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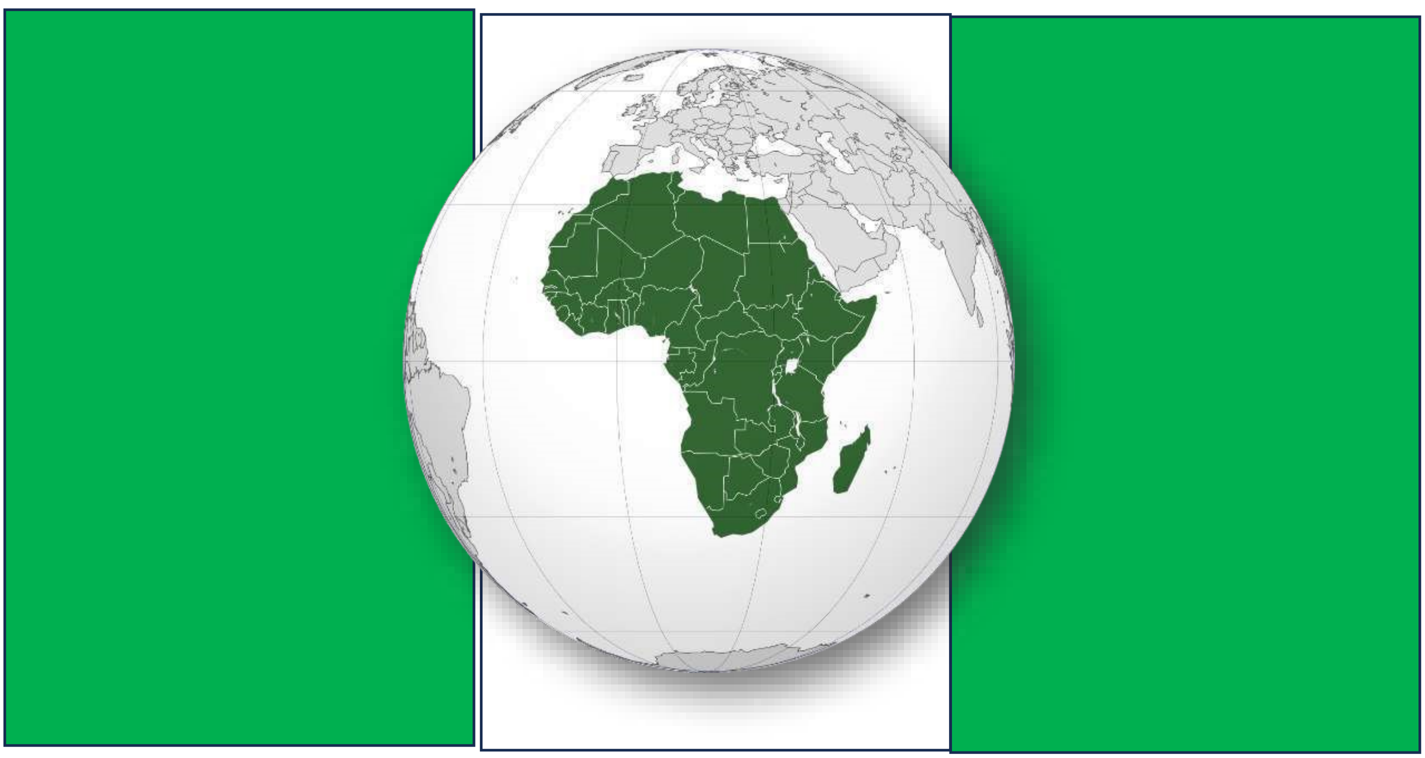

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[Secretariat]

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 4 October, 2025

Strengthening Mathematics and Science Education in Africa

SMASE-AFRICA

Table of Contents

Preface

Welcome to Volume 1, Number 4, January 2025 Edition of the Journal for Science, Technology, Engineering and
Mathematics Education in Africa (JSTEMEA)

The **21st Conference on Mathematics, Science and Technology Education in Africa (COMSTEDA 21)**, held from **10th – 12th September 2024** in Kaduna, Nigeria, brought together educators, policymakers, researchers, industry experts, and development partners in a blended format (physical and virtual). Guided by the theme, *"Empowering the Next Generation through Innovative STEM Education"*, 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 **sixteen (16) peer-reviewed papers** presented at the conference. These papers reflect diverse strands of discourse, including:

1. **Curriculum Design, Development and Assessment in STEM Education**
2. **Innovative Pedagogical Approaches and Emerging Technologies in STEM Learning**
3. **Teacher Training and Professional Growth in STEM Education**
4. **Emerging Issues in STEM Education: Access, Equity, and Outreach**
5. **Artificial Intelligence in STEM Education**

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 competence-based curriculum implementation to AI-driven learning models that mirror the dynamism of education systems across the continent.

Acknowledgements

We extend our deepest appreciation to the **Federal Republic of Nigeria** and the **National Teachers' Institute (NTI), Kaduna**, for graciously hosting this milestone event in partnership with **SMASE-Africa**. Special gratitude is due to the traditional leadership of Kaduna, notably the **Emir of Kaduna,** for providing cultural blessings and moral support that anchored the success of COMSTEDA 21.".

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 Kaduna as we prepare for **COMSTEDA 22 in Malawi**, 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 5th 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)

The Objectives of COMSTEDA-21

The 21st Conference on Mathematics, Science and Technology Education in Africa (COMSTEDA-21) 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 this fourth volume of the 2025 Edition of the Journal on STEM Education in Africa, containing seventeen research papers from COMSTEDA 21, Kaduna. May these pages inspire, provoke, and guide collective action toward empowering Africa's next generation through innovative STEM education.*

Editorial

Article 1

Impact of Inquiry-Based Learning on STEAM Education and Gender Differential on Academic Performance Among Basic Science Students in Nassarawa Local Government Area, Kano State by Saudat Shehu Bala, Gali Musa, and Nazifi Wada Salisu investigated the effectiveness of inquiry-based learning in STEAM education and its relationship to gender differences in student achievement. The study employed a quasi-experimental design involving pretests and posttests, with a sample of 200 students randomly drawn from four junior secondary schools out of the ten in the population. Data were collected using the Heat Concept Performance Test (HCPT), while two research questions and two null hypotheses were formulated to guide the investigation. The null hypotheses were tested using the t-test at a significance level of $p \leq 0.05$. The findings revealed a significant difference between the mean performance scores of students taught the heat concept through inquiry-based learning in STEAM education compared to those taught with traditional methods, favoring the inquiry-based approach. However, there was no significant difference between the mean scores of male and female students exposed to inquiry-based learning within the experimental group.The study concluded that inquiry-based learning was an effective pedagogical strategy for improving academic performance in STEAM education. It recommended that schools and educators actively work to challenge gender stereotypes within STEAM fields and encourage all learners, regardless of gender, to engage in inquiry-based activities. Furthermore, educators and policymakers were urged to prioritize the adoption of inquiry-based learning to enhance academic performance and raise awareness about future careers in STEAM education.

Article 2

Bashir Kawu, in the paper titled ***Creativity and Differential Aptitude Tests as a Means of Assessing General and Special Abilities,*** **explored** the multifaceted nature of creativity and its measurement, emphasizing its significance in both educational and professional contexts. Creativity was defined as the production of novel and appropriate responses to open-ended tasks, drawing upon cognitive complexity and diverse personality traits. The study reviewed different psychological theories—including psychoanalytic, personality, humanistic, and holistic perspectives—that offered comprehensive insights into creativity. Contributions by prominent psychologists such as Thurston, Kim, Bertlet, and Rollo were also highlighted, underscoring attributes like originality, bold thinking, and flexibility.The paper further examined the Differential Aptitude Tests (DAT), developed to assess specific skills across educational phases. These tests, tailored for different grade levels, measured abilities including verbal reasoning, numerical ability, abstract reasoning, mechanical reasoning, space relations, spelling, and language usage. Their role in career guidance and vocational counseling was emphasized, showcasing their value in identifying individual strengths.In addition, the paper discussed creativity assessment methods such as the Guilford Test of Divergent Thinking and the Torrance Test of Creative Thinking (TTCT), which evaluate originality, fluency, flexibility, and elaboration. The integration of creativity assessments with DAT was presented as a comprehensive approach, enabling educators and employers to gain a holistic view of individuals' abilities. This combined framework was argued to foster innovative thinking, align learners with appropriate educational or career pathways, and enhance broader educational and professional outcomes.

Article 3

Effect of E-Instructional Material on Social Studies Academic Performance Amongst Upper Basic Schools Kaduna, North-West Nigeria by Kemi Adeyemo investigated the impact of e-instructional materials on the academic performance of Social Studies students in upper basic schools. E-instructional materials were described as indispensable tools for achieving effective curriculum delivery in classrooms. The study employed both a quasi-experimental and a descriptive survey design. The population comprised 5,706 students, from which a sample of 89 was selected. Two research questions and two null hypotheses guided the study. Data were collected using the Social Studies Academic Performance Test (SOSAPT), which had a reliability coefficient of 0.67 using the Kuder-Richardson formula 21. Mean and standard deviation were applied to answer the research questions, while independent t-tests were used to test the hypotheses. The findings revealed that students taught with e-instructional materials performed significantly better than those taught using the traditional lecture method. Furthermore, gender was found to have no significant effect on the performance of students exposed to e-instructional materials. The study recommended, among other measures, that government should provide e-instructional materials to all upper basic schools in North-West Nigeria to improve the quality and effectiveness of Social Studies instruction.

Article 4

Sanura Jaya, Phiri Cornelius, and Parvin Der Singh, in the study titled ***Exploring the Effectiveness of the Magnetcode Application through Project-Based Learning: A Case Study among Preservice STEM Teachers at Malcolm Moffat College of Education,*** examined the role of digital tools in strengthening project-based learning for preservice STEM teachers in Zambia. The study focused on how the Magnetcode application could enhance creativity, problem-solving abilities, and the integration of coding and programming into STEM education. Using purposive sampling, qualitative data were collected through open-ended interviews with four preservice STEM teachers. The findings demonstrated that Magnetcode significantly enhanced usability and encouraged innovative teaching approaches by emphasizing hands-on activities and the practical application of theoretical knowledge. Participants reported increased confidence in using technology, improved peer collaboration, and deeper engagement with coding applications. The study concluded that incorporating tools like Magnetcode into preservice teacher training programs could effectively prepare future educators to deliver innovative STEM education through project-based learning. Such integration was argued to equip teachers to inspire learners and adapt effectively to the evolving educational landscape.

Article 5

Toyin R. Ogalue, in the paper ***Design and Development of Institutional Repository (IR): An Innovative Solution for Scholarly Communication in National Teachers Institute (NTI) Nigeria,*** explored the creation of a centralized digital repository to improve scholarly communication and resource management at NTI. The study examined how traditional methods of distributing teaching and learning materials had been inefficient and demonstrated how a repository could enhance equitable access, preserve knowledge, and promote collaboration among educators and learners. Using a mixed-methods approach and a system development life cycle model, the research assessed infrastructure readiness, collected user requirements, and designed an interactive repository built on the Joomla platform. The findings revealed that the repository effectively streamlined access to NTI's modules, dissertations, multimedia resources, and other academic outputs, thereby supporting professional growth and scholarly communication.

Article 6

Daniel Karanja Mutitu, in the paper ***Modeling School-Based Teacher Professional Development for Effective Implementation of CBC in STEM Subjects, A Case of Nyeri County****,* explored the challenges and opportunities associated with preparing teachers for the effective implementation of Kenya's Competency-Based Curriculum (CBC). The study investigated the subject specialization of Junior School teachers, the support systems available to them, and the adequacy of professional development opportunities provided. Anchored on the Diffusion of Innovations theory and Resource Dependence theory, the research adopted a mixed-methods design, drawing a 30% sample from the target population, which included 71 respondents. Findings revealed that although all teachers had attended CBC workshops, the training was inadequate in equipping them with the pedagogical competencies required for full implementation. Furthermore, the study identified limited access to CBC-aligned instructional resources as a significant barrier. Based on these findings, the study recommended institutionalized investments in school-based professional development programs and continuous teacher support systems to ensure sustainable and effective implementation of CBC in STEM subjects.

Article 7

The paper ***Application and Impact of Emerging Technologies in Mathematics Education*** by Hassan Suleiman examined how technologies such as artificial intelligence (AI), virtual reality (VR), augmented reality (AR), and adaptive learning platforms are reshaping mathematics education. The study investigated how AI-driven adaptive systems personalized learning experiences, VR and AR provided immersive contexts for abstract concepts, and adaptive platforms adjusted problem difficulty to strengthen mastery and confidence. It also highlighted how data analytics allowed educators to monitor student progress with precision, enabling more targeted instruction. Evidence from recent research showed notable improvements in student performance and attitudes toward mathematics when these technologies were applied. Nonetheless, the study underscored challenges including inequitable access to resources and inadequate teacher training in technology use. The findings emphasized the potential of emerging technologies to make mathematics more personalized, engaging, and effective, while recommending government and institutional investment in digital infrastructure and teacher professional development to ensure successful integration of these tools in classrooms.

Article 8

Ibrahim Laro Yusuf, Khadijat Bola Lawal, and Salman Umar Ombuguhim, in Teachers' **Citizenship Behaviour as a Predictor of Secondary School Students' Academic Performance in Science Subjects in Igabi Local Government Area of Kaduna State,** investigated the influence of teachers' citizenship behaviour on learners' outcomes in science subjects. The study adopted a descriptive correlational research design with a target population of 15 principals, 30 vice principals, and 52 science teachers from sampled schools. Using purposive sampling, 52 science teachers were selected, while 80 out of 97 respondents were chosen through simple random sampling, guided by the research advisor's sample size table. Data were gathered using the *Teachers' Citizenship Behaviour Questionnaire (TCBQ)*. Findings revealed that teachers' citizenship behaviour significantly influenced students' academic performance in science subjects. The study recommended the promotion of a professional culture in teaching through collaborative and instructional leadership by school leaders. It also emphasized the need for government support in organizing regular trainings, workshops, and seminars for supervisors, principals, and teachers on teacher citizenship behaviour (TCB) to strengthen service delivery and ultimately improve students' performance.

Article 9

Artificial Intelligence (AI) in STEM Education: Design Development and Applications in STEM Education by Suleiman Dauda and Awujoola J. Olalekan explored the transformative role of AI in enhancing teaching and learning experiences in STEM education. The study investigated the design, development, and applications of AI tools, focusing on their potential to support personalized learning, intelligent tutoring, and student performance analytics. It discussed the guiding principles and challenges of designing AI-based tools and presented case studies that illustrated successful implementations in STEM classrooms. The paper also examined ethical considerations, including issues of privacy, data security, and algorithmic bias, which remain critical in educational contexts. Furthermore, future directions and opportunities for AI in STEM education were highlighted, emphasizing collaboration among educators, technologists, and policymakers. The study concluded by underscoring the transformative potential of AI to reshape education, while recommending ongoing research and ethical integration to maximize its benefits.

Article 10

Regina Fumbuka and Peter Kajoro, in their study **Exploring the Impact of Technology Integration on Mathematics Teachers,** investigated how technology use influences teaching practices in Tanzania. Using a participatory action research design, the study unfolded in three phases: reconnaissance, two intervention cycles, and post-intervention. Guided by constructivist philosophy, the research was conducted in a purposively selected school with strong technological infrastructure, stable internet connectivity, and reliable electricity, which created a suitable environment for implementation. The participant was a Mathematics teacher handling a Form One B class of 24 students with varied abilities. Data were collected through semi-structured interviews, structured classroom observations, and document reviews, including lesson plans, schemes of work, textbooks, and reflective journals. Findings revealed that technology integration positively impacted Mathematics teachers by enhancing motivation, confidence, productivity, and teaching effectiveness, while also inspiring knowledge sharing among colleagues. The study concluded that technology integration enriches Mathematics teaching and recommended that educational stakeholders invest in facilities, infrastructure, and professional development programs to ensure effective integration and sustainable improvements in Mathematics education practices.

Article 11

AI-Driven Feedback Mechanisms: Revolutionizing STEM Education Assessments by Philiph K. Saina explored the transformative role of artificial intelligence in assessment practices within STEM education. Employing a mixed-methods research design, the study combined pre- and post-test analyses with surveys, interviews, and case studies, involving 300 students and 50 teachers across different educational levels. Findings revealed a notable improvement in student outcomes, with an average 15-percentage-point increase in post-test scores, demonstrating the effectiveness of AI-powered feedback in enhancing understanding of complex STEM concepts. Both students and teachers reported that AI feedback was timely, useful, and beneficial for personalized learning, though concerns remained about usability and alignment with diverse learning styles. Additionally, AI tools were found to reduce grading time and improve accuracy in assessments, thereby supporting teaching efficiency. However, challenges such as limited adaptability, the need for improved user interfaces, and continuous educator training were identified. The study concluded that AI has significant potential to transform assessment practices in STEM education, while highlighting the importance of addressing implementation barriers and ensuring inclusivity. Practical recommendations were offered for refining AI-driven feedback tools and guiding future research.

Article 12

Anecetus Moonga and Benson Banda, in **Implementing a Competence-Based Curriculum: A Case Study of Physics Lesson on Energy**, investigated the implementation of a Competence-Based Curriculum (CBC) in physics education with a focus on energy concepts. Using a mixed-methods research design, the study engaged 30 high school students from Lusaka, Zambia, in a CBC-based instructional intervention. Quantitative findings from pre- and post-tests showed a significant improvement in student performance, with average scores increasing from 45% to 75%, reflecting enhanced conceptual understanding and application skills. Qualitative insights gathered from semi-structured interviews with students and teachers highlighted improved engagement, contextualized learning, and strengthened problem-solving abilities, though challenges such as limited teacher preparedness and resource constraints were reported. The study concluded that CBC provides a promising alternative to traditional content-memorization approaches by emphasizing competencies and real-world application. Recommendations were made for continuous teacher professional development, stronger policy support for CBC implementation, and further research on long-term impacts across varied educational contexts. This research added to the growing body of evidence affirming the value of competency-based approaches in advancing science education, especially in developing countries undergoing educational reforms.

Article 13

Effects of Realistic Mathematics Education and Mathematical Modelling Approaches on Senior Secondary School Students' Attitude and Achievement in Geometry in North Central, Nigeria by Abubakar Mohammed Ndanusa, Hassan A. A., Gimba R. W., Usman Hussaini & Usman Hassan investigated how Realistic Mathematics Education (RME) and Mathematical Modelling (MM) approaches influence students' attitudes and achievement in geometry. The study employed a pretest–posttest control group factorial design with a sample of 361 students selected from twelve co-educational secondary schools across North Central Nigeria. The Geometry Achievement Test (GAT) and Mathematics Attitude Questionnaire (MAQ), both validated by experts with reliability coefficients of 0.80 and 0.87 respectively, were administered to collect data. Students were assigned to three groups: experimental group I (RME), experimental group II (MM), and a control group taught using conventional lecture methods. Data analysis using descriptive statistics, ANOVA, ANCOVA, and Scheffé post hoc tests revealed significant differences in achievement scores among the groups. Students taught with RME and MM not only performed better in geometry but also demonstrated improved attitudes towards the subject. Gender differences in achievement were also observed within the experimental groups. The study concluded that RME and MM approaches are effective instructional strategies for enhancing both academic achievement and attitudes in geometry. These findings carry strong implications for curriculum reform and teacher professional practice in mathematics education.

Article 14

Yakubu A. A. and Nuhu I. L, in their work **Integration of STEM Curriculum at Secondary School Level of Education in Nigeria**, explored the rationale, challenges, and opportunities of embedding STEM into the Nigerian secondary school science curriculum. The paper emphasized the importance of STEM education in equipping learners with 21st-century skills relevant to global competitiveness, with applications across healthcare, agriculture, engineering, mathematics, and environmental conservation. Particular attention was given to biology, where the current thematic and spiral organization of the curriculum revealed gaps in biotechnological topics and broader STEM representation. The study further examined challenges such as inadequate numbers of qualified teachers, limited resources, and ethical issues, which hindered effective integration. At the same time, it highlighted opportunities like advancing practical and inquiry-based learning, and strengthening interdisciplinary connections. The authors concluded that integrating STEM into secondary school science education requires systematic curriculum review, strategic partnerships to expand access to STEM resources, and continuous professional development for teachers. These steps were seen as critical in enabling Nigerian students to develop the knowledge and competencies necessary for thriving in an innovation-driven global economy.

Article 15

Effectiveness of Personalized-Learning Strategy on Performance in STEM Concepts among Senior Secondary School Biology Students in Kaduna North Education Zone, Kaduna State, Nigeria by Ahmed Muideen, Misbahu Adamu Sani & Zainab Muhammad Shuaibu investigated the impact of personalized-learning strategy on students' performance in biology nutrition concepts. The study adopted a quasi-experimental design involving 150 students drawn from a population of 6,721 SS2 students in Kaduna North Education Zone. The experimental group received instruction through personalized-learning strategy, while the control group was taught using the conventional method. Data were collected using the Biology Performance Test (BPT), which had a reliability coefficient of 0.82. Descriptive statistics were used to answer the research questions, and independent samples t-test was employed to test the null hypotheses at $P \leq 0.05$. Findings revealed a statistically significant difference in performance between students taught with the personalized-learning strategy and those taught conventionally, with no significant gender difference observed. The study concluded that personalized-learning strategy is effective in improving student performance in STEM concepts and recommended its adoption by STEM teachers due to its positive impact and suitability across gender.

