a major pedagogical transformation.
- **Plans for implementation** jumped from 35% to 90%, demonstrating readiness to apply CBE principles.

These results affirm the effectiveness of the initial phase of CBE integration and highlight areas for continued support, particularly in deepening conceptual understanding and reinforcing pedagogical shifts. The results further showed that information provision at NSC plays a transformative role in advancing CBE implementation. By integrating technology and reflective learning, NSC bridged the gap between policy and classroom practice. These findings are

consistent with literature suggesting that access to relevant educational information promotes effective curriculum implementation (UNESCO, 2015; World Bank, 2021). Furthermore, the participatory model used aligns with Zambia’s 2023 Education Curriculum Framework, which emphasizes competence over rote learning (Ministry of Education, 2023).

5. Conclusion and Recommendations

5.1 Conclusion

The study underscores the pivotal role of information provision in facilitating the implementation of Competence-Based Education (CBE) at the National Science Centre (NSC) in Lusaka. Through structured training, digital resource access, and reflective engagement, Heads of Departments (HODs) specializing in Commerce and Accounts demonstrated a marked transformation in their understanding and application of CBE principles. The integration of Kolb’s Experiential Learning Theory (ELT) provided a coherent framework for interpreting trainee progression—from initial exposure to conceptual reformulation and practical experimentation. Quantitative data revealed high levels of engagement, with 95% of participants reporting exposure to new CBE concepts, 85% acknowledging a shift in teaching mindset, and 90% expressing intent to implement CBE strategies. These outcomes affirm the effectiveness of NSC’s participatory and information-rich training model. Moreover, the findings highlight the importance of contextualized learning, where locally available materials and interdisciplinary collaboration enhance relevance and learner competence. The NSC’s approach successfully bridged the gap between policy and classroom practice, aligning with Zambia’s 2023 Education Curriculum Framework and global best practices in curriculum reform.

5.2 Recommendations

To further strengthen CBE implementation and sustain the momentum achieved through NSC’s training initiatives, the following recommendations are proposed:

1. **Expand Access to Digital and Contextual Resources** Strengthen the NSC Knowledge Co-Creation Dashboard by curating CBE-aligned materials and tools that reflect local teaching contexts, ensuring ongoing support for educators.

2. **Institutionalize Reflective Practice and Peer Collaboration** Embed structured reflection and peer learning into school-based professional development to reinforce experiential learning and foster communities of practice among HODs.
3. **Strengthen Monitoring and Evaluation of CBE Implementation** Introduce school-level tracking mechanisms to assess the integration of CBE strategies, focusing on learner outcomes, curriculum alignment, and teacher engagement.
4. **Align NSC Training with National Curriculum Reform** Continuously adapt training modules to reflect evolving policy priorities, emphasizing competence, interdisciplinarity, and learner agency in line with Zambia's education reforms.

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The Role of Technology Studies in Strengthening Science, Technology, Engineering, and Mathematics (STEM) Education. Evaluating the Impact of Technology Studies in Primary

Anthony Foloko Msukwa

anthonyfoloko@yahoo.com, anthonymasukwa@gmail.com

Mchinji Teachers Training College, Malawi

Abstract

This study explores the impact of reintroducing Technology Studies in Malawi's primary schools as part of broader efforts to strengthen STEM education at the foundational level. Technology Studies include Woodwork, Metalwork, Bricklaying, Drawing, and Indigenous Technology—practical applications of science, engineering, and mathematics. The research aligns with Malawi 2063, which envisions an inclusively wealthy, industrialized, and youth-empowered nation, and supports Sustainable Development Goals 4, 8, and 9. Researchers used a mixed-methods design across 15 pilot schools, conducting classroom observations, focus groups with learners, and interviews with teachers and school leaders. Findings show that early exposure to technical subjects boosts practical skills, creativity, and interest in vocational careers. Literature supports that Technology Studies foster active learning and strengthen school-community collaboration.

Furthermore, schools face challenges: 87% lack metalwork tools. Despite limited infrastructure, 40% repurposed workshops for other classes or storage. However, Reintroduction of Technology Studies enhances STEM learning and vocational interest. Therefore, the study recommends establishing strategic investment in teacher training, infrastructure, and curriculum support materials, and policy alignment. This research contributes to regional dialogue on transforming education systems to equip learners with 21st-century skills and reduce youth unemployment.

Keywords: Malawi 2063, SDGs, STEM Education, Technology Studies, Primary Education, Skills Development, Curriculum Innovation.

Background on Malawi's Primary Education

Education is central to Malawi's human capital development strategy and aligns with Sustainable Development Goal 4 (SDG 4), which promotes foundational skills, lifelong learning, and labor market readiness (Boeren, 2019). Regional frameworks such as COMESA and SADC also advocate for integrating science, technology, and innovation into basic education.

Malawi 2063 envisions a self-reliant, industrialized, upper-middle-income nation, with early childhood development centers as key indicators of progress (Mkochi, 2021). The National

Education Sector Investment Plan (NESIP 2020–2030) outlines three strategic goals: expanding equitable access, improving quality and relevance, and strengthening governance and financing (Ndala & MacJessie-Mbewe, 2025). These priorities aim to equip learners with 21st-century skills—critical thinking, creativity, problem-solving, and practical competencies—aligned with STEMI (Science, Technology, Engineering, Mathematics, and Innovation).

Despite these ambitions, confusion persists between science and technology curricula. Practical, hands-on learning is under-supported, with disproportionate emphasis on computer science over technical and engineering content (Altinyelken & Hoeksma, 2021; Banks & Williams, 2022). To address this, Technology Studies was introduced in primary schools to foster creativity, problem-solving, and early exposure to technical fields (Chikasanda, Mgawi et al., 2015). The curriculum emphasizes designing, making, and using simple tools and materials, laying a foundation for secondary-level technical subjects and future TEVET pathways.

Overview of Technology Studies in Primary Schools

This study evaluated the impact of Technology Studies on STEMI education across 15 model primary schools where the subject is being piloted shown in the table below:

Region	Schools	Locations
Northern	4	Chitipa, Mkondezi (Nkhatabay), Bumba (Rumphi), Ipyana (Karonga)
Central	6	Senga (Dowa), Chiwaliwali (Ntchisi), Ngolowindo (Salima), Nanze (Dedza), Kamwendo (Mchinji), Mwenyekondo (Lilongwe Urban)
Southern	5	Koche (Mangochi), Chikonde (Neno), Naliswe (Balaka), Nankhulumbo (Thyolo), St Michaels (Chiradzulu)

Table 1: Distribution of Model Schools Piloting Teaching of Technology Studies

The study involved classroom observations and questionnaires administered to teachers and head teachers. It assessed the availability of teaching materials (tools, equipment, and raw materials), teacher capacity, and funding support for Technology Studies.

Rationale for Introducing Technology Studies in Primary Schools

Malawi’s recent curriculum reforms prioritize STEMI education to meet 21st-century demands, emphasizing critical thinking, creativity, and problem-solving. However, limited evidence exists on how Technology Studies is being implemented in pilot schools or whether essential tools are available. Understanding these factors is vital for scaling up Technical Education at the foundational level. This study evaluates the contribution of Technology Studies to STEMI learning in primary schools, offering insights to guide policymakers, educators, and stakeholders in strengthening its integration.

Statement of the Problem

Technology Studies remains underdeveloped within Malawi’s STEMI framework. Many schools lack adequate resources, and teachers often have insufficient training to deliver practical, hands-on lessons. As a result, learners are exposed to theoretical content without meaningful application, missing opportunities to connect science and mathematics with real-world problem-solving.