Article 16

Moses Kayola Phiri, Chipo Namakau Sakala, and Benson Banda in article Revolutionising **Physics Education: A Case Study on Implementing Concept-Based Learning in a STEM Secondary School in Zambia**, explored the effectiveness of concept-based learning (CBL) in

enhancing physics education. The study employed a quasi-experimental design with two classes: one consisting of 40 learners taught using CBL, and another taught through traditional methods. Data were collected over a three-month period through pre- and post-tests, classroom observations, and student interviews. Analysis using SPSS version 28 for quantitative data and NVivo 14 for thematic qualitative analysis revealed a significant improvement in learners' understanding of energy concepts. The CBL group achieved a mean difference of 40.67 with a 74.28% improvement, compared to the traditional group's mean difference of 19.0 and a 34.8% improvement. Qualitative findings showed that students in the CBL group demonstrated higher engagement in designing and construction, greater confidence in applying physics principles, and a deeper appreciation for the subject. The study concluded that CBL not only improves academic performance but also fosters competencies such as critical thinking, designing, and problem-solving. It recommended broader adoption of CBL in STEM-focused schools in Africa, alongside further research into its long-term effects across STEM disciplines.

Article 1

Impact Of Inquiry-Based Learning on Steam Education and Gender Differential on Academic Performance Among Basic Science Students in Nassarawa Local Govt. Area Kano State

[1]Saudat Shehu Bala, [2]Gali Musa PhD.

saudatshehubala@gmail.com , galimusa01@gmail.com

[1]Department of Science and Technology Education, Aliko Dangote Universty of Science and Technology, Wudil
.
[2]Department of Integrated Science, Sa'adatu Rimi Unuversity of Education, Kumbotso

[3]Nazifi Wada Salisu
wadasalisunazifi@gmail.com
[3]Department of Biology, Federal College of Education, **Azare**

Abstract

The study examined the Impact of Inquiry-Based Learning on STEAM Education and Gender differential on Academic Performance among Basic Science Students in Nassaraw Local Government Area, Kano State. The study used a quasi-experimental design, involving pretest and posttest for data collection. A sample of 200 students was randomly selected from four schools out of 10 Junior Secondary School that formed the population. Data were collected using the instruments tagged Heat Concept Performance Test (HCPT). Two research questions were raised and two null hypotheses were formulated. The null hypotheses were tested using t-test statistical tool at P≤ 0.05 level of significance. The finding of the study revealed that there is a significant difference between the mean performance scores of Basic Science students taught heat concept using inquiry-based learning in STEAM education and those taught same using traditional method. There is no significant difference between the mean performance scores of male and female Basic Science students taught heat concept using inquiry-based learning in STEAM education in experimental group. The study recommended that Schools and educators should actively work to mitigate gender stereotypes within STEAM fields. Encouraging all students, regardless of gender, to participate in inquiry-based learning activities can help break down barriers and foster a more inclusive learning environment. Educators and policymakers should prioritize the adoption of inquiry-based learning approaches in STEAM education to improve academic performance and increase the awareness to future careers in STEAM Education.

Keywords: *Inquiry-Based Learning STEAM Education, Gender differential Academic Performance and Basic Science*

1. Introduction

Inquiry-based learning is a student-centered instructional approach that makes use of meaningful tasks such as cases, projects, and research to situate learning (Avsec & Kocijancic, 2016). Inquiry-based learning is an instructional practice where students are at the center of the learning experience and take ownership of their own learning by posing, investigating, and answering questions (Caswell & LaBrie, 2017).

Inquiry-based learning is rooted in constructivism, which is a learning theory, and states that humans construct their own knowledge and meaning from their personal experiences (Duran & Dökme 2016). Therefore, in such a case, knowledge is being built rather than delivered by the teacher. John Dewey, a constructivist and an advocate of IBL, states that students should actively be in engaged in the learning process. He explains: "if you have doubts about how learning happens, engage in sustained inquiry: study, ponder, consider alternative possibilities, and arrive at your belief grounded in evidence" (Dewey, 1998, as cited in Mapes, 2009, p.11). John Dewey strongly believed that students need to be reflective problem solvers (Santrock, 2017). Guido (2017) identifies seven benefits of IBL, arguing that it: (a) reinforces curriculum content, 2). warms up the brain for learning, 3). promotes a deeper understanding of the content, 4). helps make learning rewarding, 5). builds initiative and self- direction, 6). works in almost any classroom, and 7). offers differentiated instruction.

Various studies have identified inquiry-based learning as a teaching method which facilitate students' understanding of the nature of science (Ajayi & Ogbeba, 2017), improves their performances and attitudes towards the learning of science courses (Alkan, 2018) and promotes students' engagement and motivation in a student-centered and active learning environment (Gómez & Suárez, 2020). Moreover, apart from the science contents knowledge, students exposed to the inquiry-based learning acquire such skills as asking questions (Tshering & Yangden, 2021). Another study by Ibrahim et al. (2018) found that inquiry-based teaching is gender friendly in teaching chemistry. Alachi et al. (2021) concluded that inquiry-based teaching method has a positive impact on students' understanding of science concepts and achievement. However, from their findings, it was noted that gender has no effect on students understanding of science concepts and achievement. Contrary to the above studies, several studies have found a gender bias with respect to the use of inquiry-based method to teach chemistry. Some have found a significant gender-related difference in students' academic performance in favour of male (Ghumdia, 2016; Filgonali, & Sababa, 2017; Gómez & Suárez, 2020) while others concluded that it is more productive for female (Tekin & Eryılmaz Muştu, 2021; Mwenda & Ndayambaje, 2021).

According to Xie, Fang and Shauman, (2015) STEAM is defined as an interdisciplinary curriculum that integrates the five disciplines of science (S), technology (T), engineering (E), art (A), and mathematics (M) in which the main features of STEAM education is collaborative, and realistic problem solving. Yakman, (2016) stated that STEAM education has the benefits of developing students' innovation abilities, cooperation abilities, and realistic problem-solving abilities. Due to the benefits of STEAM education, it has been regarded as one of the most promising education methods in the world since its inception (Kim & Bolger, 2017). However, little research has been conducted on STEAM education that takes students' gender and gender grouping into account, especially at the elementary level.

Gender plays an important role in education. Gender is associated with psychological differences between boys and girls, and these differences affect their behavior and performance. Despite the proven psychological and behavioral differences in gender, there are mixed findings regarding their impact on learning. While some studies have reported that boys demonstrate superior abilities in science, reasoning abilities, and abstract knowledge (Voyer and Voyer 2014), girls have been found to outperform boys in speech and reading comprehension. Other studies have found that girls outperform boys in most subjects in K-12 education (Chaplin and Aldao 2014). These inconsistent conclusions may be related to the fact that gender differences are influenced by age, relationships, and field (Siddiq and Scherer 2019). Students in grade 6 (age 11–12) of elementary school are about to enter adolescence and have certain logical thinking and teamwork abilities. However, few studies have explored gender differences in STEAM education for this particular group of students.

Furthermore, some research studies have revealed that the gender composition of groups also leads to different learning performances during collaborative learning. Studies by Jiang, Li, Zheng and Han (2017) have concluded that mixed-gender groups perform better than same-gender groups. This may be because during group interaction, boys talk more about task related topics while girls are better at planning and communication, which makes mixed-gender groups more relaxed and prone to engaging in cooperative behavior than same-gender groups. Some studies suggest that same-gender groups are better, as they are more purposeful and consensual than mixed-gender groups (Zhan, Fong, Mei and Liang, 2015). Other people believe that the influence of group gender composition is limited and that it only affects students' attitudes rather than their performance (Li, Luo, Zhao, Zhu, Ma and Liao 2022).

In addition, in terms of boy and girl students' performance in different gender groupings, boys' performance in mixed-gender groups is significantly better than that in same gender groups, and boys prefer mixed-gender groups (Herro, Quigley, Andrews and Delacruz 2017). This may be because, in mixed gender groups, boys are more likely to demonstrate leading behaviors, while girls are more likely to be agreeable (Li, Luo, Zhao, Zhu, Ma and Liao 2022). In this study academic performance of Basic Science students was examined using STEAM Learning Approach.

Basic Science is the science taught at the primary and junior secondary level in Nigeria. The syllabus of Basic Science is designed with a lot of activities, as such methods used for its teaching should be in such a way that it will allow the learner to learn through the activity-based method of teaching. NTI (2007) reported that methods of teaching Basic Science should include the guided discovery method which is resource based. According to Ndu, Olarewaju, Ndu, and Somoye, (2017), Basic Science is the foundation that prepares pupils for future learning and study of science subjects like Chemistry, Physics and Biology at the Senior Secondary School level. This means, for a student to be able to study single science subjects at the senior class, such a student must perform well in Basic Science at the Junior Secondary School Certificate Examination (JSSCE). In addition, Basic Science lays emphasis on inquiry into nature in the environment through the use of activity-based method of teaching. Therefore, this study investigated the effects of inquiry-based learning STEAM Education and gender differential on academic performance among Basic Science students in Nassarawa Local Govt, Kano State.

1.1 Objectives of the Study

The objectives of the study were to;

1. investigate the effect of inquiry-based learning on academic performance in STEAM education among basic science students.
2. examine the impact of inquiry-based learning on gender differentials on academic performance among basic science students.

1.2 Research Questions:

1. Does the implementation of inquiry-based learning in STEAM education significantly improve academic performance among basic science students?
2. Can inquiry-based learning reduce gender differentials on academic performance among basic science students?

Null Hypotheses:

1. There is no significant difference in the academic performance of basic science students who receive inquiry-based learning in STEAM education compared to those who receive traditional teaching methods.

2. There is no significant difference between mean performance score of male and female Basic Science students taught heat concept using inquiry-based learning in STEAM education in the experimental group.

2. Methodology

In this study, a quasi-experimental design, involving pretest and posttest as suggested by Kerlinger (1973), was used. The study involved two groups experiment and control. The population of the study consisted of all public Junior Secondary (JSII) Basic Science Students in Nassarawa Local Govt, Kano State. The size of the population is Two thousand Four hundred and Ninety-three students (2493) in which One Thousand Three-hundred (1300) were males and One Thousand Two-hundred and Ninety-three (1193) were female students. Simple random sampling, involving 'balloting method' was used to select four schools out of the ten (10) in the population. From the four (4) schools, one intact class of JSII was selected using balloting method of simple random sampling because they were found to be equivalent. This gave a total number of four (4) intact classes in which two hundred students were randomly selected for the study. The total number of the sampled subjects for the study was 200. One-hundred and two (102) subjects formed experimental group while the remaining ninety-eight (98) subjects formed the control group. The instruments used for the study was Heat Concept Performance Test (HCPT). The HCPT was adapted from past questions papers of JSSQE, which consisted of thirty (30) items with multiple choices of letters A-D. HCPT was used for pretest and posttest in order to measure the level of performance among JSII Basic Science students. The HCPT was administered to the sampled groups as a pretest by the researchers and the research assistants. The HCPT was then administered to the two groups in the form of examination as a posttest. The HCPT items, was graded by the researchers and the scores were used to determine the level of students' performance.

3. Results and Discussion

Null Hypothesis one: There is no significant difference in the academic performance of basic science students who receive inquiry-based learning in STEAM education compared to those who receive traditional teaching methods.

Table 1: t-test comparison of posttest mean performance scores of experiments and control group taught heat concept using inquiry-based learning in STEAM Education

Variable	Groups	N	Mean	Std. Dev	Df	t-cal	t-crit	P
Performance mean scores	Exp.	102	21.85	2.25	200	36.4	1.96	0.01
	Control	98	10.51	2.10				

Table 1 show that there was a significant difference between the mean performance scores of Basic Science students taught heat concept using inquiry-based learning in STEAM education and those taught same using traditional method. This is because the calculated p value of 0.01 is lower than the 0.05 alpha level of significance and the calculated t value of 36.4 is higher than the 1.96 t critical value at df 200. This implies that students in the experimental group performed better than their counterpart in the control group. Therefore, null hypothesis one is rejected.

Null Hypothesis Two: There is no significant difference between mean performance score of male and female Basic Science students taught heat concept using inquiry-based learning in STEAM education in the experimental group.

Table 2: t-test comparison of posttest means performance scores of male and female Basic Science students in the experiment group taught heat concept using inquiry-based learning in STEAM education

Variable	Groups	N	Mean	Std. dev	Df	t-cal	t-crit	P
Performance mean scores	Male students	58	12.85	2.89	190	21.4	1.26	0.01
	Female students	42	10.38	1.44				

Table 2 show that there is no significant difference between the mean performance scores of male and female Basic Science students taught heat concept using inquiry-based learning in STEAM education in experimental group. This is because the calculated p value of 0.01 is lower than the 0.05 alpha level of significance and the calculated t-value of 21.4 is higher than the 1.26 t-critical value at df 190. This implies that both male and female students in the experimental group performed better in learning heat concept using inquiry-based Learning in STEAM education. The inquiry-based learning in STEAM Education is gender friendly. Therefore, null hypothesis two is retained.

4. Discussion of Result

Table 1 show that there is a significant difference between the performance mean scores of students taught heat concept using inquiry-based learning in STEAM education in experimental and control group. This implies that students in the experimental group performed better than their counterpart in the control group. The finding of this study is in agreement with finding Connor, Karmokar and Whittington (2015) have found that combining inquiry-based learning in STEAM education with the learning of elementary science could improve the academic performance of students, compared with the lecture-centered teaching model. Annan et al. (2019) found that students taught using the Inquiry-based teaching method did better on the biology test than those taught using the lecture method. In the same vein, Alachi et al. (2021) concluded that inquiry-based teaching method has a positive impact on students' understanding of science concepts and achievement. The study conducted by Feyzioglu and Demirci (2021) that did not demonstrate a statistically significant difference when comparing students in both experimental and control group exposed to inquiry-based learning.

Table 2 show that there is no significant difference between the mean performance scores of male and female students taught heat concept using inquiry-based learning in STEAM education in experimental group. The finding of this study is in agreement with the finding of Nadeem, Ali, Maqbool and Zaidi (2012) who studied the impact STEAM education on the Academic performance of Students at University level in Bahawalpur, Pakistan. The in-depth investigation of the findings obtained through the analyzed data reveals that STEAM education had its impact on academic performance of both male and female students. The results also showed that poor implementation of STEAM education affect academic performance of both in male and female students. Another study by Ibrahim et al. (2018) found that inquiry-based teaching is gender friendly in teaching chemistry. However, from their findings, it was noted that gender has no effect on students understanding of science concepts and achievement using inquiry-based learning. Adejo (2015) found that the post-test mean scores of males and females in the conceptual understanding of the selected topics of chemistry subject were not statistically significant with the use of inquiry-based teaching method. However, some studies have found a significant gender-related difference in students' academic performance in favour of male (Ghumdia, 2016; Filgonali, & Sababa, 2017; Gómez & Suárez, 2020) while others concluded that it is more productive for female (Tekin & Eryılmaz Muştu, 2021; Mwenda & Ndayambaje, 2021).

5. Conclusion

This study investigated the impact of inquiry-based learning on STEAM education and gender differentials in academic performance among basic science students. Research suggests that while initial academic performance gaps based on gender may exist, inquiry-based learning environments tend to reduce these differentials by providing equitable opportunities for all students to explore and excel. The results show that inquiry-based learning significantly improved academic performance in STEAM subjects, with female and male students showing a greater increase in performance. The findings suggest that inquiry-based learning can help reduce the gender gap in STEAM education, promoting gender equity and inclusivity in science education. The study's results have important implications for teaching and learning practices in STEAM education. The findings also highlight the need for educators to address gender stereotypes and biases in STEAM education, providing equal opportunities for all students to develop their skills and interests in science and technology. This study demonstrates the potential of inquiry-based learning to promote gender equality and academic excellence in STEAM education, providing valuable insights for educators, policymakers, and researchers seeking to improve science education outcomes for all students."

6. Recommendations

Based on the study's results, the following recommendations are made:

1. Schools and educators should actively work to mitigate gender stereotypes within STEAM fields. Encouraging all students, regardless of gender, to participate in inquiry-based learning activities can help break down barriers and foster a more inclusive learning environment.

2. Educators and policymakers should prioritize the adoption of inquiry-based learning approaches in STEAM education to improve academic performance.

3. Teachers should receive training and support to effectively implement inquiry-based learning strategies and address gender stereotypes and biases in the classroom.

4. Curriculum developers should create STEAM education materials that promote gender inclusivity and challenge stereotypes, encouraging all students to pursue science and technology fields.

5. Educators and policymakers should provide opportunities and resources to support female students' participation in STEAM extracurricular activities, such as science fairs, robotics clubs, and coding workshops.

6. Educators and policymakers should regularly assess and evaluate STEAM education outcomes to ensure that inquiry-based learning approaches are effective in promoting gender equity and academic excellence.

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Article 2

Creativity And Differential Aptitude Tests as A Means of Assessing General and Special Abilities

Bashir Kawu

bkawu41.bk@gmail.com

NTI Gombe State Office

Abstract

This paper examines the intricate nature of creativity and its measurement, emphasizing its importance in educational and professional contexts. Creativity is defined as the production of novel and appropriate responses to open-ended tasks, involving cognitive complexity and diverse personality traits. Different psychological theories, including psychoanalytic, personality, humanistic, and holistic perspectives, provide comprehensive insights into creativity. Prominent psychologists such as Thurston, Kim, Bertlet, and Rollo offer varied definitions, highlighting attributes like bold thinking, originality, and flexibility. The paper also delves into the Differential Aptitude Tests (DAT), developed to assess specific skills across educational phases. These tests, including versions for different grade levels, measure abilities such as verbal reasoning, numerical ability, abstract reasoning, mechanical reasoning, space relations, spelling, and language usage. The DAT's role in career guidance and vocational counseling underscores its significance in identifying individual strengths. Moreover, the paper discusses various methods to measure creativity, such as the Guilford Test of Divergent Thinking and the Torrance Test of Creative Thinking (TTCT), which assess originality, fluency, flexibility, and elaboration. By integrating creativity assessments and DAT, educators and employers can gain a holistic view of individuals' capabilities, guiding them toward suitable educational and career paths. This combined approach can foster innovative thinking, align students with appropriate roles, and enhance overall educational and professional outcomes.

Keywords**:** *Creativity, Differential Aptitude Tests, General and Special Abilities*

1. Introduction

Creativity is the production of novel and appropriate responses, products, or solutions to open-ended tasks. Although the response must be new, it cannot be merely different; the nonsensical speech of a schizophrenic may be novel, but few would consider it creative. Thus, the response must also be appropriate to the task to be completed or the problem to be solved; that is, it must be valuable, correct, feasible, or somehow fitting to a particular goal. Moreover, the task must be open-ended (heuristic), rather than having a single, obvious solution (purely algorithmic). Ultimately, a response or product is creative to the extent that it is seen as creative by people familiar with the domain in which it was produced.

Creativity is challenging to understand. Different types of thought are expressed to understand creativity from various aspects. Many psychologists agree that creativity plays a crucial role in generating new thoughts, transforming old things into new ones, and building relationships with unrelated objects. Some psychologists have expressed their views to clarify the idea of creativity:

Thurston (1955) described creativity as "any action that is creative if it provides an immediate solution through innovative thinking." Kim (2009) suggested that "creativity is the essence of making pre-existing understanding errors un-received and rare elements in their improvement by reviewing the concepts." Bartlett (1968) defined creativity as "bold thinking," which means thinking beyond the mainstream, experiencing new things, and integrating present relationships with future ones. Rollo (1960) stated, "creativity is the process of bringing something new into existence. It requires passion and commitment, bringing awareness to what was previously hidden and pointing to new life." According to Kim (2005), creativity has four components:

1. **Continuity**: A creative child can consistently change in a useful manner, generating different types of ideas continuously.
2. **Flexibility**: Creativity in a person refers to self-control, foresight, and considering others' likes and dislikes. Such a person adapts their thoughts according to time and circumstances.
3. **Originality**: A creative child does not adhere to old ideas but develops original thoughts. This child is strong-willed, industrious, and courageous, eager to start tasks independently, and often holds opinions different from other children.
4. **Expansion**: A creative child can exaggerate any matter or event, possess a rich vocabulary, and has an interesting way of expressing ideas.

Various theories of creativity offer unique perspectives on what fosters creativity in individuals. Some of the theories include:

1. **Holistic Approach to Creativity**: Proponents like Johann Wolfgang von Goethe, Immanuel Kant, Wolfgang Köhler, and Kurt Koffka argue that creativity involves various

factors influencing the creative process, such as abilities, skills, personality traits, motivation, and creative experiences.