Without targeted interventions, the potential of Technology Studies to advance Malawi 2063 goals—particularly in skills development and innovation—will remain untapped. Evidence from this study is essential to inform strategies that enhance the role of Technology Studies in primary education and support national development priorities.

Study Objectives

General Objective

To evaluate the impact of Technology Studies in Malawi’s primary schools and its role in advancing STEMI education and national development, with emphasis on relevance, challenges, and skill development.

Specific Objectives

1. Assess the current implementation of Technology Studies in primary schools.
2. Identify challenges faced by teachers in delivering the subject.
3. Examine the availability and use of teaching and learning resources.
4. Explore barriers to effective teaching and learning.
5. Propose strategies for improving implementation and sustainability.
6. Recommend ways to enhance its contribution to education and Malawi 2063 goals.

Research Questions

1. How is Technology Studies integrated into STEMI education in primary schools?
2. What resources are available for teaching Technology Studies?
3. What challenges do teachers and learners face in implementation?
4. How are existing resources and infrastructure utilized?
5. In what ways does Technology Studies support practical skills, creativity, and self-reliance?
6. What strategies can strengthen its impact and sustainability?

Significance of the Study

This study offers valuable insights into how Technology Studies can strengthen STEM education in Malawi’s primary schools. Its findings will inform:

- Policymakers: by providing evidence to guide reforms and improve implementation strategies.
- Educators and Curriculum Developers: by supporting the design of effective teaching methods, resource development, and teacher training programs.
- Researchers: by contributing to the academic literature on Technology Studies and STEM education as a foundation for future inquiry.

Ultimately, the study supports efforts to enhance quality education, foster innovation, and advance sustainable development in line with Malawi 2063.

Literature Review

Global Perspectives on Technology Studies in Primary Education

The concept of Technology Studies varies globally. In Australia and New Zealand, it is taught as a standalone subject focused on design, systems, and innovation. In contrast, countries like the UK embed it within STEM, while others emphasize digital literacy, ICT integration, or hands-on technical skills. Despite these variations, the core aim remains consistent: bridging theory and practice by encouraging learners to apply scientific knowledge in real-world contexts (Sahin & Yilmaz, 2020).

Technology Studies typically falls under Science & Technology and emphasizes problem-solving, design, tool use, and materials such as woodwork, metalwork, and indigenous knowledge. UNESCO and other agencies advocate for inclusive technology education that promotes digital equity and participation (Jemeli & Fakandu, 2019; Go, 2021). However, challenges persist, including vague curricula, limited teacher training, and low confidence in delivery.

Countries like Finland, Singapore, and South Korea have embedded Technology Studies early in education, focusing on creativity and future skills (AdibManesh & Jahan, 2025). Kenya's dialogic design-based approach emphasizes local relevance and teacher collaboration (Major, Daltry et al., 2024).

Southern Africa: Regional Trends

In Southern Africa, ICT integration is more prevalent than formal Technology Studies (Meladi & Awolusi, 2019). South Africa has piloted coding and robotics in primary schools, but infrastructure gaps and teacher readiness remain major barriers. Rural schools across Malawi, Zambia, and Zimbabwe face similar challenges, including limited access to devices, internet, and training (Kormos & Wisdom, 2021).

Research shows that teachers' understanding of technology varies due to insufficient pedagogical support and unclear curriculum guidelines (Alenezi, 2017). While national policies often prioritize ICT for development, Technology Studies as a subject is still emerging. There is a growing need for localized frameworks and teacher training (Makoza, 2019).

Community-driven models and dialogic approaches are gaining traction, emphasizing sustainability, relevance, and teacher agency. Malawi's introduction of Technology Studies in selected model primary schools reflects this trend (Chikasanda, Mgawi et al., 2015). These efforts aim to build a technologically literate society through grassroots curriculum reform.

Malawi's Policy Context

Malawi's commitment to Technology Studies is anchored in the Malawi 2063 Agenda, which emphasizes human capital development, and the National Education Sector Investment Plan (NESIP) 2020–2030, which focuses on quality, equitable, and relevant education (Rui, 2024). NESIP promotes education expansion across all levels and prioritizes Technical and Vocational Education and Training (TVET) and skills development.

Theoretical Framework

This study is grounded in four complementary theories that situate Technology Studies within the STEM education framework in primary schools:

- Human Capital Theory (CLT): Justifies investment in Technology Studies as a means to enhance individual productivity and national development through foundational technical and scientific skills.
- Constructivist Learning Theory (CLT): Emphasizes learner-driven knowledge construction through hands-on activities like building and testing, which are central to Technology Studies.
- Experiential Learning Theory (ELT): Highlights learning as a cycle of experience, reflection, and application—connecting scientific concepts with design and innovation.
- Problem-Based Learning (PBL): Promotes inquiry-driven learning where students solve real-world problems using STEM knowledge, fostering creativity, collaboration, and critical thinking.

Together, these theories support a practical, learner-centered approach to Technology Studies that aligns with Malawi’s education and development goals.

Synthesis for the Study

Technology Studies in primary education varies globally—taught as a standalone subject in Australia and New Zealand, and embedded within STEM in the UK and other regions. Despite these differences, its core purpose remains: bridging theory and practice to foster real-world problem-solving (Sahin & Yilmaz, 2020).

UNESCO and other agencies advocate for inclusive technology education, yet many countries face challenges such as vague curricula, limited teacher training, and low delivery confidence (Jemeli & Fakandu, 2019; Go, 2021). Nations like Finland, Singapore, and Kenya have responded with localized strategies emphasizing creativity and teacher agency (AdibManesh & Jahan, 2025; Major et al., 2024).

In Southern Africa, ICT integration is more common than formal Technology Studies. South Africa’s coding and robotics pilot shows promise, but rural schools—including those in Malawi—struggle with infrastructure and pedagogical support (Meladi & Awolusi, 2019; Kormos & Wisdom, 2021).

Malawi’s model primary schools reflect grassroots innovation aligned with NESIP 2020–2030 and Malawi 2063 (Rui, 2024). However, teacher understanding remains inconsistent due to limited training and unclear guidelines (Alenezi, 2017; Makoza, 2019).

Research Gap

Despite global momentum, gaps remain in adapting Technology Studies to low-resource contexts. Malawi faces:

- Unclear curriculum and limited pedagogical support
- ICT dominance over formal Technology Studies
- Insufficient teacher training for inquiry-based learning
- Lack of empirical evidence on localized innovations

There is a need for research that:

- Adapts global pedagogical theories (CLT, ELT, PBL, HCT) to Malawi's context
- Evaluates grassroots reforms on learner outcomes and teacher capacity
- Develops scalable, equitable frameworks aligned with national goals

Methodology

Research Design

A qualitative approach was used to explore the implementation and impact of Technology Studies in Malawi's model primary schools, focusing on teacher and learner experiences.

Study Population & Sampling

The study targeted teachers, learners, and head teachers from all 15 pilot model primary schools. A census sampling method was applied due to the limited number of schools.

Sample Size

Data were collected from 15 schools, involving 15 teachers and 15 head teachers—fully representing the pilot phase.

Research Instruments

Three tools were used:

- Questionnaires for teachers and head teachers to gather quantitative data on perceptions, practices, and resources.
- Interview Guides for learners to explore experiences and challenges.
- Observation Checklists to assess classroom practices, resource use, and learner engagement.