2. **Psychoanalytic Theory of Creativity**: Proponents like Freud, Jung, Kris, Rank, Adler, and Hammer believe that creativity arises as a reaction to difficult circumstances or repressed emotions. According to this theory, individuals retreat from their surroundings during challenging situations or traumatic events and rely on their creative side to find solutions or express repressed emotions (Baer, 2009).
3. **Personality Traits Theory of Creativity**: Figures like Raymond Cattell, Eysenck, McCrae, and Costa suggest that creativity is determined by personality traits such as imagination, ingenuity, inquisitiveness (Gage & Berliner, 1994), emotionality, self-confidence, diligence, critical thinking, boldness, independence, flexible thinking (Fraise, 1982), receptivity, dominance, and initiative. Researchers also mention sensitivity to problems, a broad range of interests, originality, eccentricity, and usefulness (Gage & Berliner, 1994).
4. **Humanistic Perspective of Creativity**: Proponents like Carl Rogers and Abraham Maslow propose that an active creative force within each individual, often called the "self," seeks expression and growth. This perspective, known as the third force, emphasizes human potential, self-awareness, and free will, viewing humans as innately good. Maslow notes that self-actualized individuals have realistic perceptions, are spontaneous, easily accept themselves and others, are creative, and appreciate life's positive aspects, like privacy and independence. The humanistic perspective links creativity to creative thinking, defined as the highest form of productive thinking (Jovaisa, 2001).

Differential aptitude tests (DAT) are instruments used to determine and measure an individual's ability to acquire specific skills through future training. The DAT were developed to test learners in the General Education Training (GET) phase and the Further Education Training (FET) phase. For each phase, two tests were developed: a standard form for general use and an advanced form for learners with favorable educational opportunities. According to Vosloo (2000), the full series comprises the following:

- **Differential Aptitude Tests Form R** – (Grades 7–10 standard form): Measures the aptitude of learners in Grades 7–10 with favorable educational opportunities.
- **Differential Aptitude Tests Form S** – (Grades 7–10 advanced form): Also used to test Grade 7 learners' aptitudes, assuming they had access to relatively good educational opportunities.
- **Differential Aptitude Tests Form K** – (Grades 10–12 standard form)
- **Differential Aptitude Tests Form L** – (Grades 10–12 advanced form)

The DAT measures a person’s ability in different areas, making it a "potency" test. The skills and abilities measured are essential in multiple educational and professional situations. DAT is a series of tests for personnel and career assessment, designed to measure an individual's ability in various fields. Employers use these tests to assess potential employees’ abilities and determine their suitability for specific positions. Initially launched in 1947 to support career guidance and vocational counseling for students, the DAT's use has expanded to measure an individual's general and specific mental abilities required for success in many job roles and training courses. In-depth research supports the increased usage of ability tests, showing that mental ability tests are highly predictive of performance.

The test covers several areas, including Verbal Reasoning, Numerical Ability, Abstract Reasoning, Perceptual Speed and Accuracy, Mechanical Reasoning, Space Relations, Spelling, and Language Use. The tests are performed under exam conditions and are strictly timed, with all questions having definite right or wrong answers. Few candidates usually complete the entire test, as questions typically become progressively more difficult. The test is also age-related.

2. How Are Creativity and Differential Aptitude Tests Measured?

2.1 Measurement of Creativity

The most common forms of creativity assessment involve objective measures, such as asking individuals to produce numerous ideas in response to a stimulus question, and self-reported measures, such as providing a list of achievements. An alternative is to gather perceptions from those outside the creative process.

Psychologists who study creativity are passionate about measuring creativity or determining how to accurately measure originality and novelty. The following are some tests used to measure creativity:

i. **Guilford Test of Divergent Thinking**: In 1967, creativity psychology pioneer J.P. Guilford developed a test to measure divergent thinking, calling it Guilford’s Alternative Uses Task. Test takers list as many possible uses for a common object, such as a cup, paperclip, or newspaper. Scoring comprises four components:

    - **Originality**: Based on each response compared to the total responses from a specific group. Responses given by 5% of the group are unusual (1 point); responses given by only 1% are unique (2 points).
    - **Fluency**: Scores relevant answers.
    - **Flexibility**: Based on the variety of categories.
    - **Elaboration**: Based on the amount of detail in the response.

ii. **Torrance Test of Creative Thinking (TTCT)**: This test, developed by psychologist E. Paul Torrance, builds on Guilford's research. The TTCT attempts to psychometrically measure divergent thinking and other problem-solving skills. The reliability and validity of the TTCT have made Torrance nationally and internationally known, often referred to as the "father of creativity research." TTCT is the most well-known and widely used test for measuring creativity (Baer, 2009; Kim, 2006; Wechsler, 2002). The test is divided into two parts: figural and verbal.

- **Figural**: Consists of three tasks: picture construction, picture completion, and repeated figures of lines or circles. In picture construction, participants receive a pear or jellybean shape and must create a picture from it. In the picture completion and repeated figures tasks, participants complete 10 incomplete pictures or figures.
- **Verbal**: Contains seven subsets: asking, guessing causes, guessing consequences, product improvement, unusual uses, unusual questions, and just suppose. Subsets are scored based on fluency, flexibility, and originality, with elaboration as an optional score. These scores are accumulated across all subsets and may be converted to standard T scores if a normative reference is designed.

2.2 Measurement of Differential Aptitude Tests

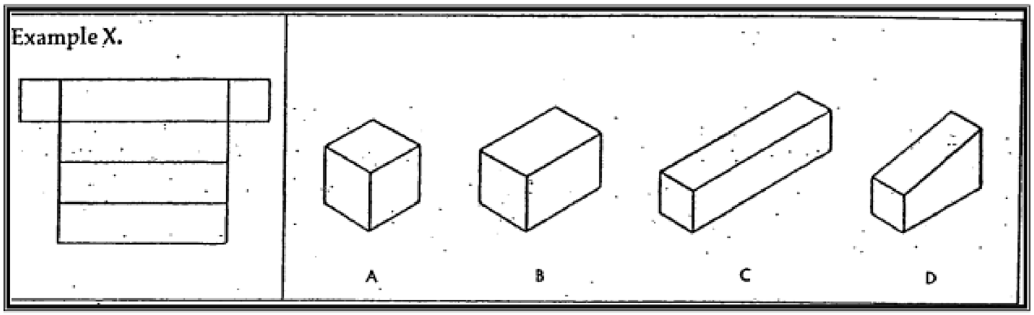
The Differential Aptitude Tests (DAT) are carefully constructed to help individuals understand their abilities. It consists of seven different tests, and individuals may be tested on all or various sections depending on the program they are applying for. The following table provides an example of how the DAT is constructed:

S/N	Test Name	Number of Questions	Time to Complete
1	Verbal Reasoning	50	30 minutes
2	Numerical Ability	40	30 minutes
3	Abstract Reasoning	45	20 minutes
4	Mechanical Reasoning	70	30 minutes
5	Space Relations	60	25 minutes
6	Spelling	90	10 minutes
7	Language Use	60	25 minutes

Each test is unique and measures different skills, providing a comprehensive understanding of an individual's strengths and areas for development. The results from the DAT can help guide career choices and educational paths, ensuring individuals are well-matched to their roles and fields of study.

2.3 Space Relations

This test consists of 60 patterns which can be folded into figures. To the right of each pattern there are four figures. You are to decide which one of these figures can be made from the pattern shown. The pattern always shows the outside of the figure. Here is an example:



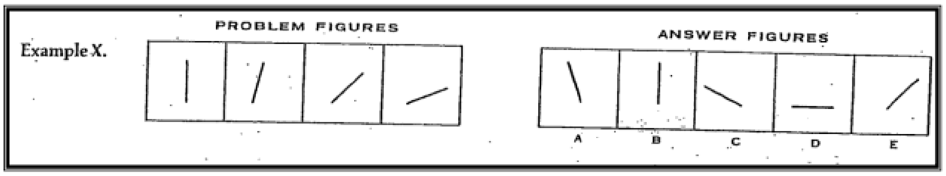
In example X, which one of the four figures—A, B, C, D—can be made from the pattern at the left? A and B certainly cannot be made; they are not the right shape. C is correct both in shape and size. You cannot make D from this pattern.

In Example Y all the figures next to the pattern are correct in shape, but only one of them can be made from this pattern. Note that when the pattern is folded, the figure it makes will have three grey surfaces. Two of these will be the largest surfaces, either of which could be the top or the bottom of a box. The other will be one of the smallest surfaces, which would be one end of the box. Now look at the four figures:

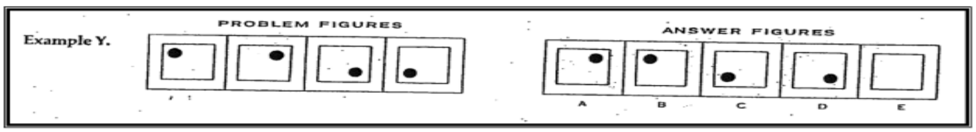
Figure A is wrong. The long, narrow side is not grey in the pattern and the largest surface must be grey Figure B is wrong. The largest surface must be grey, although the grey end could be at the back Figure C is wrong. The grey top and end are all right, but there is no long grey side in the pattern. Figure D is correct. A large grey surface is shown as the top, and the end surface shown is also grey. So, you see, all four figures are correct in shape, but only one—D—show the grey surfaces correctly.

2.4 Abstract Reasoning

In this test you will see rows of designs of figures like those below. Each row across the page is one problem. You are to mark your answers on the Answer Sheet. Each row consists of four figures called Problem Figures and five called Answer Figures. The four Problem Figures make a series. You are to find out which one of the Answer Figures would be the next (or the fifth one) in the series of Problem Figures. Here are two examples:



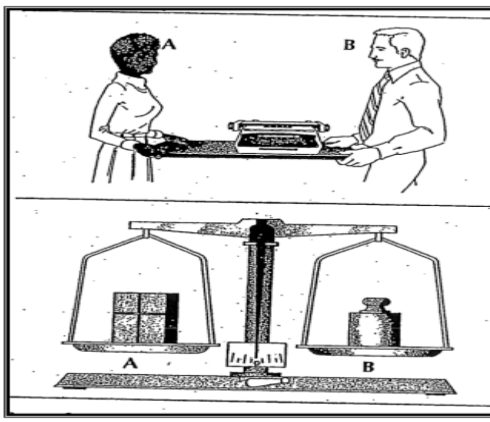
In Example X, note that the lines in the Problem Figures are falling down. In the first square the line stands straight up, and as you go from square to square the line falls more and more to the right. In the fifth square the line would be lying flat, so the correct answer—chosen from among the Answer Figures—is D.



In Example Y, study the position of the black dot in the Problem Figures. Note that it keeps moving around the square clockwise: upper left corner, upper right corner, lower right corner, lower left corner. In what position will it be seen in next? It will come back to the upper left corner. Therefore, B is the correct answer.

Mechanical Reasoning

This test consists of a number of pictures and questions about those pictures. Look at the two examples below, to see just what to do.



Example X.

Which person has the heavier load?

(If equal, mark C)

Example X shows a picture of two people carrying a typewriter on a board and asks, which person has the heavier load? (If equal, mark C.) Person B has the heavier load because the weight is closer to him than to person A. Example Y asks, which weighs more? (If equal, mark C.) As the scale is perfectly balanced, A and B must weigh the same, so the correct answer is C. Do not forget that there is a third choice for every question. You will have 30 minutes for this test. Work as rapidly and as accurately as you can. If you are not sure of an answer, mark the choice that is your best guess.

2.5 Numerical Ability

This test consists of forty numerical problems. Next to each problem there are five answers. You are to pick out the correct answer and mark its letter on the Answer Sheet. If you do not find a correct answer among the first four choices. Choice N for every problem is none of these, which means that a correct answer is not among the first four choices. Only on answer should be marked for each problem. Do your figuring on the scratch paper you have been given, and reduce fractions to lowest terms. Here are some examples.

Example X	Add		
		A. 14	
	13	B. 16	In example X, 25 is the correct answer, so C
	12	C. 25	would be letter you would bubble in on the
		D. 59	Answer Sheet
		N. none of these	

Example Y	Subtract		
		A. 8	
	30	B. 15	In example Y, the correct answer has not
	20	C. 16	been given, so the circle with the letter for
		D. 26	none of these -N- would be the correct
		N. none of these	answer.

3. Conclusion

In conclusion, understanding and measuring creativity alongside differential aptitude provides a comprehensive framework for assessing and nurturing individual potential. Creativity, characterized by novel and appropriate responses, is a complex construct influenced by cognitive processes and diverse personality traits. Theories from psychoanalytic, personality, humanistic, and holistic perspectives offer valuable insights into its nature. Assessments like the Guilford Test of Divergent Thinking and the Torrance Test of Creative Thinking effectively measure creativity, while Differential Aptitude Tests (DAT) evaluates specific skills critical for academic and career success. Integrating these assessments offers a holistic view of students' abilities, aiding educators in providing targeted support and career guidance. This approach ensures that individuals are well-matched to their roles, fostering innovative thinking and maximizing their potential.

The use of DAT in educational and professional settings highlights its importance in identifying strengths and guiding career choices, contributing to improved outcomes. Ultimately, the synergy between creativity and differential aptitude assessments can transform educational practices, promoting a well-rounded development of individuals' capabilities. As these methods continue to evolve, their application will play a crucial role in shaping future educational policies, ensuring students are equipped with the skills and mindset needed for success in a dynamic and competitive world.

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Article 3

Effect of E-Instructional Material on Social Studies Academic Performance Amongst Upper Basic Schools Kaduna, North-West Nigeria

Kemi Adeyemo,
toturomu@gmail.com

Totus International School Barkallahu, Kaduna Nigeria

Ibrahim Sani
ibrahimsani1970@gmail.com

Department of Science and Mathematics Education.Nationalteachers'institute,Kaduna,Nigeria

Abstract

E-instructional material is seen as one of the indispensable tool or powerful force of achieving effective classroom curriculum delivering in our educational system. The study investigated the effect of E- instructional materials on Social Studies Academic performance amongst Upper Basic Schools in North West Nigeria. The researcher employed quasi-experimental and descriptive survey design. The population of the study comprised of five thousand, seven hundred and six (5,706) with a sample size of eighty-nine (89) Upper Basic students. Two research questions and two null hypotheses guided the study. Social Studies Academic Performance Test (SOSAPT) was used for data collection. The reliability of SOSAPT was 0.67 using Kuder Richardson formula21. Mean and Standard deviation were used to answer the research questions, while independent t-test was used to test the null hypothesis. The result revealed that students exposed to E-instructional materials performed significantly higher than their counterparts exposed to lecture method and gender have no significant effect on Academic performance of Upper Basic Students taught social studies using E-instructional materials. The researcher recommended among others that government should provide E-instructional materials to all Upper Basic Schools in North West Nigeria.

Keywords: *E – Instructional materials, Academic performance, Gender, North-west*

1. Introduction

E-Instructional materials have been named differently by authors depending on their area of specialization. It has been referred to as information communication technology, digital materials, educational facilities, learning resources, educational technology, media materials and curriculum materials. Traditionally, classroom teachers have relied heavily on the 'talk-chalk' teaching method. Therefore, instructional materials constitute the media of exchange through which a message transaction is facilitated between a source and a receiver. Educational media are used to retrieve information according to Egede (2004), this includes, opaque projectors, slide projector, radio, cassette recorder and television among others. One major problem facing Social Studies in Kaduna North West Nigeria is the low performance of Upper Basic Secondary School students in both local and standardized examinations. The examinations conducted in Upper Basic Secondary Education between 2017 to 2022, result, revealed 59%, 61%, 76%, 67% and 71% as the number of students that failed to obtain credit. This causes a great concern for researchers, parents, curriculum planners, educators, and all stakeholders. "Where lies the problem?" Could it be the curriculum? Could it be non-resourcefulness, innovative and incompetence of Social Studies teachers? Students tend to learn concepts by memorization just to pass examination, in most cases students neither assimilate nor acculturate scientific concepts and norms. Despite all the emphasis on the acquisition of practical skills and basic knowledge and other teaching materials by Ministries of Education, Social Studies teachers still lack the basic experience/method of teaching. In most societies, issue of gender inferiority or superiority and consequences has filled almost every aspect of the nation's economic, political and educational system

The study also investigated the effect of e-instructional on academic performance of male and female students. The Nigerian National Policy on Education (2014) clearly stipulate equal opportunity for its citizens. Shaibu and Maikano (2016) reported that "though male and female differ in physical appearance, they do not differ in mental abilities. Gender is one of the factors that is confronting the use of learner centered method is its ability to have the same effect on both male and female students equally. According to Bateku (200), gender refers to s of male and female the characteristics of the male which particular society has determined and assign each sex. In most societies gender has roles on the women folk preventing their participation in and benefiting from development. This issue of gender superiority or inferiority and consequences have permitted almost every aspect of the nations, economy, political and educational system especially in area of some specific subject. This trend in difference needs to be verified further the influence of gender on effect of E-instructional materials among Social Studies student.

1.1 Purpose of Study

The purpose of this study was to determine the effect of e-instructional materials on academic performance of social studies students taught using e-instructional materials and those taught using lecture method alone in North-West, Nigeria. Specifically, the study sought to:

i. determine the effect of e-instructional materials on the academic performance of students taught Social Studies using E-Instructional Materials and those taught using conventional method in Upper Basic Schools.

ii. Determine the effect of e-instructional materials on Academic Performance of male and female social studies students taught using E-Instructional Materials and those taught using the conventional lecture method alone.

1.2 Research questions

The following are the Questions that prompt this research:

1. What is the effect of e – instructional material on the mean academic performance score of students taught Social Studies using E-Instructional Materials and those taught using the conventional lecture method in Upper Basic Schools, Kaduna North-West, Nigeria?
2. What is the effect of e – instructional material on the mean performance score of male and female Social Studies students taught using E-Instructional Materials and those taught using the conventional lecture method in Upper Basic Secondary Schools, Kaduna North-West, Nigeria?

1.3 Hypotheses

The following hypotheses were formulated to guide the study and tested at 0.05 level of significance:

HO_1: There is no significant difference in the mean Performance scores of social studies Students taught using e-instructional materials and those taught using conventional lecture method in Upper Basic Schools, North-West, Nigeria;

HO_2. There is no significant difference in the mean academic performances scores of male and female students taught Social Studies using E-Instructional Materials and those taught using the conventional lecture method in Upper Basic Schools, North-West, Nigeria, and Nigeria

2. Methodology

This study adopted Quasi-experimental design employing pre-test,posttest and control group design. The population was five thousand seven hundred and six (5,706) Drawn from the twelve educational zones of Kaduna state. Two secondary schools were randomly selected as (experimental and control groups) Eight six (86) students were selected from the school for the study The instrument used for the study was thirty multiple choice Social Studies Academic Performance Test (SOSAPT) on ‘Promoting peaceful living in our society’ developed by the researcher and was validated by experts in the field of measurement and evaluation and social education. The instrument was pilot tested in two schools that were not part of this study. The reliability of the instrument was 0.82, and the value was considered high enough to qualify the instrument used for the study

Earlier to the treatment a pre-test was administered to all students in the two groups. The pre-test was administered to determine students’ knowledge “on Peaceful Living in Our Society. At the end of the treatment, a post—test was administered to the two groups (Experimental and control groups) the data obtained from the test was analyzed using mean and standard deviation to answer the research questions and independent t-test to test the research hypotheses at 0.05 level of significance.

3. Results

Research question one: What is the effect of e – instructional material on the mean academic performance score of students taught Social Studies using E-Instructional Materials and those taught using the conventional lecture method in Upper Basic Schools, Kaduna North-West, Nigeria?

Table 1 Difference in the mean performance scores of students Experimental and Control Groups

Variable	**study group**	**N**	**Mean**	**Std. Deviation**	
mean performance	**Experimental group.**	45	74.4	16.6	14.4 diff.
	Control Group	44	60.3	16.5	

Result of descriptive statistics in the table 1 showed that Experimental Group had a mean score of 74.4% with deviation standard of 16.6 while the mean performance is in the Control Group had a mean score of 60.3 with standard deviation of 16,5. This showed that the mean performance scores of experimental groups is higher than those in the control group.

Research Question Two. What is the effect of E-Instructional Materials E-Instructional Materials on the mean performance scores of male and female Social Studies students taught using E-Instructional Materials and those taught using the conventional lecture method in Upper Basic Secondary Schools, Kaduna North-West, Nigeria?

Table 2 difference in the mean scores of males and female in Experimental Group

Variable	GENDER	N	Mean	Std. Deviation ………. mean diff.
Mean Score Performance scores	Male	23	74.4	16.6
	Female Score	22	73.9	16.7

The result in table 2 reveals that there is no significant difference in the mean performance scores of male and female students taught using E-Instructional Materials. The mean performance scores of male74.4 with standard deviation 16.6 while the mean performance scores of fe male is 73.9 standard deviation 16.7

Hypothesis One: There is no significant difference in the mean performance scores of students taught Social Studies using E-Instructional Materials and those taught using conventional Materials in Upper Basic Schools, Kaduna, North-West, Nigeria

Independent t-test statistics on difference in the mean performance scores of students in experimental and control groups.
Table 3

Group	N	M	STD	t.	Df	T computed	T critical	Decision
Experimental	45	57.12	7.25					
Pretest performance score				8.72	82	4.037	1.96	Rejected
Control	44	38.02	5.05					

Result of the independent t-test in table 3 showed that significant difference exists in the mean performance scores of students taught social studies of using e -instructional materials and those taught using conventional Materials in Upper Basic secondary Schools,Kaduna North-West, Nigeria. Reason is that the computed mean score (4.037) is greater than t-critical value of (p=1.96 at df 82). The computed mean score 57.12 and 38.02 by experimental and control groups of e-instructional materials experimental group and control group respectively favor the experimental group. Therefore, null hypothesis which states there is no significant difference in the mean performance scores of students taught social studies using e instructional materials and those taught in the conventional method was not true for this reason the hypothesis was rejected.

Hypothesis Two: There are no significant differences in the academic performance of male and female students taught Social Studies using E-Instructional Materials and those taught using the conventional Materials in Upper Basic Schools, North-West, Nigeria.

This hypothesis was tested using independent sample t-test statistics. The summary of test of hypotheses is here presented in what follows Independent -Sample t-test on difference in the academic performance of male and female students taught Social Studies using E-Instructional Materials and those taught using the conventional Materials in UpperBasic Schools, North-West, Nigeria.

Table 4: difference in the mean performance scores of male and female students exper

Group	N	M	STD	t.	Df	T computed	T	Decision
Experimental	20	45.10	827					
pretest performance score				40	1.10	0.05	1.65	Accepted
Control	25	44.50	7.50					

Table above showed that there is no significant difference that exist in the mean performance scores of male and female students taught social studies using E-Instructional Materials. This is because the calculated t-value of 0.05 is lower than the critical t-value of 1.68, hence the null hypothesis was retained.

Discussion / Result

The result obtained in table 1 gives answers to research question one and Table 3 shown the analysis of independent t-test of null hypothesis one. The finding revealed that there was a significant difference in the mean performance scores of experimental groups exposed to Social Studies concepts using e- instructional material. They performed better than their counterparts in the control group exposed to conventional strategy. This means that the mode of instruction had significantly affected the mean performance levels of students taught social studies using Social Studies Academic Performance Test, (SOSAPT) is more effective in promoting the performance level of students in social studies than those exposed to conventional method of teaching. The findings are in line with the study Bimpe(2019) which says e – instruction material have higher mean effect on students' academic performance except if not efficiently used to achieve the pre-determined objectives The result in Table 2 reveals answer to research question two and table 4 shown the analysis of independent t-test of hypothesis two. The findings revealed that there is no significant difference in the mean performance scores of male and female students taught social studies in the experimental. This clearly indicated that the sex of has no influence on their performance in the teaching and learning of Upper basic secondary school This implies that academic performance do not affect gender, This agreed with Peter (2014)finding that gender has no significant effect on students' achievement in social studies academic performance This result agreed with the findings of Chikelu (2011), Dahiru(2013) and Shuaibu and Maikano (2016), who reported that sex plays no significant role in academic performance of students. However, the result of our findings is not in agreement with the studies of Ezeudo and Obi (2013), Ajayi and Osoko (2013), Okeke (2007) and Ibe (2006) who reported that there was difference in the academic achievement of male and female. The boys therefore, appear to have natural positive attitude to some subject which helps them to perform better in some subjects.

4. C**onclusion**

On the basis of the findings of this study, it was concluded that e- instructional has significant effect on academic performance in social studies and more effective in enhancing student's performance in learning social studies concepts in Kaduna, North west of Nigeria. Also, gender has no influence on the academic performance taught social studies using e-instructional materials, because there was no significant difference in the mean performance scores of male and female students taught social studies using e-instructional material in Kaduna North West Nigeria.

5. Recommendations

Based on this study, the researcher recommends the following:

i. E-Instructional Materials are needed to facilitate teaching/learning; therefore, it should be compulsorily used in Upper basic secondary schools in North-West Nigeria.
ii. Foster collaboration among schools, teachers, and educational experts to share best practices and resources related to the use of e-instructional materials.
iii. Government to supply all Upper basic schools in Kaduna, North-West Nigeria E-instructional materials at all levels and make the e-instructional materials accessible to all students.
iv. Regular in-service training for upper basic Social Studies teachers to improve on the use of E-Instructional Materials in teaching.

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7. Appendix 1

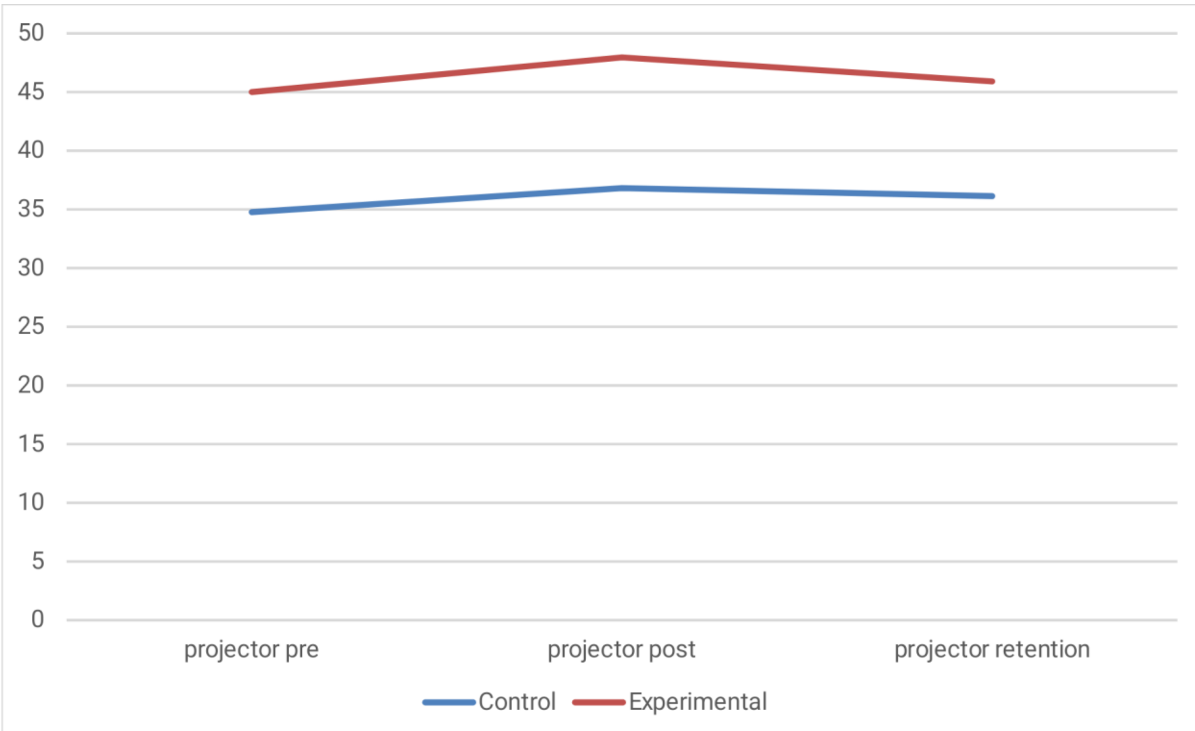

Figure 1

Article 4

Exploring the Effectiveness of the Magnetcode Application through Project-Based Learning: A Case Study among Preservice STEM Teachers at Malcolm Moffat College of Education

[1]Sanura Jaya, [2] Phiri Cornelius
[1]sanurajaya@student.usm.my,[2] Corneliusmariaphiri@gmail.com

[1] Universiti Sains Malaysia,[2] Malcolm Moffat College of Education,

[3]Parvinder Singh s/o Amar Singh,[4]Rozniza Zaharudin
[3]Parvinder@recsam.edu.my, [3]Roz@usm.my

[3] SEAMEO RECSAM,[4] Universiti Sains Malaysia

Abstract

In the digital age, project-based learning has emerged as a crucial skill, serving as the backbone for problem-solving and innovation in STEM education. This case study explores the effectiveness of the Magnetcode application on enhancing STEM activity through project-based learning among Zambian preservice STEM teachers at Malcolm Moffat College of Education. By integrating coding and programming into the project based, Magnetcode application fosters creativity and strengthens problem-solving abilities. Using purposive sampling, qualitative data were collected through open-ended interviews with four preservice STEM teachers. The findings demonstrate that Magnetcode significantly enhances usability and innovative teaching approaches using project-based learning by emphasizing hands-on activities and the practical application of theoretical knowledge. Participants also reported increased confidence in using technology, improved collaboration with peers, and a deeper engagement with coding applications. These results suggest that incorporating tools like Magnetcode into preservice teacher training programs can effectively prepare future educators for delivering innovative STEM education through project-based learning, thereby equipping them to inspire and lead in the evolving educational landscape.

Keywords: *Computational thinking, Project-based learning, Magnetcode application, Pre-Service STEM teachers*

1. Introduction

Project-based learning is an essential skill in STEM (Science, Technology, Engineering, Mathematics) education (Barak, 2020; Directorate of National Science Centre, 2020) , and has gained increasing importance globally, particularly as a driver for innovation and economic development (Suryani et al., 2024). In Zambia, STEM educational approach focuses on teaching individual STEM-related subjects such as integrated science, physics, chemistry, biology, ICT, agricultural science, design and technology, food and nutrition, and mathematics at the secondary school level. This method emphasizes the separate instruction of each discipline rather than integrating the disciplines of Science, Technology, Engineering, and Mathematics into a cohesive curriculum (Phiri et al., 2022). According to Phiri et al (2022), project-based learning in STEM education is part of a broader strategy to enhance educational outcomes and equip pre-service teachers and students with the necessary skills to succeed in the modern economy (Mulenga & Kabombwe, 2019; Phiri et al., 2022). The Zambian government has recognized the need to reform its education system to produce learners who are creative, confident, and capable of contributing to the country's development (Directorate of National Science Centre, 2020). However, the implementation of STEM education in Zambia has encountered several challenges, including inadequate resources, insufficient teacher training, and infrastructural deficits (Oliver et al., 2022) .

Therefore, Malcolm Moffat College of Education is dedicated to empowering the nation through education, with a mission to provide every student with a comprehensive education that prepares them for success in an ever-changing world. The college offers full-time preservice teacher programs, including Primary Teacher Diploma (PTD) and Secondary Teacher Diploma (STD), which are designed to equip future educators with the skills necessary to thrive in both primary and secondary education settings. The college plays a pivotal role in the preparation of future educators, particularly in STEM subjects. As a leading institution for teacher education in Zambia, it is crucial that Malcolm Moffat College effectively integrates innovative pedagogical tools and technologies to enhance the competencies of preservice teachers. In line with its commitment to fostering project-based learning, particularly in STEM education, the college established the Science Innovation Club (SIC) in 2017. The SIC aims to enhance preservice teacher' constructivist-based pedagogical skills, ensuring they are well-prepared to teach STEM based subject effectively through the innovation. According to Oke & Fernandes (2020) to enhance learners experience, preservice teachers must harness hand-on activities such as project-based in STEM education that may require a significant improvement in teaching and learning using innovative pedagogies. Therefore, the study begins to shed light on how to enhance computational thinking skills through project-based learning using Magnetcode application among preservice STEM in Zambia.

1.1 Research Objective

The research aims to explore the effectiveness of the Magnetcode application through the Project-Based Learning related to STEM based subject contents in agricultural science.

1.2 Research Question

This research tends to seek answers to the following question:

How effective is the Magnetcode application in enhancing STEM-related knowledge and skills in agricultural science through Project-Based Learning?

2. Literature Review

2.1 Project Based Learning

Project-Based Learning (PBL) has emerged as an effective pedagogical approach for enhancing CT in STEM education. According to Chistyakov et al., (2023) , PBL engages STEM and science education in hands-on, real-world projects that require the application of theoretical knowledge to solve practical problems (Barak, 2020; Chistyakov et al., 2023; Condliffe et al., 2017). This approach not only fosters deeper understanding but also encourages creativity, collaboration, and critical thinking (Barak, 2020; Chistyakov et al., 2023; Mazlini Adnan et al., 2018). Several researchers indicates that PBL the integration of computational tools like coding applications, significantly enhances students' problem-solving abilities and innovation (Wang, 2023). Schmidthaler et al. (2023) highlighted how coding in a PBL environment helps students to better understand in biology and apply the concepts through the project-based learning (Barak, 2020; Schmidthaler et al., 2023). In the context of teacher education, PBL allows preservice teachers to experience the benefits of coding and programming firsthand, equipping them with the skills and confidence to implement similar strategies in their future classrooms.

2.2 Magnetcode Application

Magnetcode application is free Android App for Coding and Circuit Simulation Controller (Sanura & Phiri, 2024b). Magnetcode Application easily can get in the Google Play. Magnetcode is an application tools for programming that use block-based programming language (Yoshiaki Matsuzawa et al., 2017) and crucial to start the next chapter in STEM education through coding and programming in project-based learning (Blackley & Howell, 2019; Stamatios et al., 2023). Magnetcode uses simple pseudocode in a text-based format, making it an exemplary tool for algorithmic design. Its focus on "text-based" coding sets it apart, providing a clear and effective platform for learning and applying algorithmic concepts (Anistyasari et al., 2018; Bennett, 2021; Nita & Kartikawati, 2020). According to Bennett (2021), the block-based programming language are simple language to solve short problems (Lazarinis et al., 2019). Figure 1 show the pseudocode in block-based language that used drag and drop in Magnetcode application.

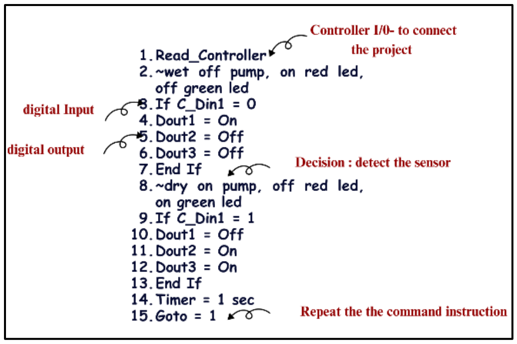

Figure 1 Pseudocode in Magnetcode application

According to Sanura & Phiri, block-based language provides an advantage to understanding coding language especially in developing the agricultural STEM project (Sanura & Phiri, 2024a; Wan Nurlisa et al., 2023). The preservice teachers can explore the algorithm creation using Magnetcode application in the project-based learning embedded with sensor and actuator in the agricultural STEM project. Magnetcode application can use smartphone or tablet to coding (Bala, 2020; Siang, 2020, 2022). Figure 2 show example of block-based programming in agricultural science STEM project using Magnetcode application (Sanura & Phiri, 2024a).

Figure 2 The Magnetcode commands for Agricultural Science STEM project

3. Methodology

3.1 Research Design

The researcher was used a qualitative approach with case study design. According to Merriam & Elizabeth (2016), case studies were used to investigate educational processes, problems, and programs to develop an understanding of the case and improve (Merriam & Elizabeth, 2016; Yazan & De Vasconcelos, 2016). Therefore, it is suitable for this case study as this research aims to explore the effectiveness of the Magnetcode application through the project-based learning related to STEM based subject contents in agricultural science. An exploratory single case study design (Yin, 2003) was employed to explore the effectiveness of the Magnetcode application through STEM agricultural project-based learning (Yazan & De Vasconcelos, 2016). Data was collected from multiple sources, including interviews, observations, and analysis of participants' work products. Open-ended interviews were conducted with four preservice STEM teachers. Fifteen preservice STEM teachers participated in the project-based activity using Magnetcode application. They were asked orally about their experiences, perceptions, and feelings about Magnetcode application during the activity. During the project-based learning activity, the preservice teachers are required to plan their agricultural science projects by creating a detailed flow chart that outlines how to integrate the Magnetcode application with sensors and actuators. After developing the flow chart, they must design commands that align with their project plan and perform circuit simulations to test the functionality of the overall system. The Magnetcode concept is then integrated into their agricultural projects, with the entire process being examined to ensure proper alignment and functionality.

3.2 Research Sample/Participants

The sample size depends on the purpose, credibility, usefulness, time, and willingness of participants to participate in the interview as a respondent in the study (Merriam & Elizabeth, 2016) .According to Creswell (2014), there is no specific number of respondents in the qualitative method, and the number of samples ranges from 1 or 2 to 30 or 40 (Creswell, 2014; Creswell & Creswell, 2018; Merriam & Elizabeth, 2016).Saturation is an essential indicator (Hennink & Kaiser, 2022) of an adequate sample size for the research study that captures the diversity, depth, and nuances of the issues studied. Therefore, the participants in this study are 15 preservice STEM teachers which is members of the SIC at Malcolm Moffat College of Education. According to Merriam & Elizabeth (2016), the suitable sample size until a point of saturation is reached.

3.3 Data Collection Method/Instrumentation

Data was collected through open-ended interviews, that allowed the researcher to ask open-ended questions and probe for more details. Observations as well as a collection of documents focusing on project-based learning and preservice STEM teachers' project work related to the objectives of the activity conducted were also carried out.

3.4 Data Analysis Method

The open-ended interview was transcribed coded and analysed to identify themes and patterns related to the effectiveness of the project-based learning using Magnetcode application. Thematic analysis was used to compare the observations made and project work with the interview data and see how they supported or contradicted each other. Finally, narrative analysis was used to construct a story of how effective the Magnetcode application in is enhancing STEM-related knowledge and skills in agricultural science through Project-Based Learning.

4. Finding And Discussion

Findings from the open-ended interviews conducted among four preservice STEM teachers revealed that the usage of the Magnetcode application assisted them effectively in delivering the STEM agricultural science concept through project-based learning. Further findings from the open-ended interview are summarized in Figure 3.

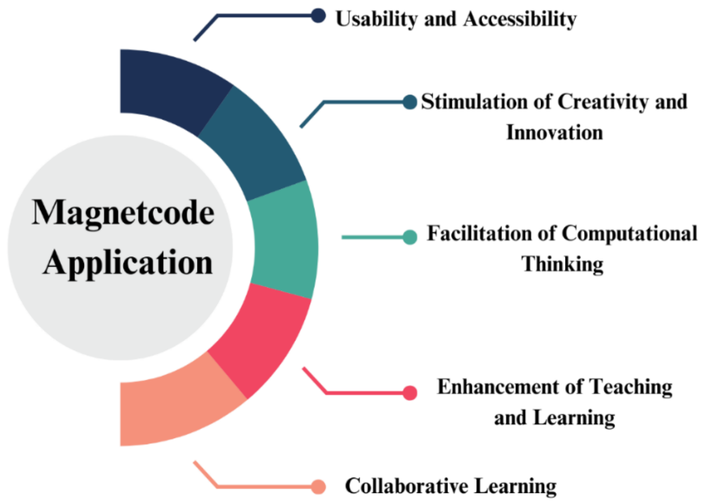

Figure 3 The effectiveness of the Magnetcode application in STEM agricultural science concept through project-based learning

As shown in Figure 1, the open-ended interview findings showed the effectiveness of the Magnetcode application in STEM agricultural science concept through project-based learning. When the preschool STEM teachers were asked "Why Magnetcode application was easy to understand and use? T1 to T4 answered as;

T1: "*Easy to download, coding language easy to understand....*"

T2: "…. *easily done on my phone...*"

T3: "…. *solutions to real life problems...*"

T4: "…. *simple and straight forward...*" [13 July 2024]

This implies that all respondents found the Magnetcode application easy to understand and use, indicating high usability and practical implementation, where respondents found it easier to create projects and innovative solutions to embed in agricultural STEM science project.

The Magnetcode application also made the preservice STEM teachers inspire the development of innovative projects and stimulation of new ideas in delivery the concept of agricultural science project through project-based learning. This is further supported by probing done for the findings from the answers given by the teachers T 1 to T4 for the following question.

"The usage of Magnetcode inspired me to develop innovative projects. Can you explain why?"

T1:... *connections on the pins easy*."

T2: "…. *making the circuits on the phone was very convenience….*"

T3: "…. *improve and innovate our project skills..*."

T4: "…. *brought about new ideas...*" [13 July 2024]

The Magnetcode application also significantly improved computational thinking skills among preservice STEM teachers and increased confidence in their computational abilities especially in coding and programming. This is further supported by the probing done by the findings from the answers given by the teachers T 1 to T4 for the following question.

"Magnetcode has helped me develop computational thinking skills. Can you explain why?"

T1:... *CT skills in coding*."

T2: "…. *able to recognize patterns….*"

T3: "….*in written and in practical..*."

T4: "…. *improved my computation thinking skills..*." [13 July 2024]

The finding also supported the answer given by all the respondents for the following question.

"I am confident in teaching computational thinking skills to students using Magnetcode. Can you explain why?"