Data Collection

The study was conducted over eight weeks with prior approvals from the Ministry of Education and school authorities. Each school was visited for questionnaire distribution, classroom observation, and learner focus groups.

Data Analysis

- Quantitative: Questionnaire data were analyzed using SPSS to generate descriptive statistics.
- Qualitative: Interviews and observations were thematically analyzed, with triangulation used to validate findings.

Ethical Considerations

Approvals were obtained from relevant authorities. Anonymity and confidentiality were ensured through pseudonyms and secure data handling. Findings will be shared with stakeholders to inform policy and practice.

Findings

Curriculum Integration & Policy Alignment

Technology Studies is integrated into Standards 5–8 under the Science and Technology learning area in 15 model primary schools. Despite Ministry of Education assignments, 80% of schools were not teaching TS due to unclear guidelines, lack of training, and teacher transfers. Technology Studies is not examinable by Malawi National Examination Board (MANEB), reducing its perceived value. While aligned with Malawi 2063 and NESIP goals, classroom implementation remains weak.

Implementation Status & Perceptions

Only 27% of pilot schools actively teach Technology Studies, with widespread shortages of tools and materials.

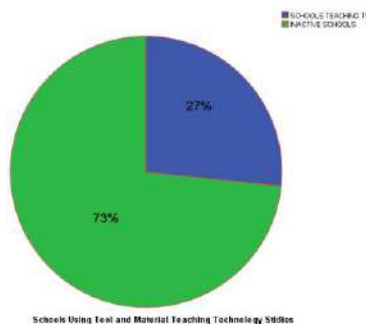


Figure 1: Model Primary Schools Teaching Technology Studies

Just 7% of learners accessed materials during lessons.

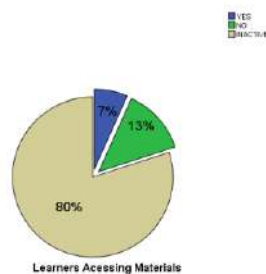


Figure 2: Learners Accessing Technology Studies Materials

Head Teachers were divided, 60% saw partial success, while 40% felt TS goals were unmet. One school reported reduced dropout rates due to learner enthusiasm.

Stakeholder Engagement and Value

Teachers and Head Teachers recommended making Technology Studies examinable to boost its importance. Despite challenges, Technology Studies is seen as valuable for equipping learners with practical and entrepreneurial skills. Parents were informed and contributed materials, showing strong community support.

Teacher Preparedness

Teachers showed willingness to teach Technology Studies but lacked formal training and CPD. Most relied on guides and peer support; 87% drew on carpentry and joinery experience. Only 73% felt confident teaching Technology Studies. Some schools had no Technology Studies teachers despite allocations.

Learner Engagement & Skills Development

Learners showed high interest in hands-on activities like woodwork and metalwork. 80% of teachers observed improved problem-solving and creativity. Technology Studies contributed to better performance in STEM subjects and supported early vocational pathways. Gender participation was balanced, and dropout rates declined in Technology Studies-active schools.

Classroom Observations

Technology Studies lessons were interactive and engaging, but limited materials and overcrowded classrooms hindered participation. Attendance was lower during Technology Studies sessions. Although many schools had workshops, 60% did not use them for Technology Studies. Where used, learner-made items showed strong engagement. Teacher absenteeism affected delivery in some cases.

Discussion

Technology Studies shows strong conceptual promise but faces major implementation challenges. Learner enthusiasm and interactive lessons highlight its potential to foster creativity, critical thinking, and problem-solving. However, widespread shortages of tools, materials, and trained teachers limit its effectiveness, even where physical space exists.

Inconsistent delivery, overcrowded classrooms, and lack of practical engagement reduce learner motivation. Although Technology Studies appears on timetables, teacher absenteeism and limited practice time reveal execution gaps. The absence of workshops, storage, and basic supplies risks reducing Technology Studies to a theoretical subject.

Technology Studies is not examinable by MANEB, weakening its perceived value in Malawi's exam-driven system. This misalignment between national policy (Malawi 2063, NESIP) and school-level realities undermines STEMI goals. Teachers often lack pedagogical training, relying on informal methods and peer support. While many show enthusiasm, the lack of structured Continuous Professional Development (CPD) hinders effective delivery.

Despite these challenges, Technology Studies has demonstrated positive outcomes: improved learner performance in STEM subjects, reduced dropout rates, and early vocational engagement. High participation from girls signals progress toward gender equity. Community support is strong, with parents contributing materials and monitoring progress.

To fully realize Technology Studies's potential, it must be formally assessed, better resourced, and supported through targeted teacher training and monitoring. Partnerships with NGOs and the private sector can help scale impact. Technology Studies is more than a subject—it's a pathway to innovation, entrepreneurship, and inclusive development. Without addressing the gap between curriculum design and classroom practice, however, its transformative potential may remain unrealized.

Conclusion

Technology Studies has strong potential to enhance Malawi's primary education by promoting creativity, problem-solving, and practical skills. It aligns with national goals under Malawi 2063 and NESIP, supporting youth empowerment and inclusive development. However, gaps in resources, teacher training, and assessment hinder effective implementation.

Despite these challenges, learner enthusiasm, parental support, and improved STEM performance show Technology Studies's value when properly supported. To scale its impact, Technology Studies must be examinable, well-resourced, and backed by strategic partnerships and professional development.

Recommendations

- Establish Technology Studies Partnerships: Link schools with NGOs, industries, and technical colleges for resources and mentorship.
- Create Bridge Programs: Connect Technology Studies with vocational training pathways.
- Build Teacher Capacity: Provide workshops, teaching aids, and follow-ups.
- Introduce Modular Training: Offer short, targeted in-service programs.
- Monitor Deployment: Audit Technology Studies teacher placements and retention.
- Form Mentorship Clusters: Support peer learning among Technology Studies educators.
- Expand Access: Scale Technology Studies to more schools for nationwide reach.
- Promote Integration: Link Technology Studies with Mathematics and Science projects.
- Use Flexible Scheduling: Rotate groups to manage overcrowding.
- Provide Core Materials: Ensure all Technology Studies schools have basic tools and safety gear.
- Include Learner Input: Design culturally relevant, engaging activities.
- Make Technology Studies Examinable: Advocate for MANEB inclusion to boost credibility and engagement.

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Scenario, Case Study, or Project? Selecting Authentic Contexts for Competence-Based STEM Assessment in Africa

Benson Banda ¹, Caroline Taliba ², Mullah Mudenda ³, Shift Mweebo ⁴

¹, bensonbanda2003@yahoo.co.uk, ², caro819@gmail.com,

⁴ shift506@gmail.com

^{1, 4} Ministry of Education, Directorate of National Science Centre, ² SESEMAT, Uganda, ³
Kamuswazi Secondary, Mbala, Zambia

Abstract

Authenticity is pivotal in Competence-Based Curriculum (CBC) assessment, but authentic contexts vary in structure and complexity. This study synthesizes African STEM educators' perspectives, drawn from the AfriSTEM WhatsApp dialogue (5–10 October 2025, facilitated by the author), on selecting between Scenario, Case Study, and Project formats. Thematic analysis identifies decision criteria based on competence targets, resource availability, and safety constraints. Educators emphasized that context choice should reflect the intended competencies, allow realistic evidence capture, and remain viable in actual school conditions. The paper presents a selection framework to guide teachers in matching authentic contexts to assessment goals.