T1:... *pseudo code language is easy to understand*."

T2: "….*i have developed skills such as pattern recognition algorithm designs.….*"

T3: "…. *develop the students critical thinking..*."

T4: "…. *help learners to computation methods...*" [13 July 2024]

All respondents indicated the Magnetcode application not only enhanced their computational thinking skills but also boosted their confidence in teaching these skills to students. The effectiveness of the Magnetcode application also allows preservice STEM teachers to practice multiple approaches in enhancing their teaching and learning through project-based learning. This was supported by the answers provided by teachers T1 to T4 to the question;

"Magnetcode has a positive impact on my approach to teaching and learning. Can you explain why?"

T1:... *It promotes STEM.*"

T2: "…. *advocates for hands on activities and creativity thus creating a positive teaching and learning.*"

T3: "…. *changing theoretical knowledge into practical and real life solution to real life problems...*"

T4: "…Transition from traditional activities to innovative activities" [13 July 2024]

All respondents agreed that Magnetcode has positively impacted their approach to teaching and learning, highlighting its effectiveness in various educational aspects through the project-based learning. The project-based learning using Magnetcode application also found to enhance the learning and innovation project. The project work fostered teamwork, knowledge sharing and new ideas in enhancing STEM agricultural science concept, which contributed to the overall effectiveness of the learning experience. This was supported by the answers provided by teachers T1 to T4 to the question on "Why collaborating with peers on Magnetcode projects has enhanced their learning and innovation process.

T1 : "Working *groups is so interesting to solve problems together.*"

T2: "learnt how to co-operate and accept new concepts and ideas from my peers..."

T3: "*brought good ideas which enhanced team work and their ideas contributed to the project.*"

T4: "…collaborating with peers they'll teach what we didn't know" [13 July 2024]

The effectiveness of the Magnetcode application through project-based learning in STEM agricultural science concept produced an exciting experience for preservice STEM teachers (Lauderdale-Littin & Brennan, 2017; Pimthong & Williams, 2020). It allowed hands-on activity to be conducted and this enabled them to apply the concepts through the project. By doing so it can increase their interest and understanding in the concept, and to explore it further (Jia et al., 2018; Pimthong & Williams, 2020). This allowed the preservice STEM teachers to further demonstrate the concept of agricultural science concept through the project-based learning using Magnetcode application as in Figure 4 and Figure 5 below;

Figure 4 Demonstrating agricultural science STEM project through project-based learning

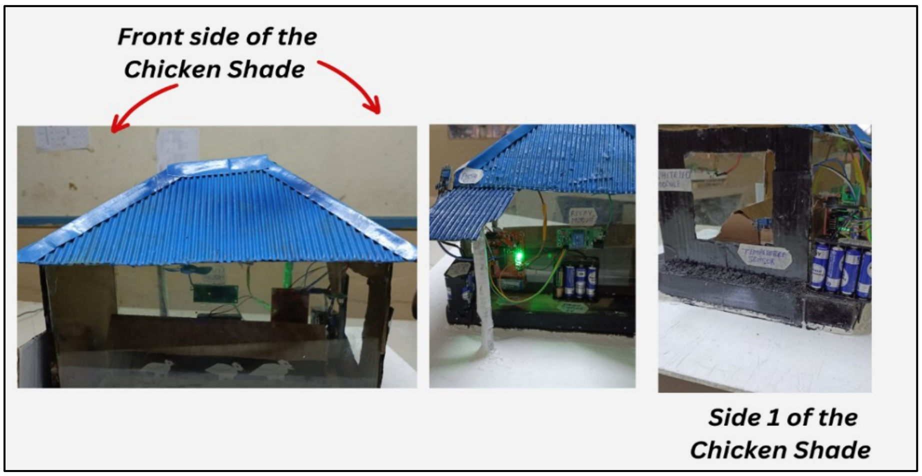

Figure 5 Agricultural science STEM project using Magnetcode application

Further evaluation regarding the preservice STEM teachers' understanding of the Magnetcode application through the coding and simulation activity carried out through the project revealed that all the teachers understood well the concept taught to them as shown in their presentation slide in Figure 6 and Figure 7.

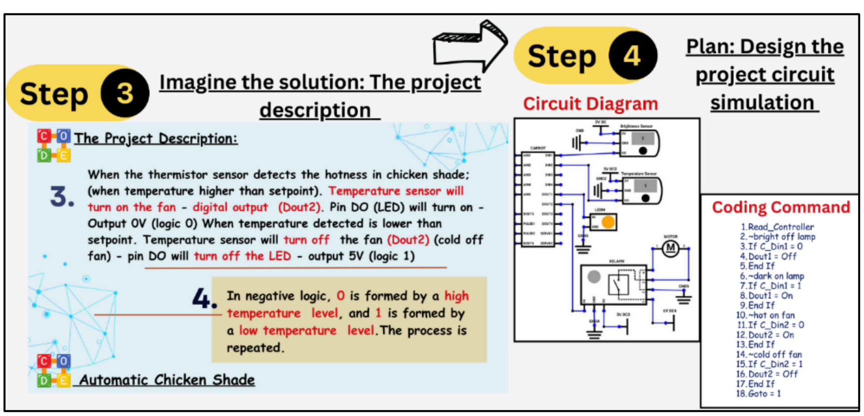

Figure 6 Agricultural science STEM project description and Magnetcode application simulation for the project.

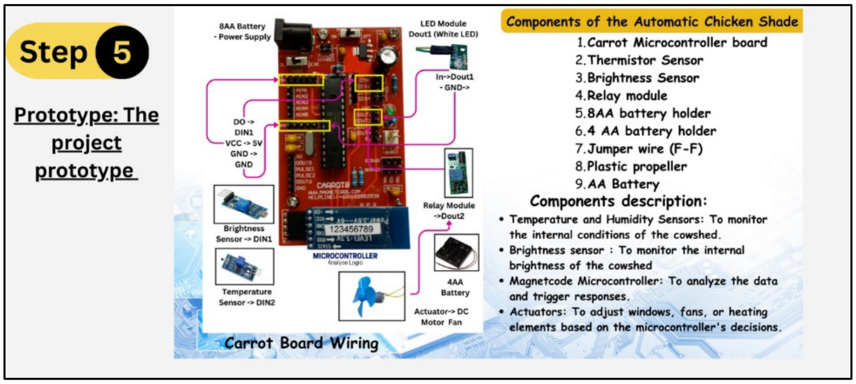

Figure 7 Agricultural science STEM project wiring system using Magnetcode microcontroller

5. Conclusion

The Magnetcode application has proven to be a powerful tool in enhancing creativity, computational thinking, and teaching methods in STEM education. It has facilitated the development of innovative projects using sensors and actuators that align with project-based learning, improved problem-solving skills, and positively impacted preservice STEM teachers by encouraging collaborative learning experiences. The Magnetcode application enables multiple STEM project-based activities, allowing preservice teachers to explore various approaches and deepen their understanding of STEM concepts. Additionally, it supports the integration of technology, real-world applications, and interactive learning experiences, thereby enhancing the teaching and learning of scientific concepts, such as those in agricultural science.

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Article 5

Design And Development of Institutional Repository (Ir): An Innovative Solution for Scholarly Communication in National Teachers Institute (NTI) Nigeria

Toyin R. Ogalue
ogaluerosetoyin@gmail.com

Department of Quality Assurance and ICT National Teachers' Institute,
Rigachikun Kaduna Nigeria

1. Introduction

The National Teachers Institute (NTI) in Nigeria plays a critical role in the professional development of teachers across the country. With the increasing emphasis on Science, Technology, Engineering, Arts, and Mathematics (STEAM) education, there is a need for an efficient and accessible platform to store, manage, and disseminate educational resources and research outputs. Institutional repositories (Irs) serve this purpose by providing a centralized digital space for the storage and retrieval of academic and educational materials.

1.1 Statement of the problem

NTI Nigeria, dedicated to teacher training and educational development, faces challenges in resource management and distribution. Traditional methods are often inefficient, leading to uneven access to crucial educational materials. The introduction of an IR can address these issues, ensuring consistent and equitable access to resources for educators and learners.

1.2 Objective of the study

The objective of this study is to successfully Design and develop a repository for the National Teachers Institute Nigeria for scholarly communication, storage and retrieval of academic and educational materials.

1.3 Significance of the study:

- Enhanced Access to Resources: Centralized repository ensures educators and students have easy access to high-quality educational materials.

- Improved Scholarly Communication: Facilitates the sharing of research findings and educational practices, fostering collaboration.
- Preservation of Knowledge: Digital archiving ensures the long-term preservation of valuable educational content.
- Efficiency: Streamlines resource management, reducing redundancy and improving resource utilization

2. Literature of Related Literatures

According to Burns, D. (2018) Creation of Local Content for Staff and Students of Lilongwe University of Agriculture and Natural Resources (Luanar), Malawi shares their experiences on how the repository was created and the steps involved in the creation of the repository.

Mishra R. (2017) explained and shared the experiences they have gained from the digitization to accessing ETD, and the challenges they faced, enhancements they incorporated with special emphasis on technical developments, and the lessons they have learnt during the various stages of development of their project for ETD.

Poornima et al. (2017) explained the working model of NAL 's Institutional Repository. They discussed the technology employed and methodology adopted in building an institutional repository. The collection process of different data types, processing and depositing the same to IR are also discussed in detail.

Prasad, (2018) discussed the Dspace digital library software. The implementation of Dspace to build a digital library of Library and Information Science is also explained. He presented a list of features of Dspace to justify its choice over competing open-source DL software. He also presents the various collections that are built under the Librarians Digital Library (LDL).

Sreekumar,M.G.. (2021) emphasized the need for deploying interoperable open access Irs, and shares their experience in creating a state-of-art scholarly Institutional Repository using the Dspace software. The method of developing the IR, which include the institutional open access policies, the installation, configuration and customization of the software along with the related workflow operations such as defining the communities

Nazmul et al (2011). Reviewed the various steps involved in using Content Management System (CMS), Open Source Software (OSS), Joomla, XAMPP, to develop digital collections for University of Bangladesh.

However, the researcher supports all of these literatures, but sees them as a stand-alone repository where users can only access the resources. But the researcher goes beyond just access but creating an interactive platform where the users can interact with the librarian via a chat forum

3. Methodology

Mixed methodology of both Quantitative and Qualitative were adopted for this study because, the data for this study were generated through the use of Interview and Check List; Questionnaire and Observations; System Development Life Circle models of Five stages (Planning, Analysis, Design, Implementation and Maintenance) was also adopted for the study, survey research design was used specifically cross sectional Survey research design to generate useful information at one point in time. Preliminary study was conducted by the researcher to access the functional ICT infrastructures in NTI Nigeria and the result showed satisfactory availability of ICT Infrastructures. The Research Settings was designed for the National Teachers Institute Nigeria to be used by the Students and Facilitators of the Institute.

Research population comprises seventy thousand and seventy-five (70,075.00) Students, four thousand nine hundred and sixty-two (4,962.00) Course facilitators and the Institute Librarian, making a sum total of seventy-five thousand and forty (75,040.00).

Stratified Random Sampling technique was employed to select the sample size of three hundred and eighty-two (382) students from the population of seventy thousand and seventy-five (70,075) students. And three hundred and fifty-seven (357) course facilitators from a population of four thousand nine hundred and sixty-two (4,962) making a sum total of seven hundred and thirty-nine (739) as the population of the Study.

In the Procedure for Data Collection, the researcher with the help of research assistants, visited all the Zones of the Federation and administered the questionnaire to the respondents within three weeks. The data collected for this study was analyzed using Descriptive Statistics done with the use of Statistical package for the Social Sciences (SPSS) 20.0 Version. The findings from the study were presented using table of frequencies and percentages.

4. Data Presentation, Analysis and Discussion of Findings

Response Rate: The response rate achieved by the study is presented in the table.

Table: 1 Response Rates

Questionnaire	Frequency	Percentages (%)
Administered Questionnaires	739	100 %
Returned Questionnaires	717	97 %

Unreturned Questionnaire	22	3 %
Valid Questionnaire	717	97 %

Source: Researcher Fieldwork, 2024

Table 1 showed that, 739 (100%) copies of questionnaire were administered to the selected Respondents. Out of which only 717 (97%) were successfully completed, returned, 22 (3%) were not returned. The 717 (97%) returned were found useful (valid) for the analysis.

Types of Scholarly Information Resources Generated by the NTI

Table 2: Responses of the Librarian on Information Resources Generated in NTI

Generated information Resources	Librarian
NTI PGDE Module	✓
NTI BDP Module	✓
NTI NCE Module	✓
NTI PTTP Module	✓
NTI SDG Module	✓
NTI News Letters	✓
Thesis/Project/Dissertation	✓
Radio Programs on CD	✓
Visual Programs on DVDs	✓
NTI Student Guide	✓
Workshop/conference papers	✓
Workshop/conference papers	✓
Reports	✓
Speeches	✓

Source: Researcher Fieldwork, 2024

Table 2 showed that, all the above information resources are generated by the NTI.

Table 3: Available Software's at the National Teachers Institute Nigeria

Available Learner System Management Software	Librarian
Dbase	✓
Greenstone	✓

Koha	✓
New Gen Lib.	✓
Joomla	✓

Source: Researcher Fieldwork, 2024

Table 3 showed availability of five System Management Software

Table 4: Users Requirement for Design and Development of IR. Table 4 showed the users agrees with all the paradental for system design

Users Response	Frequency	Percentage
Eligibility		
Easy to get familiar with the design the first time you try	717	100%
Explore new features by trial and error	717	100%
Efficiency		
Users can accomplish their goal within the interface design	717	100%
The design should be Fast enough to save time of users	717	100%
Provide multiple data search interface	717	100%
Memorability		
The IR interface should be easy to remember or worth remembering	717	100%
Errors Tolerance		
The design interface should be resilience to human error and gracefully detect and handle errors	717	100
Users Satisfaction		
The design should meet users' expectation when they use the proposed IR	717	100%

Source: Researcher Fieldwork, 2024

Findings

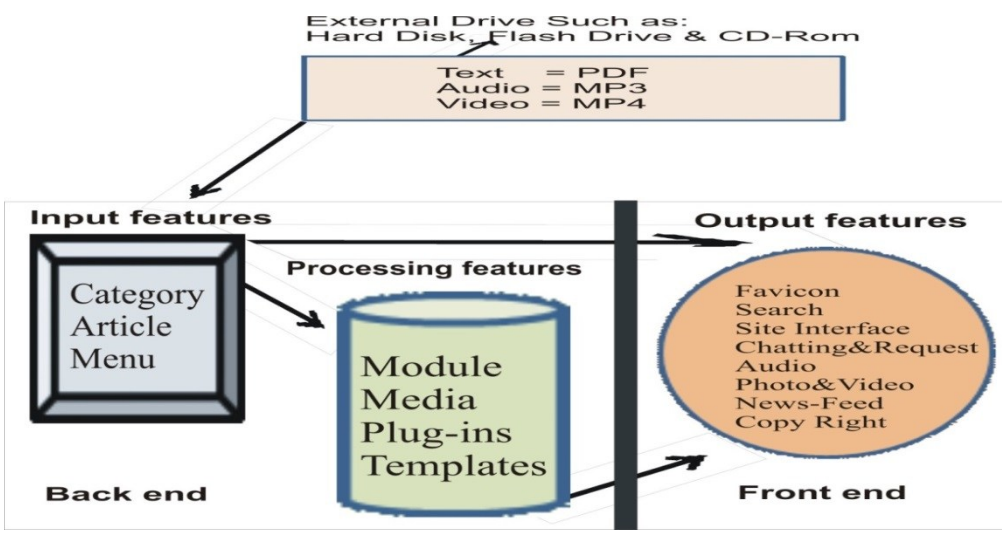
1. The study found the following Information resources generated by NTI to include: PGDE Module, Bachelor Degree Module, NCE Module, Pivotal Teachers Training Program (PTTP)

Module, Advance Diploma in Education (ADE) Module, Sustainable Development Goal (SDG) Module, News Letters, Project and dissertations, Radio programs, Visual Programs, Student guide, Workshops and conference papers, Report and Speeches.

2. The study found the following software Dspace, Greenstone, NewGenlive, Koha and Joomla) available in the NTI although not used for developing IR. However, they are mostly used during accreditation as available software.

3. The study found that the following are the users requirements for the development of IR to include: Eligibility (Easy to get familiar with the design the first time you try), Efficiency (Users can accomplished their goal within the interface design, The design should be Fast enough to save time of users, Provide multiple data search interface), Memorability (The IR interface should be easy to remember or worth remembering), Errors Tolerance(The design interface should be resilience to human error and gracefully detect and handle errors), Users Satisfaction (The design should meet users expectation when they use the proposed IR). Based on this finding the NTI Repository blueprint of backend and frontend was designed.

Figure 1: Schematic Diagram of Back End Blueprint



Source: Researcher 2024

The back-end design as shown in figure 9 shows the input, Processing and output features of the IR for ease of access and retrieval of information resources by the end users. The input was used to classify all the content be it text, audio and video that were uploaded for the development of the repository and how they were uploaded using various categories in which an article was attached to each category and the menu enable the uploaded contents to be visible and accessible at the front end by users. The processing features enable contents to be acceptable for upload into the repository. And some of the processing features included: The module an element which enables access to the following:

i. Video gallery Display: it enables development of video files
ii. Search: it enables users search for needed information
iii. MarqueeAlholic: it enables messages to scroll on the screen
iv. Main Menu: help to Display resources at the front end
v. Image slider; enable several pictures slides on the screen
vi. News Feed: enable current awareness services
vii. Login form: create room for users to login
viii. Images: to upload pictures
ix. Audio: to upload Audio resources etc

Media: All the Resources used by the researcher in the development of the Repository were uploaded into the media file in Folders and Subfolders. Under the media file the researcher has following: Folders: NTI Resources (PGDE, ADE, BDP, PTTP), Pictures, Banner, NTI logo, Radio Programs, Video files, NTI Anthem etc

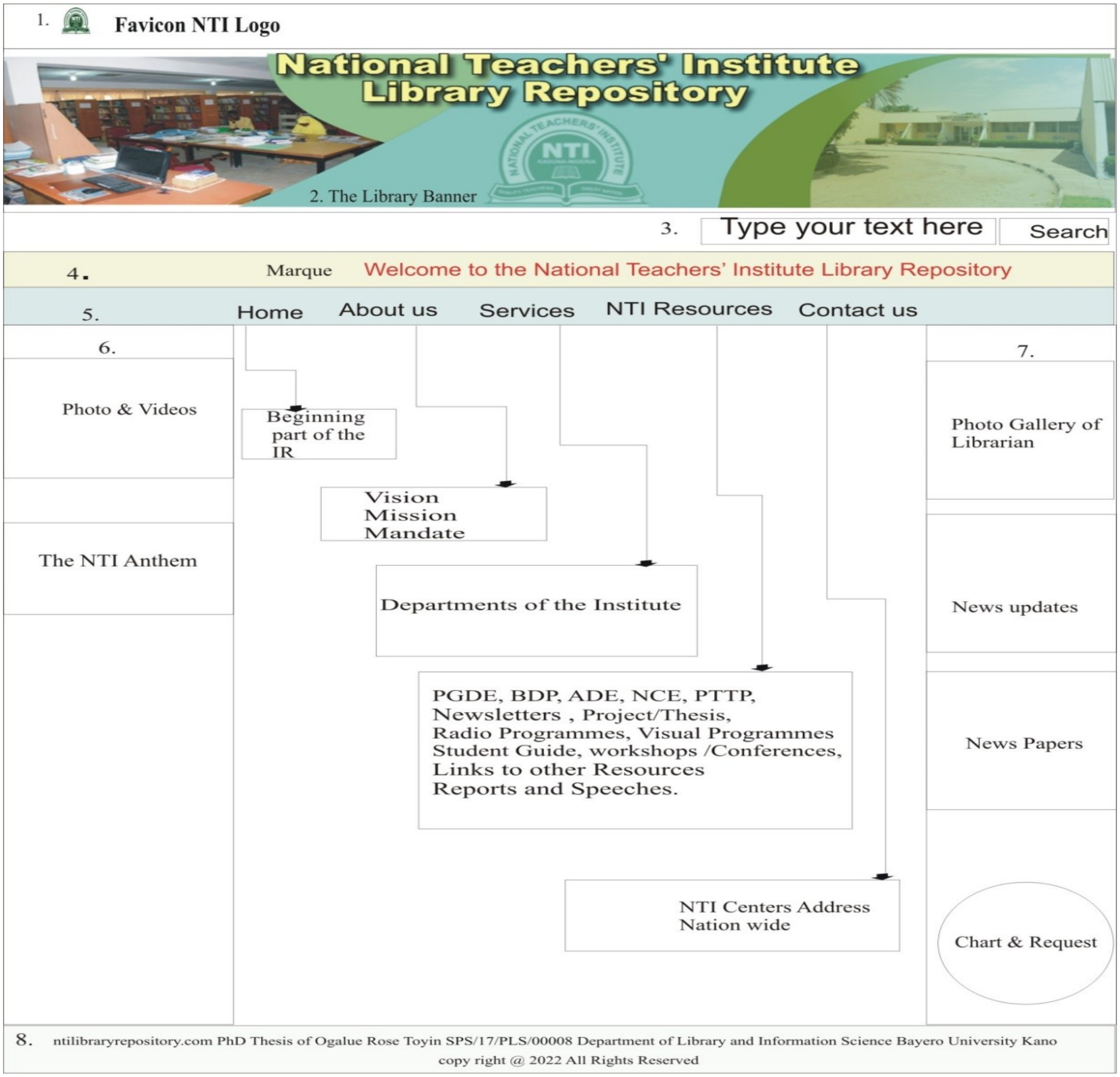
Plugins: This plugin does category processing for core extensions such as. Contents Editor which enables the researcher edit resources, TinyMCE this enables the system read text files, Button makes searching possible by clicking on the button, Authentication Handles default User authentication. **You must have at least one authentication plugin enabled or you will lose all access to your site.**

Templates: Template deals with styles. And the template styles used for this repository are

- . Beez3, an Accessible site template for Joomla! 3. X the HTML5 version.
- Photostat is the Joomla 3 site template based on Bootstrap and the launch of the Joomla User Interface library (JUI).

Output Features: The output features with all the elements available at the front end of the repository such as: favicon, search, site interface, chatting, audio, photo and video, News feed etc as seen in figure 2.

Figure 2 Schematic Diagram of Front – end Blueprint `



Source: Researcher 2024

Figure 2 showed the front-end blueprint of the NTI Library Repository Design. The whole interface design was divided into eight (8) major parts such as two (2) Headers (displaying the Institute logo and the Title of the Repository in a Banner), three (3) Horizontal menus (containing Search Engine; Marque scroll of welcome to NTI Library Repository; Home, About us, Services, Resources and Contact Us), two (2) vertical bars meant for other important title and links such as (Photo and Video Gallery of Library and Management Staff, the NTI Anthem, librarian image, News updates, Newspapers, Chart and Request forms) and lastly, footer (displaying the copyright Reserved). The contents for the repository were based on users' information needs and are displayed on the home page Menus built on both vertical and horizontal positions in sub and sub-sub menus to create links to the contents in the Database.

Implementation stage/development

Developing a Repository as web-based application requires the selection of various software's such as"

a. Operating system software

b. Server

c. Platforms

The use of an Operating System (OS), which serve as an enabling environment within which other applications run. There are different types of Operating Systems such as Linux, Ubuntu, Windows, UNIX, Mac and host of others. Nevertheless, for this Research, Windows Operating System was used because of its user friendliness, ease of use and flexibility. It does not require use of codes to perform common tasks and operations, and different applications could run on it without much training. Hence, windows 7 Ultimate edition Operating System was used.

In addition to that, other software such as Apache server, MySQL, PhPMyAdmin which are found in preconfigured package software's' such as LAMP, WAMP or XAMPP in which the three components are already embedded and are necessary to make a perfect environment completely enabled and ready for development activities were also used. Therefore, the researcher used WAMP for the implementation of the project, because of many functionalities included in it and flexibility associated with its capabilities.

Joomla Platform an Open-Source Content Management Software was chosen for this research based on the fact that Joomla is more flexible. Supported by Nasir, (2021)

Steps to Implementation and Development Stage

Choose a Domain Name: pick a unique and memorable domain name for your website

1. Select a web Hosting Provider: Choose a reliable hosting provider based on your needs and budget

2. Register Domain and Purchase Hosting

3. Set up DNS (Domain Name System): update your domains DNS settings to point to your hosting providers servers.

4. Configure e-mail: Set up email Accounts Associated with your domain if needed

5. Test your website: Ensure everything is working perfectly

6. Install Joomla: download and Install JOOMLA on your webserver and follow the entire instructions wizard to set up your Joomla site'

7. Install Extension Manager. In the administrator's panel, go to Extension – Manager-Install. Upload and install the "plugins "extension that suits your needs

8. Configure Repository Extension, once installed configure the plugins extension settings based on your requirements, set up access control

9. Create Categories and Packages: organize your content by creating categories within the plugin extension, add packages to the created categories using the plugins extension

10. Test Repository: Verify that your repository is accessible and functioning as expected (ntilibraryrepository.com)

5. Conclusion

In conclusion, the successful development and deployment of the NTI Repository using Joomla software mark a significant milestone in advancing scholarly communication and knowledge dissemination within the National Teachers Institute (NTI) community in Nigeria. With the versatility and user-friendly features of Joomla, NTI has established a dynamic platform that empowers educators, researchers, and learners to access, share, and engage with a wealth of teaching and learning resources online. The implementation of the NTI Repository represents a paradigm shift in how educational materials are curated, accessed, and utilized in Nigeria. Through a seamless and intuitive interface, users can navigate through a diverse array of instructional materials, research publications, multimedia resources, and interactive tools, thereby enhancing pedagogical practices, fostering collaboration, and enriching the educational experiences of students across the country. The online hosting of the NTI Repository underscores NTI's commitment to promoting open access principles, digital literacy, and academic excellence. By making educational resources freely accessible to educators, researchers, and policymakers nationwide, NTI is democratizing access to quality education and driving positive social change in Nigeria. The NTI Repository stands as a testament to NTI's vision of excellence, collaboration, and academic leadership in Nigeria. Let us embrace the opportunities that lie ahead and continue to strive for excellence in scholarly communication and educational advancement.

6. Recommendation

Looking ahead, the success of the NTI Repository depends on continuous engagement, feedback, and support from the NTI community and stakeholders. NTI must prioritize user training, capacity-building initiatives, and ongoing maintenance to ensure the sustainability and relevance of the Repository in meeting the evolving needs of its users. As we celebrate this milestone achievement, let us remain vigilant in our commitment to advancing educational innovation, promoting lifelong learning, and empowering educators to shape the future of education in Nigeria. Together, we can harness the transformative power of technology to build a more inclusive, equitable, and knowledge-driven society for generations to come.

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Article 6

Modeling School-Based Teacher Professional: Development for Effective Implementation of CBC in STEM Subjects, A Case of Nyeri County

Daniel Karanja Mutitu
dmutitu@cemastea.ac.ke
CEMASTEA, Kenya

Abstract

In Kenya, a competency-based curriculum (CBC) is being rolled out in phases and currently, the implementation is at Junior School (JS). At this level the curriculum is broad based to enable the learners realize their competencies. For effective implementation, teachers need to have acquired appropriate pedagogical skills to align with the vision of the curriculum. The challenge lies in ensuring that teachers have access to high-quality and continuous professional development opportunities that address the specific requirements for effective CBC implementation. In this light, this study sought to assess the subjects of specialization of teachers handling JS learning areas, to identify the support systems and resources provided to them to enhance their preparedness in handling CBC. This study findings could form a data-driven proposal for sustainable approaches of capacity building these JS teachers. The study was anchored on Diffusion of Innovations theory and Resource Dependence theory. The study adopted a mixed-methods research design to determine the extent of preparedness by JS teachers in handling CBC, a case of Nyeri County, Kenya. The study used a sample of 30% of the target population comprising of 71 of the respondents. Despite all the teachers having received workshop-training on CBC, the training was deemed to be inadequate in providing professional development opportunities to fully implement CBC. There was limited availability of CBC-aligned instructional resources. This study recommends that there should be institutionalized investments in school-based teacher support and professional development programs.

Key Words: *Competency, curriculum implementation, instructional resources, pedagogical skills, professional development.*

1. Background of the Study

The evolution of global market dynamics and technological breakthroughs have resulted in massive curricular reforms globally. In the 1960s, the United States of America was the first country in the world to establish and apply the CBC learning approach (Barrick, 2016). Kuwait set aside a sizable amount for the 2015–2016 fiscal year, to encourage the adoption of CBC in schools

(Sadeq, Akbar & Wazzan, 2020). This was informed by substantial World Bank advisories to improve literacy levels in early learning years in Kuwait. Insufficient learning resources, inadequate teacher preparedness and lack of institutionalized teacher support at the school level has compromised the achievement of this curriculum. In South Africa, teacher performance declined after adopting the CBC approach. This was attributed to inadequate government financing, unclear assessment methods, untrained teachers, and low teachers' pay (Momanyi & Rop, 2020). In Tanzania, since 2005, the CBC model has been utilized due to its significance and changing labour dynamics (Nzima, 2016). According to Nsengimana, *et al.,* (2020), the CBC strategy in Tanzania has worked below expectations since most high school learners in Tanzania are not taught with a learner-centred approach.

Effective teacher preparedness is demonstrated by a deeper understanding of their subject/learning area content and pedagogical techniques, employing diverse instructional strategies to meet the needs of diverse learners. Teachers create inclusive and supportive learning environments that foster critical thinking, creativity, and collaboration which empowers learners to reach their full potential (Cahyati & Agustina, 2017). A prepared teacher manages resources effectively, maximizes instructional time and minimizes distractions to optimize learning. They set clear expectations, establish routines, and implement effective classroom management strategies to maintain a positive and productive learning environment. Assessing teachers' preparedness involves evaluating their effectiveness in facilitating learning and keeping track of learners' acquisition of the expected knowledge, skills and values. This could be done through classroom observations, learner's/parent's feedback, peer evaluations, standardized test scores, among other measures of learner achievement and progress (Ratanya, Mudanya & Nzaro, 2022).

Teachers' preparedness in handling the Competency-Based Curriculum (CBC) is essential for a successful implementation of this innovative education system. The CBC framework shifts the focus from rote memorization of content knowledge to developing practical skills, competencies, and values among learners (KICD, 2026). Currently, all teachers handling CBC in Kenya, underwent through a different education system, both at their basic education levels as well as during their teacher training level. Therefore, to effectively implement the CBC, teachers need to undergo comprehensive in-service teacher training to acquire the new pedagogical skills, and adapt their teaching methods to align with the goals and principles of CBC.

In Kenya's 8-4-4 teacher training curriculum, a post primary teacher undertakes two teaching subjects and related subject-based pedagogies. All practising teachers in Kenya, including those in Junior school (JS) in Nyeri county, due to their professional training model, are prone to unique opportunities and challenges in enabling the learner to acquire the desired competencies as envisioned under the basic education curriculum framework for CBC. The findings of this study should be used to enhance the teacher's preparedness, mobilize resources and institutionalize teacher support systems to effectively implement CBC at junior school level.

1.1 Statement of the Problem

Learning areas at the Junior school level are a rationalization of varied subjects, some of which have unrelated content. A good example is Pre technical studies learning area, which has concepts drawn from Drawing and Design, Computer Studies, Business Studies and Wood/Metal Work based on the 8-4-4 curriculum. These subjects were optional, under one cluster, and there was no way a teacher could have been assessed in more than one. This implies that teachers' competencies in such a learning area are not well established. Regardless, these teachers are expected to teach this these concepts as a single learning area. The identified gap lies in the need to bridge the disparity between the ideal state, where a teacher is expected to prepare, gather relevant resources, and effectively facilitate learning in a learning area/subject alone. The current state is marked by issues such as teachers' low mastery of subject content, inadequacies in learning resources, inefficient school-based teacher support systems and poor parental support.

1.2 Research Objectives

1.1.1. General objective

The general objective of the study was to identify a sustainable teacher professional development model for Junior school teachers handling CBC in STEM rationalized learning areas in Nyeri County, Kenya.

1.1.2. Research Questions

i. What are the subjects of specialization of the Junior School teachers in Nyeri County?
ii. Is there any support system for Junior School teachers in Nyeri County?
iii. Which resources are provided to Junior School teachers to enhance the implementation of CBC in Nyeri County?
iv. What are the sustainable approaches for capacity building Junior School teachers' competencies in handling rationalized STEM learning areas within Nyeri County?

1.3 Significance of the Study

The research findings may be used by the Ministry of Education (MoE), related educators' agencies, and County education directorates to formulate teacher balancing/transfer policy, across Nyeri county or the entire country at large. The MoE together with the county directorates may also be able to develop sustainable in-service courses for the novice teachers handling Junior Schools. This study recommendations will guide teachers on conceptualizing innovative ways to generate learning resources using homemade solutions to complement the standard resources that will boost long-term teacher performance.

1.4 Scope of the Study

The study population consisted of Junior School teachers currently teaching pre-technical studies and Agriculture and nutrition after rationalization.

2. Literature Review

Two theories were relied on when contextualizing this study. The proponent of the Diffusion of Innovations theory was Everett Rogers in his work titled "Diffusion of Innovations" (Rogers, 1995). The theory assumes that the adoption of innovations occurs gradually over time, with some individuals or groups adopting the innovation earlier than others (Rogers, *et al*., 2014). The theory provides insights into how innovations, such as CBC, are adopted by individuals within a social system. Overall, the Diffusion of Innovations theory offers valuable insights and strategies for promoting teachers' preparedness in adopting and implementing CBC, thereby facilitating successful curriculum implementation. The Resource Dependence theory was primarily developed by Jeffrey Pfeffer and Gerald Salancik (Pfeffer & Salancik, 2015). The theory assumes that organizations depend on external resources such as capital, raw materials, information, technology, and human resources to sustain their operations and achieve their goals (Biermann & Harsch, 2017). Teachers rely on various external resources, such as curriculum materials, teaching aids, technology, training programs, and support services to effectively implement a curriculum. The theory helps identify the critical resources needed for CBC implementation and requisite teachers' strategies to access and secure these resources.

2.1. Empirical Literature

Jabeen and Khalil (2023) focused on the impact of training on teachers' preparedness in Karachi, Sindh, Pakistan. It was revealed that training programs should be imparted to the teachers to make them focused on the educational enhancement goals. Equal opportunity for all cadres of teachers in school education is to be given to maintain homogeneous enhancement of pedagogical skills and techniques. Career planning and development schemes should be implemented, and they should be closely and effectively monitored.

Mgimba and Mwila (2022) studied infrastructural challenges influencing academic performance in rural public secondary schools in Iringa District, Tanzania. This study concluded that school infrastructure is very essential to develop and provide quality education, which leads to growth and excellence. The study recommended that the government, with other stakeholders, should increase funding for schools to provide and support adequate teaching and learning materials besides standard infrastructure in secondary schools. Wamuyu, (2020) studied the influence of the training of head teachers on competence-based curriculum implementation in public primary schools in Kiambu County, Kenya. The study concluded that the training practices, programmed instruction, and role modelling of public primary school head teachers positively influence the implementation of the competence-based curriculum in Kiambu County, Kenya. The study recommended increased training and the introduction of coaching and mentorship programs to further guide employees.

Mang'uui *et al.,* (2021) studied effects of availability of teaching and learning resources on teacher performance in public secondary schools in Kitui County, Kenya. The study concluded that on the influence of availability of teaching/ learning resources such as teacher use of learner centred methods while teaching, teachers use-of demonstration during subject delivery and teacher use of functional project, influenced teacher's performance. It was recommended that there is need for the school principal to ensure that teaching and learning resources are availed for success in teacher performance.

Several studies have revealed a great relationship between infrastructure and academic performance, self-worthiness, confidence and sense of belonging. It was recommended that educational key actors allocate reasonable and reliable funds and invest in monitoring and evaluation of infrastructure.

3. Research Methodology

The study adopted a mixed-methods research design to determine the extent to which Junior School teachers are prepared to handle CBC in Nyeri County. This design allowed the researchers to draw upon the strengths of qualitative and quantitative methodologies, thereby providing a more comprehensive understanding of the research topic. Stratified random sampling approach was utilized. The researchers first classified the respondents into various strata; then, the respondents were randomly picked for data collection according to Table 1.

Table 1

Sample Size after Stratification

Sub-County	Sample Size	Percentage
Kieni East	10	14.4
Kieni West	8	11.9
Mathira East	9	13.1
Mathira West	6	8.1
Mukurweini	8	11.9
Nyeri Central	13	18.2
Nyeri South	8	11.9
Tetu	8	10.6
Total	**71**	**100.0**

4. Presentation, Analysis, And Interpretation Of Data

The study sampled 71 respondents, of whom 62 were able to submit their filled questionnaires. This forms a response rate of 87.3%, which was sufficient to draw conclusions for the study as the rate of participation was representative.

4.1. Background Characteristics

Of the sample population, 59.7% (n=37) were female, while 40.3% were male. Approximately 55% were aged between 31 and 40 (Figure 1). The majority (72.6%, n=45) of the respondents taught in public schools. All the respondents had basic teacher training where 64.5% had a bachelor's degree level of training (Figure 2).

Figure 1

Age Distribution of Study Respondents

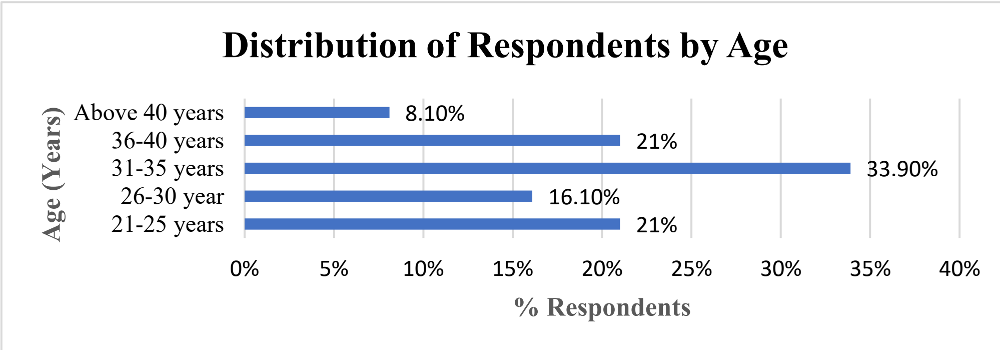
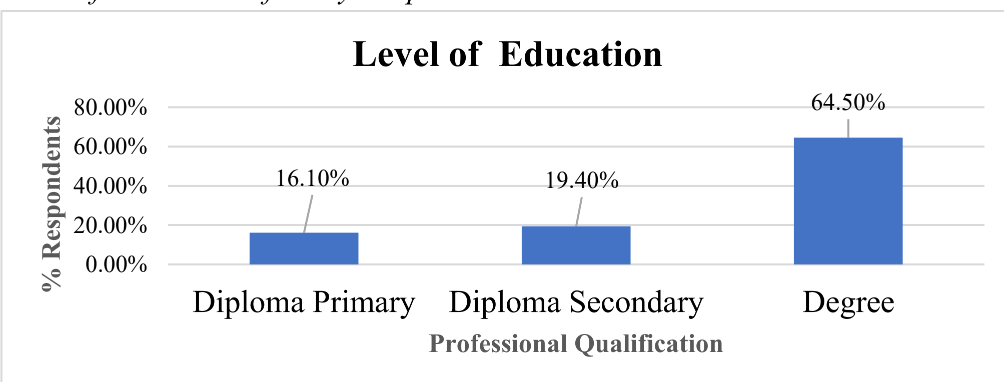


Figure 2

Level of Education of Study Respondents.



4.2. Curriculum Delivery

4.2.1. Teachers' subjects of specialization compared to the JS Learning areas

Teachers were asked if they are currently handling learning areas related to the subjects they trained in their colleges or university as their teaching subjects. Table 2 summarizes the subjects of specialization for the teachers who were handling Pre-technical studies.

Table 2

Subjects of Specialization of Teachers Handling Pre technical Studies.

Subject of specialization	Frequency	Per cent, %
English and Literature	3	9.7
English and Religious Education (RE)	4	12.9
Kiswahili and History	7	22.6
Kiswahili and RE	9	29.0
Kiswahili and Geography	3	9.7

Mathematics and Other subject	5	16.1
Total	**31**	**100.0**

25.8% of the teachers handling junior school specialized in applied science-related subject in their teacher training education. A larger proportion of 74.2 % of the teachers handling Pre technical studies specialized in Arts-related subjects at their teacher training level.Teachers masterly of content has a significant influence on the learner's ability to acquire the desired competences, knowledge and skills. The negative is also true. This may disadvantage the learners from acquiring the set of competencies to place them in STEM pathway at senior school. A similar trend was observed on the teachers who were handling Agriculture and Nutrition at junior school.

This study found that majority of the teachers handling Pre technical studies and or Agriculture and Nutrition are specialized in Art-related subjects. Based on their subjects of specialization, it may imply that they have no adequate masterly of content in STEM related subjects.

4.2.2. Learning areas allocation at Junior school

Table 3 shows the learning areas allocation to teachers currently handling junior school.