Keywords: Authentic Contexts, Scenario-Based Assessment, Project-Based Assessment, Case Study, Assessment Selection Framework

1. Introduction

1.1 Background

African education systems are transitioning from knowledge-recall models to Competence-Based Education (CBE), which emphasises meaningful performance in authentic situations (Stiggins, 2019; Black & Wiliam, 2020). Authentic assessment mirrors real-world practice, requiring learners to apply knowledge, reason, design solutions, and implement ideas in context (Wiggins, 1998; Gulikers et al., 2004). CBC therefore prioritises performance-based evidence, where learners demonstrate skills by solving meaningful problems, making decisions, and creating solutions (Muijs & Reynolds, 2022).

However, in many African settings, authentic learning has often been reduced to theoretical “real-world examples” presented on paper, with limited opportunities for structured performance.

Teachers must therefore negotiate authenticity within resource-constrained realities, balancing competence expectations, classroom safety, learner readiness, and feasibility (Jegstad & Sinnes, 2024; Polk et al., 2025). In practice, educators blend scenarios, community-based case studies, and low-cost projects to enable meaningful competence demonstration in African CBC classrooms.

This paper advances an Africa-grounded inquiry into how teachers intentionally select between scenario, case study, and project formats in CBC assessment, highlighting the balance between competence demands, feasibility, and contextual realities. Authentic contexts used in CBC can be broadly categorised as:

- a) Scenario – simulated situations requiring application and decision-making without execution;
- b) Case Study – realistic problem analysis using genuine data and constraints; and
- c) Project – live design, construction, or implementation producing tangible outcomes.

Understanding how these formats are chosen in African schools is crucial, as teachers must ensure that assessment tasks authentically reflect competence-based learning while remaining achievable and safe in real classroom conditions.

1.2 Problem Statement

Teachers often default to scenarios, even when projects or case studies would yield deeper competence evidence. This may stem from lack of clear criteria for context choice.

1.3 Objectives

- 1. Identify educator thinking on context selection.
- 2. Develop guidelines linking competences to context type.
- 3. Recommend policy and training supports.

2. Research Questions

RQ1: How do African STEM educators decide between scenario, case study, and project formats in CBC assessments?

RQ2: What factors influence the authenticity and feasibility of each context type?

RQ3: How can criteria be systematised for consistent practice?

3. Literature Review

Competence-Based Education (CBE) centres on learners demonstrating what they can do with knowledge in authentic contexts rather than recalling information (Stiggins, 2019; Black & Wiliam, 2020). Authentic assessment, rooted in situated learning theory, asserts that learning is most meaningful when embedded in real-life practice and social activity (Brown, Collins, & Duguid, 1989). It requires learners to perform tasks that reflect actual professional and community contexts, demonstrating cognitive, procedural, and dispositional competence (Gulikers et al., 2017; Wiggins, 1998).

Within this paradigm, task design must align competence targets with the performance conditions under which they are demonstrated. Recent scholarship emphasises the importance of graduated authenticity, where learners move from conceptual decision-making to real-world application as readiness and conditions allow (Muijs & Reynolds, 2022; Darling-Hammond & Adamson, 2014). Kolb's experiential learning cycle reinforces this progression, showing that competence deepens through experience, reflection, conceptualisation, and performance (Kolb, 2015).

In African CBC implementations, teachers express strong commitment to real-world learning but face contextual realities related to class size, safety, time, resources, and community expectations (Chisholm, 2019; Tabulawa, 2017). Emerging African scholarship argues that authentic assessment should be context-responsive, locally grounded, and socially purposeful, advancing learners' capacity to address real community needs and sustainability goals (Jegstad & Sinnes, 2024; Ssenyonjo & Nakabugo, 2023; Polk et al., 2025).

These perspectives align with decolonial calls for STEM education that values indigenous knowledge, community resources, and everyday problem-solving — not only high-technology or imported models of practice (Aikenhead & Ogawa, 2007; Facer, 2021). Within this framing, selecting the right assessment context—scenario, case study, or project—becomes a pedagogical act requiring intentional judgment, attentiveness to feasibility, and equity in access to performance opportunities.

4. Methodology

This study adopted a qualitative research design grounded in thematic analysis, appropriate for exploring professional reasoning, shared meanings, and decision-making processes among educators (Braun & Clarke, 2021). The inquiry sought to understand how African STEM educators conceptualise and select authentic assessment contexts within Competence-Based Education.

4.1 Data Source

Data were drawn from a moderated AfriSTEM WhatsApp professional dialogue held from 5–10 October 2025, involving STEM teachers, classroom teacher, Headteachers, teacher trainers, curriculum designers, standards offices, policy makers across Eastern, Western, Southern, and West Africa. WhatsApp-based research has emerged as a valuable approach in African education contexts due to accessibility, rich professional discourse, and equity of participation (Katz et al., 2021; Odena, 2020).

4.2 Participants & Sampling

Approximately 81 participants contributed to the dialogue. Participation was voluntary, naturalistic, and context-driven, reflecting a purposeful sample of educators engaged in CBC practice and policy (Creswell & Creswell, 2018). Personal identifiers were removed to ensure ethical confidentiality.

4.3 Analytical Process

A **reflexive thematic analysis** was conducted (Braun & Clarke, 2006, 2021). Statements referencing “scenario”, “case study”, “project”, “competence”, “context”, “constraints”, “safety”, and “authenticity” were coded and grouped into thematic categories. Codes emphasised meaning-making, not frequency, consistent with interpretive qualitative methods (Miles, Huberman & Saldaña, 2020).

Key analytical steps included:

- (i) Familiarisation with chat transcripts
- (ii) Initial open coding
- (iii) Collapsing codes into themes
- (iv) Refining categories aligned to research questions
- (v) Interpretation informed by authentic-assessment theory

4.4 Trustworthiness

Credibility was supported through researcher reflection and member-perspective grounding in a real professional community. Authentic teacher discourse allowed access to practice-proximal knowledge, aligning with teacher professional voice scholarship in CBC research (Sayed & Abdel-Malak, 2021).

5. Findings (with verbatim excerpts)

Analysis of the AfriSTEM professional dialogue revealed three interconnected themes that explain how educators select assessment contexts in CBC classrooms. These themes illustrate deliberate pedagogical reasoning grounded in feasibility, learning purpose, and contextual realities across African schools.

Theme 1: Match context to competence target

Educators demonstrated a strong commitment to aligning the task format with the level of competence being targeted. Projects were associated with hands-on implementation and innovation; case studies were preferred for analytical thinking; and scenarios served as a feasible alternative when physical execution was not possible.

- i. *“If actual implementation and resources allow—go for a project.” —
Participant 63 (06/10/2025 09:30 am)*
- ii. *“When analysis and decision-making are central, a case study works best.” —
Participant 129 (06/10/2025 12:08 pm)*
- iii. *“Scenario is useful when live task is impractical.” —
Participant 186 (07/10/2025 06:42 am)*

Participants emphasised that competence depth determines context choice. Projects were seen as the gold-standard for “doing,” case studies for “thinking and justifying,” and scenarios for “application without physical execution.” This reflects a strategic continuum of authenticity, where teachers select tasks to progressively build towards real-world competence.

Theme 2: Consider safety and resources

Educators also highlighted practical realities in African schools, with safety, resources, and feasibility emerging as critical decision factors. They justified simulated or case-based tasks when real projects were not safe or feasible.