Table 3

Learning Areas Allocation in Grade 7 and 8

Grade 7	Grade 8	Percent
Mathematics, Pre technical Studies, Creative Arts & Sports	Social Studies and Pre technical Studies	10%
Social Studies and English, English and Agriculture & Nutrition	Social studies and English, English and Agriculture & Nutrition and Pre technical Skills	42%
Mathematics, English, Kiswahili, Pre technical Studies, Social Studies, Integrated Science, Creative Arts & Sports, Religious Education	Mathematics, English and Social Studies	15%
Kiswahili, Pre technical and Integrated Science	Religious Education, Pre technical Studies, Religious Education and Kiswahili	25%
Creative Arts & Sports, Kiswahili	Creative Arts & Sports and Pre technical studies	8%

Currently, junior school has only Grade 7 and Grade 8. From the findings, various teaching combinations emerged. For instance, 42% of JS teachers who taught Social Studies, English, Agriculture & Nutrition in Grade 7 also taught the same combination along with Pre technical studiess in Grade 8. Similarly, 8% of JS teachers who handled Creative Arts & Sports, along with Kiswahili in Grade 7, also taught Creative arts & Sports as well as pre-technical studies in Grade 8.

These summary results from table 3 clearly demonstrates that there appears not to be a well-defined criteria being used to allocate the learning area to a teacher. Learning areas allocation appears to be motivated merely by the number of teachers available at any time in junior school and not their subjects of specialization.

4.3. In-service training and School-based teacher support

4.3.1. Cumulative Number of Training Weeks Partaken by JS Teachers

Table 4 summarizes the cumulative duration of inset training attendance in weeks.

Table 4

Cumulative Number of Training Weeks undertaken by JS Teachers

Duration	Frequency	Percentage
1 Week	16	25.8
2 Weeks	25	40.3
3 Weeks	12	19.4
4 Weeks	9	14.5
Total	62	**100.0**

The study established that majority (66.1%) of the teachers had undergone a one week or two weeks CBC-based training. KICD, (2016) recommends continuous training of teachers on CBC components to ensure that teachers are well versed with the curriculum designs for productive acquisition of the envisioned competences at this level. This implies that the teachers currently handling junior school, requires further capacity building on content and pedagogical knowledge to be able to facilitate learning, effectively.

4.3.2. Usefulness of the In-Service Training and school-based teacher support

Table 5

Perception of Teachers regarding the In-Service Training

Aspect	Per cent response, %				
	Always	Often	Sometime	Rarely	Never
The in-service training I have received is adequate to enable me handle any learning area/subject in JS	10.0	15.0	45.0	14.5	15.5
I find the content across the learning areas easy to teach	3.3	2.7	8.9	54.5	30.6
My Head teacher is supportive.	22.3	25.5	12.9	24.5	14.8

I need further capacity building on how to handle several learning areas	79.0	21.0	0.0	0.0	0.0
I collaborate with my colleagues to prepare lessons in areas I have difficulties in	54.8	40.2	1.4	2.0	1.6

The results show that all teachers agree that the in-service training received so far is not adequate to enable them to handle the learning areas/subjects in JS. Only 14.9% of the teachers indicated that they find the content in the learning areas they are handling easier to teach. The results show that only a total of 3.6% of teachers of junior school, rarely or never collaborate with their peers for lesson preparation, even in areas they have difficulty in teaching. This could imply that if a teacher is not in a community of practice with his/her peers, the teacher could go to class but no learning takes place, at all.

Generally, the results from table 4.9, indicate that the teachers currently handling learners at junior school, require professional support to be able to handle the rationalized learning areas.

Table 6, summarizes the cumulative duration of school-based support in days by educational field officers/subject experts for last two school terms.

Table 6

Cumulative Number of Days for School-Based Support Undertaken by JS Teachers

Duration	**Frequency**	**Percentage**	**The support I have received is adequate to enable me teach the learning area/subject am handling in JS**
0 Days	25	40.3	No support Received
1 Day	12	19.4	Disagree
2 Days	11	17.7	Somehow
3 Days	8	12.9	Somehow
4 Days	6	9.7	Agree
Total	62	**100.0**	

The study established that majority (59.7%) of the teachers had undergone at-least a one day school-based support. The more the days of school-based support the more the teachers appreciated that the support equipped them with strategies to handle the learning areas they were teaching. Some of the verbatim responses from teachers on school-based support were:

"In the meeting, there was discussion on how to enhance the use of learner centred pedagogies, improvisation of learning resources, virtual resources and Communities of practice in the school"

"The support was helpful since it enhanced my understanding of improvisation of learning resources and learner centred pedagogies"

"The support was timely and should be provided regularly to promote my professional growth"

"I need further support on interpretation of curriculum designs and integration of ICT in learning"

"I am grateful for the live class observation which provided me with valuable insights into the specific challenges I face while teaching"

"I would recommend for a regularized in-school support through peer teaching"

"School based support was more helpful to me than all the workshops I have attended"

"The follow-up school support after the in-service workshop enabled me actualize the workshop-action plan"

"I was supported in empowering and fostering meaningful partnerships with parents/guardians, and the wider community which can help learner acquire skills related to community service learning"

5. Summary Findings and Conclusions

This section presents the key findings, conclusions and recommendations. The conclusions are drawn in response to the four research questions. The recommendations section discusses the key issues from findings which are suggested for consideration to inform practice, policy formulation and further research.

1) On assessing the subjects of specialization of teachers, handling JS learning areas, the study revealed that teachers are allocated to teach learning areas not necessarily related to their subjects of specialization done at their teacher training level. Some of the teachers indicated that they are handling learning areas they have never learned in school at any level. This implies that teachers have diverse training needs and are at varied teacher-competence levels.

2) On establishing the support systems and resources provided to JS teachers to enhance their preparedness for handling CBC, the study established that majority of the JS are not well equipped with adequate instructional, infrastructural and technological resources. The teachers also indicated that they do not receive professional support to enable them handle the varied learning areas adequately. This implies that these teachers require deeper capacity building, not only on pedagogy but on content as well.

3) Based on the teachers' propositions, there is an urgent need to establish sustainable capacity-building programs to enable them acquire content and pedagogical knowledge, skills and values at self-paced mode. The situation has become even more complex considering that majority of the learning areas have been rationalized.

4) Teachers have inadequate forums where they can share ideas on CBC implementation. Although, there were educational workshops and conferences which provided JS teachers a

forum to attend sessions, workshops and presentations, teachers found them insufficient to bridge their gaps.

5) Teachers who had been supported at their school level by education field officers or subject experts were found to be well versed in interpretation of curriculum content and more effective in lesson delivery.

6. Recommendations

To enhance preparedness of Junior School teachers in handling CBC in Nyeri County, several mitigation measures are recommended.

i. There is need to have a workshop-training follow-up support at school level, to ensure that the training action plan is implementedin the contexted of the school.
ii. There should be established clustered school-based teacher support and professional development programs specifically tailored to meet the specific training needs of teachers who are at varied teacher-competence levels. These initiatives should aim to improve teaching and learning outcomes, foster positive school cultures, and promote continuous improvement in teaching practices.
iii. The Ministry of Education and related stakeholders/agencies should invest in digital learning platforms and educational technology tools that can support CBC implementation. These platforms could include interactive e-books, multimedia resources, educational apps, and online learning management systems (LMS) that provide access to a wide range of teaching and learning materials.Teachers could access them on need bases and at their own pace.

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Article 7

Application And Impact of Emerging Technologies in Mathematics Education

Hassan Suleiman

hassansuleiman2000@gmail.com

Department of General and Allied Studies
Niger State School of Health Technology, Minna

Abstract

The application of emerging technologies in mathematics education is revolutionizing how students engage with and understand mathematical concepts. This article examines the transformative impact of technologies such as artificial intelligence (AI), virtual reality (VR), augmented reality (AR), and adaptive learning platforms in the mathematics classroom. AI-driven adaptive learning systems customize educational content to meet individual student needs, enhancing personalized learning and improving comprehension. VR and AR offer immersive experiences that make abstract mathematical ideas more concrete and engaging, fostering deeper understanding. Adaptive learning platforms dynamically adjust the difficulty of problems in real-time, promoting student mastery and confidence. The integration of data analytics allows educators to track student progress with unprecedented precision, enabling more targeted and effective instruction. Evidence from recent research highlights significant improvements in student performance and attitudes towards mathematics when these technologies are utilized. However, challenges such as ensuring equitable access to technology and providing adequate training for educators remain critical. Overall, the findings emphasize the potential of emerging technologies to create more personalized, engaging and effective mathematics education, advocating for their broader implementation to enhance students learning outcomes. It was recommended among others that ggovernment and educational institutions should prioritize investment in digital infrastructure to ensure equitable access to emerging technologies in mathematics education and it is essential to offer comprehensive professional development programs that equip teachers with the skills and knowledge required to effectively integrate emerging technologies into mathematics instruction.

Key Words: *Application, Impact, Emerging, Technologies and Mathematics Education*

1. Introduction

In the 21st century, the educational landscape has undergone a significant transformation, driven by the rapid advancement of technology. Mathematics education, in particular, has seen a surge in the integration of emerging technologies, reshaping traditional teaching methods and learning experiences. The infusion of digital tools and platforms has not only enhanced the accessibility of mathematical content but also facilitated innovative pedagogical approaches that cater to diverse learning needs. This article explores the application and impact of emerging technologies in mathematics education, with a focus on how these innovations are transforming teaching and learning practices, improving student outcomes, and addressing educational challenges in both developed and developing countries.

1.1 The Role of Technology in Mathematics Education

The integration of technology in mathematics education is not a new phenomenon. However, the pace and scope of technological adoption have accelerated in recent years, driven by the increasing availability of digital tools and the growing recognition of their potential to enhance educational outcomes. Technologies such as computer-based learning platforms, interactive simulations, and mobile applications have become essential components of modern mathematics instruction, providing students with opportunities to engage with mathematical concepts in dynamic and interactive ways (Becta, 2009).

Emerging technologies, including artificial intelligence (AI), augmented reality (AR), and virtual reality (VR), are now being leveraged to create immersive learning environments that foster deep understanding and critical thinking. For example, AI-powered adaptive learning systems can personalize instruction based on individual student needs, offering targeted support and feedback to help students master complex mathematical concepts (Luckin, Holmes, Griffiths, & Forcier, 2016). Similarly, AR and VR technologies enable students to visualize and manipulate mathematical objects in three-dimensional space, enhancing their spatial reasoning and problem-solving skills (Wu, Lee, Chang, & Liang, 2013).

1.2 The Impact of Emerging Technologies on Student Learning

The impact of emerging technologies on student learning in mathematics is multifaceted, with benefits observed in areas such as student engagement, achievement, and retention. Research has shown that the use of digital tools in mathematics education can significantly increase student motivation and engagement by making learning more interactive and enjoyable (Lee & Hammer, 2011). Interactive platforms, such as Khan Academy and GeoGebra, allow students to explore mathematical concepts at their own pace, receive immediate feedback, and track their progress over time, leading to improved learning outcomes (Khan Academy, 2020).

Moreover, technology-enabled formative assessment tools have been shown to enhance student achievement by providing teachers with real-time data on student performance, enabling them to adjust instruction to meet the needs of individual learners (Black & Wiliam, 2009). Nicol and Macfarlane-Dick, (2006) opined that these tools also empower students to take ownership of their learning by identifying areas where they need to focus their efforts and seeking additional support when necessary

1.3 Challenges and Considerations

Despite the numerous benefits of integrating emerging technologies into mathematics education, several challenges must be addressed to ensure their effective implementation. One of the primary challenges is the digital divide, which refers to the gap between those who have access to technology and those who do not (Warschauer, 2004). United Nations Educational, Scientific and Cultural Organization (2017), opined that in many developing countries, limited access to digital devices and reliable internet connectivity can hinder the adoption of technology in mathematics education, exacerbating existing educational inequalities.

Another challenge is the need for teacher training and professional development. Effective integration of technology into mathematics instruction requires teachers to possess not only technical skills but also pedagogical knowledge of how to use digital tools to enhance learning (Mishra & Koehler, 2006). Professional development programs must therefore focus on equipping teachers with the skills and knowledge needed to incorporate technology into their teaching practices in meaningful and effective ways (Darling-Hammond, Hyler, & Gardner, 2017).

2. Case Studies on Application of Emerging Technologies in Mathematics Education

The following are the case studies of application of emerging technologies in mathematics education;

A. Case Study 1: Artificial Intelligence in Mathematics Education

Artificial Intelligence (AI) has emerged as a powerful tool in mathematics education, offering personalized learning experiences that cater to the unique needs of each student. One notable example is the use of AI-powered tutoring systems, such as Carnegie Learning's MATHia, which provides individualized instruction based on a student's current level of understanding. Pane, Griffin, McCaffrey, and Karam, (2014) stated that these systems use data analytics to identify areas where students are struggling and offer targeted support, thereby improving learning outcomes.

In Nigeria, AI-based platforms like Passnownow and ULesson are helping to bridge the gap between students in urban and rural areas by providing access to high-quality educational resources. These platforms offer interactive lessons, practice exercises, and assessments that adapt to the learner's pace, making mathematics education more accessible and effective for students across the country (Okebukola, Owolabi, & Oyekanmi, 2020).

B. Case Study 2: Augmented Reality in Mathematics Education

Augmented Reality (AR) is transforming mathematics education by providing students with immersive learning experiences that enhance their understanding of abstract concepts. For instance, the AR-based application GeoGebra Augmented Reality allows students to visualize and interact with 3D geometric shapes, making it easier for them to grasp complex mathematical ideas. Houghton Mifflin Harcourt, (2018) stated that this technology has been particularly beneficial in helping students develop spatial reasoning skills, which are critical for success in fields such as engineering and architecture.

In South Africa, the use of AR in mathematics education is gaining traction, with initiatives like the Siyavula Project incorporating AR into their digital textbooks. These textbooks provide students with interactive content that brings mathematical concepts to life, thereby improving comprehension and retention (Siyavula, 2019).

C. Case Study 3: Virtual Reality in Mathematics Education

Virtual Reality (VR) offers a unique opportunity to create immersive learning environments where students can explore mathematical concepts in a virtual space. VR applications like Labster and Google Expeditions allow students to engage with mathematical problems in a hands-on manner, providing a deeper understanding of topics such as geometry, calculus, and statistics. Freina and Ott, (2015) view that these virtual environments also enable collaborative learning, where students can work together to solve complex problems in a simulated setting.

In Kenya, VR is being used to enhance mathematics education in schools through initiatives like the African Virtual University, which provides VR-based learning modules that help students understand difficult mathematical concepts. This approach has been shown to improve student engagement and achievement, particularly in areas where traditional teaching methods have been less effective (African Virtual University, 2021).

3. Policy Implications and Future Directions

The integration of emerging technologies into mathematics education has significant implications for educational policy and practice. Policymakers must prioritize investments in digital infrastructure to ensure that all students have access to the tools and resources they need to succeed in a technology-driven world. This includes expanding access to high-speed internet, providing schools with the necessary hardware and software, and supporting the development of locally relevant digital content (UNESCO, 2017).

In addition, there is a need for ongoing research to evaluate the effectiveness of emerging technologies in mathematics education and to identify best practices for their implementation. This research focused on understanding the impact of technology on student learning outcomes, as well as the factors that influence its successful adoption in different educational contexts (Cheung & Slavin, 2013).

4. Conclusion

Emerging technologies hold great promise for transforming mathematics education by making learning more interactive, personalized, and accessible. The application of technologies such as AI, AR, and VR in mathematics instruction has the potential to enhance student engagement, achievement, and retention, thereby improving educational outcomes. However, to fully realize the benefits of these technologies, it is essential to address the challenges of the digital divide and to provide teachers with the training and support they need to integrate technology into their teaching practices effectively. By investing in digital infrastructure, supporting teacher professional development, and promoting ongoing research, policymakers can help ensure that emerging technologies are leveraged to enhance mathematics education and prepare students for success in the 21st century.

5. Recommendations

The following recommendations were made;

1. Governments and educational institutions should prioritize investment in digital infrastructure to ensure equitable access to emerging technologies in mathematics education.
2. It is essential to offer comprehensive professional development programs that equip teachers with the skills and knowledge required to effectively integrate emerging technologies into mathematics instruction.
3. Educational stakeholders should promote the use of collaborative platforms and tools that enable students to work together in solving mathematical problems.
4. Ongoing research is needed by policymakers, educators, and researchers to evaluate the effectiveness of emerging technologies in mathematics education in other to inform policy decisions and the development of best practices.
5. Government and educational donors should ensure that all students benefit from providing affordable digital devices and resources to students from low-income families and implementing policies that promote digital literacy and inclusivity in education.

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Article 8

Teachers’ Citizenship Behaviour as a Predictor of Secondary School Students Academic Performance in Science Subjects in Igabi Local Government Area of Kaduna State.

Ibrahim Laro Yusuf, Khadijat Bola Lawal & Salman Umar Ombuguhim

Ibrahimlaroyusuf@gmail.com, Ik.biola@gmail.com, ombuguhim@gmail.com

National Teachers’ Institute, Kaduna

Abstract

Teacher Citizenship behaviour is central to the foundation of every school setting. This study examined teachers’ citizenship behaviour as a predictor of students’ academic performance in science subjects in public senior secondary schools in Igabi Local Government Area, Kaduna State. The study adopted a descriptive research design of correlation type with the target population comprised 15 principals 30 vice principals and 52 science teachers in the sampled schools. Purposive sampling technique was used to select 52 science teachers as participants for the study. Then, simple random sampling techniques was used to select 80 out 97 respondents using research advisor table of determining sample size. Appropriate data were collected for the study through the questionnaire tagged “Teachers’ Citizenship Behaviour Questionnaire (TCBQ)”. The findings of the study revealed that teachers’ citizenship behaviour influences students’ academic performance in science subjects in Igabi Local Government Area, Kaduna State. Based on the findings of the study, it was recommended among others that Developing and nurturing positive culture of professionalism in teaching through progressive, collaborative and instructional leadership should be demonstrated by the school leaders. Similarly, there is need for the government to organize trainings, workshops, seminars and conferences for the supervisors, principals and teachers of schools on TCB to serve as a driving force for effective service delivery that will in turn enhance students’ performance.

Keywords*: Teacher, Citizenship behaviour, Science subject, Students, Academic performance*

1. Introduction

The significance of science subjects cannot be over emphasized because, science is a systematic inventiveness that shapes and unify knowledge in the form of testable explanations and knowledge that can be rationally explained and reliably applied to everyday life. Science was introduced into the Nigeria educational system, treated as general science but was later broken down into three disciplines Biology, Chemistry and Physics. (Emmanuel & aondofa, 2018) these practices restricted to only higher classes with little or no room for those in the junior classes. However, the period from 1968 to 1970 witnesses a series of joints effort by science teachers' association of Nigeria (STAN) and comparative education studies and adoption centre (CESAC), to redesign science to meet the need of less science-oriented students and to be taught in junior secondary school classes hence the introduction of integrated science. (Emmanuel & aondofa, 2018). According to national policy on education, the national education aims and objectives to which the philosophy of education is directed are;

1. The inculcation of national consciousness and national unity
2. The inculcation of right type of values and attributes for the survival of the individual and the Nigeria society
3. The training of the mind in the understanding of the world round
4. The acquisition of the appropriate skills abilities and competences both mental and physical as equipment for the individual to live in, and contribute to the development of the society. National Policy on Education (2013). It is crystal cleared that the nation policy on education if well implemented will enable the nation attain equivalence with the leading nation of the world with regard to technological development as well as promote the spirit of self-reliance in Nigeria.

Science Subjects play very important role in scientific advancement that affects the lives of mankind. Despite its importance in the society, available statistics from the West African Examination Council (WAEC 2007-2016) on senior secondary school students' academic performance in three Major Science Subjects revealed fair performance at Senior School Certificate Examination as shown below;

Year	Biology			Chemistry			Physics		
	Total sat	Credit passed (A1-C6)	% Pass	Total sat	Credit passed (A1-C6)	% Pass	Total sat	Credit passed (A1-C6)	% Pass
2007	1,238,163	413,211	33.37	424,747	196,063	46.16	409,449	180,797	44.16
2008	1,259,964	427,644	33.94	456,980	202,762	44.37	408,237	200,345	49.08
2009	1,259,964	453,928	33.87	456,980	203,365	43.49	444,236	222,722	50.14
2010	1,300,418	427,644	32.88	465,643	263,059	50.70	463,755	237,756	51.27
2011	1,505,199	579,432	38.50	565,692	280,250	49.54	563,161	360,096	63.94
2012	1,646,150	587,044	35.66	627,302	270,570	43.13	624,658	429,415	68.74
2013	1,648,363	852,717	51.73	639,296	462,517	72.34	637,023	297,988	46.77
2014	1,365,384	766,971	56.17	636,268	397,649	62.49	635,729	386,270	60.76
2015	1,390,234	798,246	57.42	680,357	412.323	60.60	684,124	410,543	60.01
2016	1,200,367	740,345	61.68	706,873	408,122	57.74	705,125	415,655	58.95

Source: Statistics Section of the WAEC Office Yaba, Lagos

The senior secondary school science curriculum is designed to serve the needs and interest of the students of different abilities. Consequently, upon the introduction of the 6-3-3-4 system of education, the curriculum recommended among others that experimentation, demonstration, problem-solving and even field trip resting on practical activities of the students should be used in the teaching of science subjects (FME, 2005 in NPE, 2013). The expectation could be that a successful implementation of the curriculum objective is based on the recommended teaching techniques. The learner would be equipped with adequate knowledge, positive attitude and science process skills that would enhance his performance, sustain his interest and also serve as springboard for the nation's scientific and technological breakthrough. Contrary to these expectations, the level of performance among secondary school science students has not been encouraging (Obochi, 2018). However, Teacher's behaviour is accompanied with feeling of hope, generosity, respect, and joy becomes effective in adapting and improving the conduct of aberrant students who have had previous bad records in science subjects (Yusuf, Fasasi, Yusuf& Mustapha, 2022).