- i. *“Avoid live experiments with hazards in schools—simulate instead.” — Participant 176 (07/10/2025 12:16 am)*
- ii. *“Constraints don’t mean inauthentic—choose realistic within limits.” — Participant 170 (07/10/2025 08:02 pm)*

Rather than viewing resource limitations as barriers, teachers adopted a pragmatic, risk-aware approach. Authenticity, in their view, is not binary but adaptive and scalable. They purposely balanced rigor, realism, and learner protection, reinforcing that CBC implementation in African contexts requires context-responsive professional judgement.

Theme 3: Openness to multiple solutions

Teachers valued assessment formats that encourage multiple solution pathways, creativity, and learner-driven innovation — especially in projects and case studies.

- i. *“In projects, allow different designs to meet the same criteria.” — Participant 207 (07/10/2025 08:17 am)*
- ii. *“Case studies should present real data with room for varied approaches.” — Participant 69 (06/10/2025 09:42 am)*

This theme reflects a clear orientation toward learner agency, creativity, and divergent thinking, as expected in CBC. Participants rejected one-right-answer tasks and emphasised the importance of assessments that develop learners’ ability to innovate, justify decisions, collaborate, and think independently — core competencies for 21st-century STEM learning.

6. Discussion

The findings demonstrate that African STEM educators exercise deliberate professional judgement in selecting scenario, case study, and project formats to align with CBC competence goals. Participants consistently matched task types to the level of performance expected — prioritising projects when authentic execution was possible, case studies when reasoning and justification were central, and scenarios when constraints limited physical implementation. This mirrors authentic assessment theory, which emphasises alignment between task structure and cognitive demand (Wiggins, 1998; Gulikers et al., 2017).

Teachers' reasoning was strongly shaped by contextual realities, particularly safety, time, and resource constraints. Rather than viewing limitations as a barrier to authenticity, educators adopted adaptive authenticity — a principle supported by research showing that authenticity can be conceptual and still valid when grounded in realistic constraints (Blumenfeld et al., 1991; Darling-Hammond & Adamson, 2014). This reflects the pragmatic conditions of African schools and reinforces the idea that CBC practice must be context-responsive (Tabulawa, 2017; Chisholm, 2019).

A strong emphasis on open-ended, multiple-path performance tasks was evident across responses, demonstrating commitment to learner agency, creativity, and innovation — values aligned with modern competency frameworks and Universal Design for Learning (CAST, 2022). This supports recent African scholarship that calls for STEM teaching that nurtures problem-solving for real societal needs such as agriculture, energy, and community well-being (Ssenyonjo & Nakabugo, 2023; Jegstad & Sinnes, 2024).

Collectively, these insights reveal not only compliance with CBC policy but African teacher-driven theorisation of authentic assessment practice. Educators are building a grounded model of authenticity based on competence-task alignment, feasibility, and learner empowerment. The resulting continuum — scenario for application, case study for analysis, and project for implementation — echoes experiential learning progression models (Kolb, 2015) and contributes a distinctly African lens to global discourse on CBE.

Ultimately, this study affirms that African teachers are exercising professional autonomy to contextualise CBC principles within local realities, offering a valuable practice-informed contribution to authentic assessment scholarship.

Key Discussion Insight	Educator Evidence	Supporting Literature
Alignment of task to competence	Projects = full performance; Case study = reasoning; Scenario = applied thinking	Wiggins (1998); Gulikers et al. (2017); Kolb (2015)
Authenticity under constraints	Teachers choose safer, feasible alternatives without losing authenticity	Blumenfeld et al. (1991); Darling-Hammond & Adamson (2014); Tabulawa (2017)
Open-ended performance pathways	Preference for multiple designs and solutions	CAST (2022); Muijs & Reynolds (2022)
Context-driven educational relevance	Tasks reflect African societal challenges	Ssenyonjo & Nakabugo (2023); Jegstad & Sinnes (2024); African Union (2015)
Teacher professional judgement & agency	Educators intentionally select formats, not follow scripts	Chisholm (2019); Sayed & Abdel-Malak (2021)
African-centred assessment model emerging	Scenario → Case → Project progression	Kolb (2015); Aikenhead & Ogawa (2007)

Figure 1: Summary of Discussion Themes with Corresponding Educator Evidence and Supporting Literature

7. Context Selection Framework

The findings from this study informed the development of a practical, teacher-led framework to support context selection in Competence-Based STEM assessment. The framework recognises that scenario, case study, and project formats serve distinct pedagogical functions along an authenticity continuum, and that African teachers make decisions by balancing competence expectations with the realities of their learning environments. In doing so, educators are not merely applying CBC

policy; they are actively shaping assessment theory through context-grounded professional judgement, advancing an African-centred contribution to global authentic assessment discourse.

This Context Selection Framework guides teachers through a structured process:

- (i) Identify the competence being assessed

Clarify the level and type of performance expected:

- Project when the goal is full implementation, creation, or demonstration
- Case study when the focus is analysis, reasoning, evaluation, or justification
- Scenario when learners must apply concepts or make decisions without physical execution

This progressional logic aligns with theory that the authenticity of a task should correspond to the depth of learning intended (Wiggins, 1998; Gulikers et al., 2017).

- (ii) Evaluate resources, time, and safety

Teachers assess classroom conditions, including materials, time, learner readiness, and hazards. This supports pragmatic authenticity, consistent with research emphasising context-responsive approaches in African settings (Darling-Hammond & Adamson, 2014; Tabulawa, 2017).

- (iii) Ensure relevance to African realities

Tasks should reflect meaningful local issues — such as agriculture, water, energy, waste management, or community wellbeing — to ensure cultural grounding and social utility. This aligns with decolonial STEM perspectives and Agenda 2063’s vision of education that equips learners to solve African challenges (African Union, 2015; Aikenhead & Ogawa, 2007).

- (iv) Design for multiple solution pathways

Tasks should enable diverse approaches rather than a single correct answer, supporting creativity, innovation, and inclusive competence development. This principle reflects Universal Design for Learning and CBC’s emphasis on learner agency (CAST, 2022).

Together, these steps provide a practical and theoretically grounded model for authentic assessment design in CBC-STEM classrooms. The framework operationalises how African educators select assessment contexts not by defaulting to a single format, but by aligning task choice with competence depth, feasibility, cultural relevance, and learner empowerment.

8. Recommendations & Implications

Policy

- a) Include clear context-selection guidance in national CBC assessment standards, showing when to use scenarios, case studies, and projects.
- b) Provide official exemplar banks and moderation tools to support schools in designing context-relevant, safe, and feasible STEM tasks.
- c) Strengthen continuous professional development pathways that train teachers to apply context-selection principles, especially in resource-constrained settings.
- d) Encourage teacher professional voice in assessment policy reviews to ensure frameworks reflect African school realities and cultural contexts.

Practice

- (a) Teachers should use simple decision aids (e.g., checklists or decision trees) during lesson planning to align competence levels with task types.
- (b) Build school and cluster-based exemplar libraries showing real scenarios, case studies, and projects aligned to CBC competencies.
- (c) Use collaborative lesson design spaces (e.g., lesson study, reflection meetings, teacher WhatsApp learning groups) to refine tasks and share best practice.
- (d) Ensure tasks allow multiple solution pathways so learners demonstrate creativity, reasoning, and problem-solving — not rote application.

Implications

- (a) Empowers teachers to select optimum context; increases validity, relevance, and learner engagement.
- (b) Promotes equity and feasibility by valuing context-responsive approaches instead of one-size-fits-all assessment expectations.
- (c) Deepens teacher professional agency and instructional decision-making within CBC implementation.
- (d) Strengthens learner engagement, innovation, and real-world problem-solving, preparing them to contribute to African development priorities.

9. Conclusion

In CBC-STEM systems, authentic context is not an accessory to learning—it is the condition that makes competence visible and meaningful. This study demonstrates that African educators are thoughtfully navigating authenticity, feasibility, safety, and contextual relevance when selecting between scenarios, case studies, and projects. The scenario-case-project continuum provides flexible modes for competence demonstration, yet the value lies not in the formats themselves, but in the professional judgement behind their selection.

By grounding task choice in competence depth, school realities, and African community contexts, teachers are advancing a context-responsive, decolonial vision of authentic assessment. This work highlights that African educators are not passive implementers of CBC policy but active contributors to its theory and practice, shaping an assessment culture that values creativity, agency, and relevance to local needs.

Meaningful CBC implementation therefore requires intentional context selection, systemic support for teacher decision-making, and recognition of everyday African environments as legitimate learning and assessment spaces. When these conditions align, authentic assessment becomes a catalyst for equity, innovation, and transformative STEM learning in Africa.

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Influence of Gender Stereotype on Institutional Leadership in Public Secondary Schools in Kajiado County, Kenya

Dr. John Ng'eda Purdul

purduljohn@yahoo.com, nkedaa@gmail.com

Gretsa University, Kenya

ABSTRACT

This study focused on investigating the influence of gender stereotype on institutional leadership in public secondary schools in Kajiado County. Gender stereotype determines the placement of women to leadership positions. The study adopted the mixed research methodology and the concurrent triangulation design. The sample size involved 5 education officers, 25 principals, 25 deputy principals and 185 secondary school teachers. The study employed the simple random sampling techniques for the selection of respondents and the stratified sampling techniques to select the various public secondary schools. Questionnaires, interview guides and document analysis checklist were used to collect data. Quantitative data was analyzed descriptively and inferentially and presented using frequencies, tables, mean and standard deviation while qualitative data was analyzed according to themes of the objective and presented in narrative form. The study revealed that gender stereotype impedes many female teachers from advancing to leadership positions in the education sector. The study concludes that men dominate women in institutional leadership as a result of the traditional and cultural view and position that the society has placed women. Women need to come out of their “comfort zones” and break the ‘glass ceiling’ that stands between women and leadership positions. The study recommends that the Ministry of Education (MOE) and the Teachers Service Commission (TSC) to facilitate community sensitization to drum up support for the domestication of women to leadership positions in education. Women can demonstrate the same leadership skills and capabilities as their male counterparts.

Keywords: Gender stereotype, institutional leadership, gender, influence, leadership

Background to the study

Discrimination against women leadership is prevalent all over the planet, with women worldwide still grappling with leadership both in education and the corporate world even in the 21st Century. Women in leadership roles are in a difficult position because in different countries across the world, the type of behaviour that is required for professional success seems incompatible with how women are expected to behave on the basis of their gender (Ellemers, 2018). In all countries except Australia, Israel and Sweden, women are under-represented in secondary school leadership positions (OECD, 2008). The cultural interpretation and negotiation of gender is crucial to the identity (including gender identity) of individuals and their communities (UNESCO, 2014).

According to the European Institute for Gender Equity Gender (EIGE, 2016), stereotype refer to a cultural and socially constructed set of beliefs about what it means to be female or male. The cultural beliefs and attitudes common in most communities form the basis of gender stereotypes. Gender stereotypes have become contested on the grounds that these are ‘alien’ concepts to ‘our culture’. It has also been labelled as being ‘Western’ with limited application to our traditions and culture (UNESCO, 2014).

African women have borne the brunt of cultural traditions many of which have been described as oppressive and which limits the advancement of women. According to Ngcobo (2016), stereotypes are enforced by the society, which results in different expectations for men and women. Because the foundations for gender stereotypes typical beliefs and behaviours are created in early childhood, it is not easy to remove gender stereotype from the society (Our Watch, 2018). Gender stereotypes reflect the primary importance we attach to task performance when judging men and to social relationship when considering women (Ellemers, 2018). According to Wakshum (2014), socialization and stereotyping of women combines to make appointment to principalship more difficult for women. The attitude of the society towards proper male and female roles continues to slow down and relegate women entrance to leadership positions. Gender roles are defined by behaviours, but gender stereotypes are beliefs in attitudes about masculinity and femininity (Dandapat & Sengupta, 2018).

Men tend to be favoured by organizational culture and societal expectations of school administrations while many people still harbour negative thoughts regarding female administration with some feeling that women principals are not as highly respected and regarded as their counterparts the male principals in the profession of teaching (Constellow, 2011). Gender roles according to Angel (2018) vary across societies. They also vary within one society or cultural setting. Leadership in Kenya has long been a male terrain, and this appears to be more pronounced in the education sector where the numbers of women principals are remarkably low compared to male principals. Gender has therefore become a determining factor in placing women to leadership positions. There is indeed a ‘glass ceiling’ standing between women and leadership positions (Ongaki, Omwoyo & Musa, 2015).

In Kajiado County, allegiance to culture and traditions has played a significant role in influencing the nature and composition of women leadership in the public secondary schools. This is because; traditionally males enjoy a privileged segregation of roles as compared to that of females (Angel, 2018). Gender roles are mainly determined by the social dynamics of the Maasai culture. Women continue to face cultural and social barriers with stakeholders perceiving male head teachers more favourably than female head teachers (Nzeli, 2013). Women in leadership positions in the education sector in Kajiado County still fall far behind the men as a result of gender stereotype because of the traditional and cultural allegiance that people still adhere to. The traditional and cultural foundation of the communities around the schools can determine the institutional leadership. Lack of role models and resistance from persons in the community has made the sex of the principals to become very important in institutional leadership to warrant a study of this nature because customary practices and culture cannot be wished away like a bad omen.

Statement of the problem

In Kajiado County, gender stereotype has relegated the role and status of female teachers in accessing leadership positions. In spite of the concerted efforts by the TSC to identify, select, recruit, appoint, promote and install principals and teachers, and the MOE role in the education sector, the traditional gender roles and societal perception still ignores the value of the women in the society. As a result male dominance in leadership positions is largely attributed to the belief that men make better leaders than women due to their masculinity, whereas, discrimination against women is largely due to the stereotyped cultural beliefs that doubts women leadership abilities. The traditional life and socio-cultural beliefs of the Maasai community continue to exercise direct influence and control on the selection and appointment to formal leadership in public secondary schools. The Maasai being a highly patriarchal community still believes that men lead and women follow and women are still regarded as social minors.

Hence, gender stereotypes serve as major barrier for aspiring female teachers in school administration. The study focused on assessing the conceptual understanding of institutional leadership on one hand and the allegiance people have over their culture and traditional, and the perception of the society towards women and leadership positions. There is little evidence of research done to investigate the influence of gender stereotype on institutional leadership in public secondary schools in Kajiado County. This study strived to fill that knowledge gap.

Objective of the study

To investigate the influence of gender stereotype on institutional leadership in public secondary schools in Kajiado County, in Kenya.

Literature review

Institutional leadership and principalship

The under-representation of women in educational leadership from school to national level continues to be a feature of education systems worldwide. Leadership is not universal; rather it can vary as a direct function of either gender or culture (Unal, 2017). Cultural considerations play a crucial role regarding the under-representation of women in institutional leadership. Principals are in-charge of public secondary schools, and just like in the corporate world, most of these positions are male dominated. The high school principalship is an intricate and demanding position (Mwaniki & Guantai, 2018). The sex of the principal is equally very important in institutional leadership in the eyes of the societies.

Stereotypes about the inability of women to steer a school to success has led to the resentment from the community members (Nzioka, 2012). The cultural attitude towards women leadership in public secondary schools is negative. According to Unal (2017), culture affects perceptions, ideas and understanding of people. It also shapes attitudes, values and beliefs of its members. Hence, culture and traditions have got a noticeable impact on determining women leaders in the public secondary schools in Kenya. According to Kinoti (2013), the traditional pattern of power has hindered many women from participating in leadership even though women and men have equal right to fair treatment including equal opportunities in institutional leadership.

Stereotype becomes a problem when forces in the schools and the society limit the academic and leadership potential of either the female or male (Igbo, Onu & Obiyo, 2015). The low number of women leaders is directly connected to cultural attitudes towards women as leaders (Nzioka, 2012). At school level, some women principals have had to contend with men in the community who are opposed to their leadership. Institutional leadership has therefore been subjected to numerous challenges emanating from the dynamic nature of the society (Ugochukwu, Kalagbor & Harrion, 2016).

This traditional and cultural orientation still determines leadership positions even today. Men continue to have access to the organization elevators while women are forced to take the stairs. By the time women climb up the stairs, men have already positioned themselves thus locking them out of senior positions (Mwaniki & Guantai, 2018). Thus, if public secondary schools are to be proficient learning institutions in Kenya today, then principals, teachers and all education stakeholders must find ways of creating structures that will continuously support women leadership. Stereotypes seem contextually relevant when emphasizing females' weaknesses and strengths (Igbo, Onu & Obiyo, 2015). The authors uphold the need to be free from age-old gender specific social bondage. Institutional leadership will entail accommodating and promotion of more women to leadership and the creation of a society where the welfare and dignity of each individual is respected and supported regardless of gender. Gender stereotype are formed by people and can be changed by people.

Gender stereotype on institutional leadership

The percentage of women seeking positions in school administration has continued to rise in the recent times. Though historically it had been viewed as a man's domain, women have currently made a tremendous gain in obtaining positions in secondary school leadership. Women in leadership roles are in a difficult position because in different countries across the world, the type of behavior that is required for professional success seems incompatible with how women are expected to behave on the basis of their gender (Ellemers, 2018). Compared to females, males have better access to leadership roles and fewer challenges in becoming successful in them (Ngcobo, 2016). Traditionally, males enjoy a privileged segregation of roles as compared to that of females (Angel, 2018). Stereotyping about women and what they can or cannot do seems to lock out many women aspiring leadership positions in educational leadership (Ongaki, Omwoyo & Musa, 2015).

In the African context, the traditional beliefs and cultural attitudes towards the role and status of women in the society are very common (Kinoti, 2013). Women have found it hard to dislodge themselves from this tradition and culture. Patriarchy is a social system in which the male is the primary authority figure- the head or the dominant figure (Ejike & Iheriohanma, 2014). According to Ndari (2014), almost every traditional African society was patriarchal and a woman's place within these schemes was decidedly subordinate. As a result, in many African cultures, men perceive themselves as heads of their families and unquestioned leaders of their societies. In Tanzania, the position and role of women is largely considered as befitting housewives who are meant to take charge of domestic duties as a result they are given less opportunities to exercise leadership skills in the work place (Mollet & Tshabangu, 2014).

In most societies in Kenya, clear lines are drawn between “women’s work” and “men’s work”. Traditional gender roles ignored the value of women in the society. Doubts about women leadership abilities still exists. According to Mwaniki and Guantai (2018), women in leadership are faced with the dilemma of balancing the societal expectations of women regarding their family responsibilities with that of leadership in a work place. Perceptions still abound that women lack leadership skills (Mollel & Tshabangu, 2014). Men’s works are recognized as compared to women’s work (Ndari, 2014). Most communities around schools prefer male principals to female principals (Ongaki, Omwoyo & Musa, 2015). Nzeli (2013) confirms that women continue to face cultural and social barriers with stakeholders perceiving male head teachers as more favourable than female head teachers. The gender policy is very clear on the requirement of one-third female representation. The Constitution of Kenya Chapter 4, section 20(2) and section 27(3) is very clear on the right to equal treatment and freedom from discrimination. Gender policy should provide a means to address key gender issues in a given society. Policies are implemented without deviating from the overall education policy of the country (Budohi, 2014). Therefore, discrimination against gender should not be tolerated at all.

In Kajiado County, the school community will most likely insist on men as opposed to women to fill in the principal’s slot. Among the Maasai community, it is believed that men lead and women follow. Literally, you will always find a Maasai man walking ahead as the woman follows at a distance. The “place of women” in the Maasai community is traditionally known largely because males have been in control of decision making be it within their homesteads, clans and the community in general (Angel, 2018). Women who ascend to power are seen as intruders to a male dominated world (Ongaki, Omwoyo & Musa, 2015). Women are therefore unfairly discriminated against and their rights to dignity infringed as well. According to EIGE (2016), the “glass ceiling” is a metaphor widely used to refer to lack of women in top managerial positions or obstacles and inequalities that contribute to explaining this situation. Below this barrier, women are able to get promoted, beyond this barrier; they are not promoted. To meet the challenges of under representation of women in secondary school leadership, new efforts and avenues to recruit women into leadership positions are essential. Kinoti (2013) recommended that all women need to be empowered.

Research Approach

The study adopted the mixed method research and the concurrent-triangulation design (Tashakkori & Teddlie, 2003). Both quantitative and qualitative approaches were used in data collection by use of questionnaires, interview guides and document analysis checklists.

Target Population

The target population involved 783 participants comprising of 8 District Education Officers (DEOs), 60 principals, 60 deputy principals and 655 teachers. A total of 5 teachers, one deputy principal and the principal were sampled in each of the 25 public secondary schools sampled. One education officer was sampled in each constituency.

Sampling Procedures and Techniques

The probability sampling method was used. Simple random sampling technique was used to select the education officers, deputy principals and secondary teachers from the target population. The

purposive sampling technique was used to select the principals on the basis of the MOE policy of male principals to head boys' only schools and female principals to head girls' only schools. Stratified random sampling technique was used to select the participating 25 schools from the total of 60 public secondary in Kajiado County according to their various levels.

Data Collection Procedures

The questionnaires were self administered in two ways depending on the wish of the subjects. Self-administration of the questionnaires involved filling of the tools in the presence of the authors or in absence. In the second option, the authors set an agreeable time with the respondents for filling the questionnaires and when to collect them. Data from principals and their deputies was collected through interviews.

Data Analysis Techniques and Procedures

The collected data was analysed quantitatively and qualitatively. Quantitative data analysed yielded the descriptive and inferential statistics. The descriptive statistics was analysed using frequencies, percentages, means and standard deviation and presented results using tables. Inferential statistics was analysed using multiple regressions and results presented in tables. The qualitative data was analysed according to themes of the objective and presented in *narrative form* and *direct quotations*. According to Orodho (2017), the qualitative data should be reported using direct quotations or narratives. Qualitative data collected using the document checklist analysis were quantified and analyzed *thematically* and presented in narrative form. Conclusions were then drawn from the data, then recommendations and suggestions for areas of further research were made.

Research findings and discussions

The study analysed the influence of gender stereotype on institutional leadership and the results are presented as follows:

Gender stereotype on qualities of leadership between men and women

Stereotypes question the capability of women to lead due to the society's attitude towards male and female roles which depicts women as lacking leadership qualities and skills. The views of teachers are presented in Table 1.

Table 1: Leadership qualities between women and men

Responses	<i>f</i>	%	Mean	Standard deviation
Strongly agree	38	28.8	1.6579	.70811
Agree	30	22.7	3.4000	.49827
Neutral	26	19.7	4.1923	.40192
Disagree	22	16.7	5.0000	.00000
Strongly disagree	16	12.1	5.0000	.00000
Total	132	100	3.5152	1.40057

Table 1 indicates that a combined 68(51.5%) of the teachers agreed that women demonstrated the same qualities of leadership as men whereas, combined 38(28.8%) of the teachers disagreed that

women demonstrate same qualities of leadership as men. 26(19.7%) of the teachers remained non committal. The data further shows that disagree and strongly disagree (Mean =5.0000, SD=.00000) were the highly rated aspect of the views of teachers on the perception of leadership qualities between men and women while the lowly ranked aspect was strongly agree (Mean=1.6579, SD=.7081). A study by Nzeli (2013) found out that teachers preferred to work with male head teachers as they had a low perception for female head teachers hence male were rated highly than women. The policy on boys and girls secondary schools leadership has made it possible for women to be represented in the leadership of public secondary schools. No matter how the leadership behaviours of women are delineated, the fact is that women do possess the capabilities and skills to be excellent educational leaders (Wakshum, 2014).

Gender stereotype on male principals being rated highly than female principals

Men are believed to make better leaders than women due to their masculinity. The male continue to dominate as result of the traditional and socio-cultural values that define the expected roles of women at home, workplace and in the society. The responses of the teachers are presented in the following Table 2.

Table 2: Views of teachers on rating between male and female principals

Rating of male and female principals	<i>f</i>	%	Mean	Standard deviation
Strongly agree	32	24	1.0000	.00000
Agree	33	25	2.3030	.52944
Neutral	25	19	3.0000	.00000
Disagree	24	18	3.8750	.33783
Strongly disagree	18	14	4.0000	.00000
Total	132	100	2.6364	1.15430

Table 2 shows that, overall 65(49%) teachers agreed with the perception that male principals are rated highly than female principals. However, overall, 42(32%) disagreed that male principals are rated highly than female principals. 25(19%) of the respondents chose to remain neutral. The data further shows that strongly disagree (Mean =4.0000, SD=.00000) was the highly rated aspect of the perception that male principals are rated highly than female principals while the lowly ranked aspect was strongly agree (Mean=1.0000, SD=.00000). According to Shava and Ndebele (2014), women are typically judged to have less leadership qualities than men, as some actions performed by men and women in leadership situations are evaluated more negatively when women are the leaders. It is true that women have been stereotyped and considered as dependent, acquiescent and ungifted of leadership qualities. They are also highly ignored in leadership positions (Wakshum, 2014).

The findings clearly stipulate and give the impression that the “place of women” in the society is traditionally known. Women are therefore unfairly discriminated against and their rights to dignity infringed as well. The stereotypical gendered expectations negate the recognition of women’s accomplishments either through devaluing their work or through attributing their success to something else other than their ability (Wynn & Correl, 2017). The implication that female principals are still perceived as being less skillful in leadership qualities than the male principals still abounds in our society today. Gender stereotyping excludes women from leadership roles (Wakshum, 2014).

Table 3: Statistical measurement on influence of gender stereotype as a determinant of principals on institutional leadership

Dependent variable: Institutional leadership		
Regression statistics		Model 1
		Gender stereotype
Predictor: Gender stereotype	R	.847
	R-squared(R^2)	.718
	Adjusted R squared(R^2)	.715
	Beta β	.847
	p-value	.000
	Standard error of estimate (E)	.26528
	Constant	11.214

Model 1 in Table 3 carries results of a simple linear regression analysis on the influence of gender stereotype (predictor) on institutional leadership in public secondary schools in Kajiado County. The Pearson's $R=.847$ indicates that there was a strong positive relationship between gender stereotype and institutional leadership in public secondary schools in the study locale. The R-squared (R^2) computed yielded a value of .718 suggesting that gender stereotype explained 71.8% of the variations in institutional leadership in public secondary schools in Kajiado County. The p -value computed by SPSS yielded a value of .000 which is less than the significance level of $p<.001$. This led to the conclusion that there was a statistically significant relationship between gender stereotype and institutional leadership in public secondary schools in Kajiado County. According to Angel (2018), gender roles are determined hugely by the social dynamics of the Maasai culture. Further analysis of qualitative data from female principals interviewed on personal challenges that they experienced as principals revealed that 8(66.7%) cited balancing of responsibilities between principalship and family as major personal challenge. Cultural attitude at 7(58.3%) was cited as the second personal challenge afflicting female principals. 5(41.7%) cited working away from home and 5(41.7%) view principalship as a challenging job. 2(16.7%) of the principals said they were not comfortable working with male deputy principals.

In addition, 12(100%) of the female principals said that many female teachers do not want to get out of their "comfort zones" in this case they do not want to leave behind their families or stay away from them. A further 11(92%) of the female principals agreed that family roles and responsibilities hamper women from taking up leadership positions. One female principal admitted that:

"As a mother, wife, caretaker of the home, nurse, I cannot think of myself working away from my home and family" (Principal 6)

Two female principals said that most women want to guard their reputation since they fear being exposed once they take up this leadership positions. One of the female principal reported that:

"Some of us women are very possessive; we cannot stay away from our husbands. Also some husbands discourage their wives from taking up this positions alleging that it is a difficult task...they do not want to be left alone" (Principal 5).

When asked their perception on whether parents are comfortable being led by female principals, 6(85.7%) of the male principals admitted that parents preferred male principals. Further, six (85.7%) of the male principals admitted that due to culture, women are being sidelined and looked

down upon while 2(14.3%) pointed out that some rural parents are not comfortable to the idea of female principals. Concerning the perception of the society towards female principals, 58.3% of female principals said that the status of women is still low compared to that of men and also felt that the suppression of women was due to cultural barriers prevailing in the society. According to Wynn and Correl (2017), stereotypes are widely shared cultural beliefs about categories of people and the perceptions of the judgements of men can affect the careers of many women.

In addition, five female principals (41.7%) cited that female principals still do not have leadership qualities as compared to men despite them competing fairly with men. The cultural aspect at (25%) was also cited by the female principals as a challenge. As one female principal reported:

“The humiliating aspect of the culture tends to label women in leadership positions as immoral and home breakers...” (Principal 9)

Conclusion

The study concludes that men dominate women in institutional leadership as a result of the traditional and cultural underpinnings that dictates the place and position of women in the society. The entrenched stereotypes in the society deprive us of effective female leaders. In addition, the study further concludes that, a gender gap exists in institutional leadership in public secondary schools, hence more female teachers need to be encouraged to come out of their “comfort zones” and break the ‘glass ceiling’ by taking up leadership positions. Women can demonstrate the same leadership skills and capabilities as their male counterparts.

Recommendations

The study recommends that the Ministry of Education (MOE) and the Teachers Service Commission (TSC) to facilitate community sensitization to drum up support for the domestication of women to leadership positions in education. Women can demonstrate the same leadership skills and capabilities as their male counterparts.

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