Conversely, teacher's negative conduct such as: referring the rude and undisciplined students to school principal, sending them out of class and overlooking students' serious difficulties had an undesired effect on the students' performance and could be a source of their failure (Anfajaya & Rahayu, 2020; Teeples, 2020). Arguably, when specific aspects of student-teacher relationship and interaction are respected, teachers have an adjustable conduct and avoid rigid and inflexible methods which make the students accept them as a friend and companion. Additionally, interactive communication of values between teacher and students indicates teacher demonstrating citizenship behaviour (Crowley, 2013). This relates to behaviour such as punctuality, helping other teachers, volunteering for things that are not required, making innovative suggestions to improve the institution, not complaining about trivial matters, responding promptly to correspondence and not wasting time. This kind of behaviour supports task performance and improves a social and psychological work environment that will eventually aid students' performance (Donglong et al., 2020; Oplatka, 2019). During the COVID 19 pandemic, Khalid et al. (2021) reported that students identified high levels of TCB behaviours in their teachers as they supported the transition to online learning platforms.

The concept of TCB was coined out from the concept of Organization Citizenship Behaviour (OCB) which was first explored exclusively in corporate and mechanical units. Barnard (1938) introduced the concept of OCB using the system approach while examining organizations. In addition, Katz (1964) in Hanson, Niqab & Arif, (2022) asserted that for any institute to operate properly, personnel must exhibit three types of conduct: workers must be motivated to join and stay with the organization; workers must be able to meet job requirements or play a specific function as and when defined; and workers must have the capacity to innovate and do so spontaneously, even beyond their assigned responsibilities (Werner, 2002). Teacher Citizenship Behaviour (TCB) is the key foundation of every teacher in a school setting. TCB is considered as Teachers' Performance that contributes to the social and psychological context of both the colleagues in the field and the students within the school where teaching occurs. TCB is a behaviour of individual teacher, which is observed as going beyond his/her stipulated assigned task (Fahmi & Permana, 2019). Three basic features of TCB include that the behaviour is voluntary, useful to the school organization, and has a multi-dimensional aspect (Hanson, Niqab & Arif, 2022). Scholars have emphasised relevance of TCB to the success of the school organization especially in the aspect of teaching science subject, it is pertinent to know that the conduct of teachers determines their level of effectiveness (Cohen & Kol, 2004). Moorman and Blakely (1995) state that a good teacher is the one who offers support to the school organisation, even when such support is not verbally demanded. High performance school organizations rely on teachers who go beyond their formal job duties to carry out their task successfully. When individuals in the school setting demonstrate TCB, the group with whom they work has a greater chance of demonstrating superior execution, resulting in improved school viability and contribute greatly to the academic performance of students (Hanson, Niqab & Arif, 2022).

TCB has been defined as, "individual behaviour that is discretionary, not directly or explicitly recognised by the formal reward system, and that in the aggregate promotes the effective functioning of the school system as a formal organisation" (Khalid, Jusoff, Othman, Ismail & Abdul Rahman, 2010). Organ (1997) conceptualizes organizational citizenship behaviour with five dimensions: Altruism, Civic Virtue, Conscientiousness, Courtesy, and Sportsmanship. Organ's five dimensions of organizational citizenship behaviour. Burns and Carpenter (2008) defined Altruism as behaviours of a discretionary nature that are targeted at helping individuals achieve organizationally assigned tasks. Civic Virtue refers to the degree of employee participation within the political elements of the organization. Volunteering to serve on a school improvement team, attending parent-teacher association meetings, and contributing to the dialogue of departmental meetings are some of the many ways that teachers may exhibit civic virtue. Courtesy as a discretionary behaviour of teachers which is respectful and well-mannered way(s) of giving advance notice prior to taking personal leave and providing detailed lesson plans for substitute teachers. The basic premise behind courtesy is that the teacher strives to prevent creating problems for individuals and the school. Conscientiousness which is also known as patriotism is the act of doing more than required in terms of executing or carrying out assigned tasks. Sometimes going the extra mile prevents occurrence of future problems. Finally, sportsmanship refers to the act of preventing negativity or negative actions, such as complaining and rumor-mongering. Again, none of the behaviours enumerated by Organ are directly or explicitly recognized by the formal reward system and as a whole they promote the effective functioning of the school setting (Organ, 1997). However, based on different researches, there are modern ways through which science teachers in secondary education can achieve effectiveness and improve students' academic achievement, the construct that has been identified is teachers' citizenship behaviour. It is against this background that the current study intends to examine teachers' citizenship behaviour as predictor of secondary school students' achievement in Igabi Local Government Area of Kaduna State.

2. Methodology

Descriptive research design of survey method was adopted in carrying out this study, the population of this study consists of 15 principals and 30 vice principals in the entire 15 secondary schools in Igabi, Local Government Area of Kaduna State. The target population comprised 15 principals 30 vice principals and 52 science teachers in the sampled schools. Purposive sampling technique was used to select 52 science teachers as participants for the study. Then, simple random sampling techniques was used to select 80 respondents out 97 participants using research advisor table of determining sample size. An instrument tagged "Teachers' Citizenship Behaviour Questionnaire (TCBQ)" was adopted from the study conducted by Yusuf, Fasasi, Yusuf, and Mustapha (2022) to collect relevant data from the respondents. The adopted instrument was given to three experts in the field of test, measurement and evaluation for the purpose of face, content and construct validity. Also, the reliability of the instrument was ascertained through a pilot study conducted that yielded a reliability coefficient of 0.83. Additionally, Students' Academic Performance Profoma (SAPP) was used to collect students' results in the West African Examination Council (WAEC). The data gathered for the study were analyzed using Statistical Package for Social Sciences (SPSS).

3. Results

TABLE 1: Relationship between the Teachers' Altruism and Students' Academic Performance in science subjects in public senior secondary schools in Igabi Local Government Area, Kaduna State.

Variable	N	Mean	SD	Df	Cal.r-value	p-value	Decision
Teachers' Altruism	80	15.46	2.30	78	0.143	0.004	**H_{01}:** Rejected
Academic Performance in Science Subject	80	49.79	13.76				

H_{O1}: There is no significant relationship between the level of teachers' altruism and students' academic performance in science subjects in public senior secondary schools in Igabi Local Government Area, Kaduna State. Result in Table 1 showed that the calculated r- value of .143 and the p-value (0.004) were found less than the significance level at (0.05). Thus, the stated null hypothesis was rejected.

This result therefore suggests that there is a significant relationship between teachers' Altruism and students' academic performance in science subjects in public senior secondary schools in Igabi Local Government Area, Kaduna State.

H02: There is no significant relationship between the level of teachers' civic virtues and students' academic performance in science subjects in public senior secondary schools in Igabi Local Government Area, Kaduna State.

TABLE 2: Relationship between civic virtues and students' academic performance in science subjects in public senior secondary schools in Igabi Local Government Area, Kaduna State.

Variable	N	Mean	SD	Df	Cal.r-value	p-value	Decision
Civic Virtues	80	15.83	2.02				
Academic Performance in Science Subject	80	49.79	13.76	78	0.153	0.003	**H_{o1}:** Rejected

As shown in Table 2, the calculated r- value of .153 and the p-value (0.003) were found less than the significance level at (0.05). Thus, the stated null hypothesis was rejected. This result therefore suggests that there is a significant relationship between the level of teachers' civic virtues and students' academic performance in public senior secondary schools in Igabi Local Government Area, Kaduna State.

Ho3: There is no significant relationship between the level of teachers' Conscientiousness and students' academic performance in public senior secondary schools in science subjects in public senior secondary schools in Igabi Local Government Area, Kaduna State.

TABLE 3: Relationship between Conscientiousness and students' academic performance in science subjects in public senior secondary schools in Igabi Local Government Area, Kaduna State.

Variable	N	Mean	SD	Df	Cal.r-value	p-value	Decision
Conscientiousness	80	15.75	1.58				
Academic Performance in Science Subject	80	49.79	13.76	78	0.150	0.002	**H_{o1}:** Rejected

Table 3: showed the calculated r- value of .150 and the p-value (0.002) were found less than the significance level at (0.05). Thus, the stated null hypothesis was rejected. This result therefore suggests that there is a significant relationship between the level of teachers' conscientiousness and students' academic performance in science subjects in public senior secondary schools in Igabi Local Government Area, Kaduna State.

Ho4: There is no significant relationship between the level of teachers' courtesy and students' academic performance in public senior secondary schools in science subjects in public senior secondary schools in Igabi Local Government Area, Kaduna State.

TABLE 4: Relationship between courtesy and students' academic performance in science subjects in public senior secondary schools in Igabi Local Government Area, Kaduna State.

Variable	N	Mean	SD	Df	Cal.r-value	p-value	Decision

Courtesy	80	15.10	1.83	78	0.149	0.001	**H_{o1}:** Rejected
Academic Performance in Science Subject	80	49.79	13.76				

Result in Table 4 indicated that the calculated r- value of .149 and the p-value (0.001) were found less than the significance level at (0.05). Thus, the stated null hypothesis was rejected. This result therefore suggests that there is a significant relationship between the level of teachers' courtesy and students' academic performance in science subjects in public senior secondary schools in Igabi Local Government Area, Kaduna State.

Ho5: There is no significant relationship between the level of teachers' sportsmanship and students' academic performance in science subjects in public senior secondary schools in Igabi Local Government Area, Kaduna State.

TABLE 5: Relationship between sportsmanship and students' academic performance in science subjects in public senior secondary schools in Igabi Local Government Area, Kaduna State.

Variable	**N**	**Mean**	**SD**	**Df**	**Cal.r-value**	**p-value**	**Decision**
Sportsmanship	80	15.90	2.03	78	0.151	0.002	**H_{o1}:** Rejected
Academic Performance in Science Subject	80	49.79	13.76				

Result in Table 5 showed the calculated r- value of .151 and the p-value (0.002) were found less than the significance level at (0.05). Thus, the stated null hypothesis was rejected. This result therefore suggests that there is a significant relationship between the level of teachers' sportsmanship and students' academic performance in science subjects in public senior secondary schools in Igabi Local Government Area, Kaduna State.

4. Discussion of the Finding

The findings of this study revealed that there is a significant relationship between teachers' altruism and students' academic performance in science subjects in public senior secondary schools in Igabi Local Government Area, Kaduna State, ($r = 0.143$, $p< 0.05$). The finding is consistent with the study of Khalid, Josoff and Othman (2010) found that Altruism was related significantly to students' need for academic achievement, which is generally consistent to a previous study by Dipaola and Hoy (2005). Burn and Carpenter (2008) described Altruism as behaviours of a discretionary nature that are targeted at helping individuals to achieve teacher assigned tasks. Ordinarily, when a teacher displays an act of altruism towards colleagues through teaching of a particular topic while the latter is not on ground, the students stand to benefit and it could lead to encouaraging performance at both internal and external examination. The fact about this is that, there are instances where teachers could not meet up with their lesson hour which eventual turnout to affect the performance of students.

There was a significant relationship between teachers' civic virtues and students' academic performance in science subjects in public senior secondary schools in Igabi Local Government Area, Kaduna State ($r = 0.153$, $p < 0.05$). Thus, the hypothesis was rejected. It means that there is a correlation between Civic virtue and students' academic performance in science subjects in Igabi Local Government Area, Kaduna State. Logically, contribution of an individual in a school organization significantly related to school effectiveness and improve on students' academic performance. The foregoing finding is in consonance with the work of Borman (2014) who found that active participation in a school improvement team, attending parent teacher association meetings without prior notice, and making an acute and genuine contribution to the dialogue of department meetings are some of the numerous ways that teachers may display that translate to success of students in the classroom setting. Podsakoff in his research found that civic virtue means having a thorough knowledge of things happening in the school organization with sincere mind to contribute to the progress and development of such an organization. For instance, high interest in new developments, work methods and school policies as well as self-improvement efforts can bring success and contribute to the school effectiveness which can enhance students' performance.

There is a significant relationship between teachers' conscientiousness and students' academic performance in science subjects in public senior secondary schools in Igabi Local Government Area, Kaduna State ($r = 0.150$, $p < 0.05$). Thus, the hypothesis was rejected. It indicated that there is a correlation between conscientiousness and students' academic performance in science subjects in Igabi Local Government Area, Kaduna State. This finding is in line with the work of Yusuf, Fasasi, Yusuf & Mustapha, (2022), they concluded that personality characteristics, conscientiousness, in particular, has been found to have a strong relationship with the general compliance component of TCB. Likewise, Burns and Carpenter (2018) concluded that conscientiousness, contributes to the group and individual's effectiveness. They explained further those teachers display the act citizenship behaviour through participating in school activities, mentoring teachers, serving on committees, sponsoring clubs, providing others with advance notice, passing on accurate information and many other many examples of behaviour that outshine the prescribed obligations set forth by schools. This behaviour considerably increases in a functioning school when healthy organizations display a strong sense of culture and positive climate. The act of being patriot to the school organization can only make all the above explanation realistic. Therefore, conscientiousness is a strong predictor of students' academic performance.

There is a significant relationship between the level of teachers' courtesy and students' academic performance in science subjects in public senior secondary schools in Igabi Local Government Area, Kaduna State ($r = 0.149$, $p < 0.05$). Thus, the stated null hypothesis was rejected. Which means that courtesy is significantly related to students' academic performance in science subjects in public senior secondary schools in Igabi Local Government Area, Kaduna State. This finding agrees with the findings of Dipaola and Hoy (2005) who discovered that among the five OCB dimensions correlated with students' academic achievement, only teachers' benevolence and courtesy were significant predictors of students' academic achievement. Yusuf, Fasasi, Yusuf and Mustapha, (2022) and Burn and Carpenter (2018) argued that courtesy helps to prevent belligerent or destructive behaviour and maximizes the use of time by all involved in the school organization. Courteous acts include: communicating appropriate information, reminders, and prior notices to members so that they would not be caught by surprise for any school events. Courtesy helps to prevent problems and facilitates constructive use of time (Yusuf, Fasasi, Yusuf & Mustapha, 2022). In actual sense, engaging in an act that could prevent work related problem in the school organization will bring about cooperation and as a result, there will be progress and development in such school. When this happens, students benefit a lot and this is reflected in their performance.

Last of all, there is a significant relationship between teachers' sportsmanship and students' academic performance in science subjects in public senior secondary schools in Igabi Local Government Area, Kaduna State ($r = 0.151$, $p < 0.05$). Thus, the stated null hypothesis was rejected. This finding substantiates the study conducted by Yilmaz and Tasdan (2019) who established that positive thinking progresses students' academic achievement. Bawuah (2016) described sportsmanship as an act of not complaining in case of problems. Sportsmanship involves the readiness to tolerate the inconveniences and impositions related to work without complaining. Also, a teacher with high degree of sportsmanship will not complain when his associate is not active enough in a group work assigned to them.

5. Conclusion

The study focuses on determining the relationship between teachers' citizenship behaviour and students; academic performance in science subjects in public senior secondary schools in Igabi Local Government Area, Kaduna State. Based on the findings of the study, generally, the level of teachers' citizenship behaviour was found to be high. This implies that the independent variables (that is teachers citizenship behaviour) was a predictor of students' academic performance in science subjects in public senior secondary schools in Igabi Local Government Area, Kaduna State. five instruments used in measuring teachers' citizenship behaviour (teachers' Altruism and teachers' civic virtue, conscientiousness, courtesy sportsmanship were predictors of students' academic performance in science subjects in public senior secondary schools in Igabi Local Government Area, Kaduna State.

6. Recommendation

From the findings of the study, it can be stated that teachers' citizenship behaviour is an instrument through which effectiveness can be accomplished in secondary schools, which will bring about excellent performance among senior secondary school students in science subjects in public senior secondary schools.

. Based on the findings of the study, the following recommendations were made:

1. The school administrators should create enabling environment for the teachers and the students through timely motivational activities conducted by the school, that all the five dimensions of teacher citizenship behaviour can be practiced as identified in this study.
2. The government at Federal, State and Local Government levels need to organize trainings, workshops, seminars, and conferences for the supervisors, principals and teachers of public secondary schools on the importance of teachers' citizenship behaviour. This is to equip them to develop high degree of teacher citizenship behaviour while at work in order to enhance students' academic performance especially in science subjects.
3. Teachers need to be actively committed to work, be friendly and accommodating to the students, other colleagues at school and the parents/guidance of students and be resourceful.
4. Developing and nurturing positive culture of professionalism in teaching through progressive, collaborative and instructional leadership should be demonstrated by the school leaders.
5. Teachers need to display a high level of teachers' citizenship behaviour by being dynamic in line with the current trends in educational system as it is found to related to students achievement.

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Article 9

Artificial intelligence (AI) in STEM education
Design development and applications in STEM education

Suleiman Dauda[1] and Awujoola J. Olalekan[2]

[1]Quality Assurance & ICT Department, National Teachers' Institute Kaduna.

[2] Directorate of ICT, Nigeria Defence Academy Kaduna Nigeria.

Abstract

Artificial Intelligence (AI) has the potential to significantly transform STEM (Science, Technology, Engineering, and Mathematics) education by enhancing both teaching and learning experiences. This paper explores the design, development, and applications of AI tools in STEM education, highlighting their impact on personalized learning, intelligent tutoring, and student performance analytics. It discusses the principles and challenges of designing AI tools, alongside case studies that illustrate successful implementations. The paper also addresses the ethical considerations associated with AI in education, such as privacy, data security, and algorithmic bias. Future directions and opportunities for AI in STEM education are examined, emphasizing the importance of collaborative efforts among educators, technologists, and policymakers. The conclusion underscores the transformative potential of AI in education, advocating for continued research and ethical integration to fully realize its benefits. This comprehensive exploration of AI in STEM education provides valuable insights into its current applications and future prospects, positioning AI as a critical component of innovative educational strategies.

Keywords: *Artificial Intelligence (AI), STEM Education, Personalized Learning, Ethical Considerations, Intelligent Tutoring*.

1. Introduction

1.1 Background on STEM Education

STEM (Science, Technology, Engineering, and Mathematics) education is a crucial element in preparing students for the complexities of the modern workforce and the global economy. STEM disciplines are considered foundational in fostering innovation, driving economic growth, and addressing critical global challenges, such as climate change, healthcare, and cybersecurity (Bybee, 2010). The demand for STEM skills has grown exponentially in recent years, leading to an increased emphasis on STEM education at all levels of the educational system. According to the U.S. Bureau of Labor Statistics (2021), employment in STEM occupations is projected to grow significantly faster than non-STEM occupations, highlighting the urgent need for a workforce equipped with strong STEM capabilities.

STEM education is not limited to content knowledge in these disciplines; it also encompasses the development of critical thinking, problem-solving, creativity, and collaboration skills (National Research Council, 2011). These skills are essential for students to navigate and succeed in a rapidly changing world. Consequently, educational institutions have increasingly prioritized STEM education, with various curricula, programs, and policies designed to enhance STEM learning and attract more students to these fields.

However, traditional methods of teaching STEM subjects have often been criticized for their rigidity and lack of engagement, leading to a persistent underrepresentation of certain groups, such as women and minorities, in STEM fields (OECD, 2020). This has sparked a growing interest in exploring innovative approaches to STEM education that can make learning more accessible, inclusive, and effective.

1.1.1 The Importance of Innovative Approaches in STEM Education

To address the challenges associated with traditional STEM education, educators and policymakers have increasingly recognized the need for innovative approaches that leverage technology and new pedagogical strategies. These approaches aim to enhance student engagement, personalize learning, and better prepare students for the demands of the modern world (Honey, Pearson, & Schweingruber, 2014).

One such approach is the integration of project-based learning (PBL), which emphasizes hands-on, real-world problem-solving activities that require students to apply their STEM knowledge in meaningful contexts. Research has shown that PBL can improve students' understanding of STEM concepts, boost motivation, and foster a deeper connection to the material (Krajcik & Blumenfeld, 2006). Additionally, interdisciplinary teaching, which integrates multiple STEM subjects into cohesive lessons, has been found to enhance students' ability to see the connections between different fields and apply their knowledge more holistically (Beers, 2011).

Another critical innovation in STEM education is the use of digital tools and resources, such as virtual laboratories, simulations, and online learning platforms. These technologies enable students to explore complex concepts in a more interactive and engaging manner, often allowing for experimentation and visualization that would be difficult to achieve in traditional classroom settings (Chen et al., 2014). Moreover, the rise of big data and learning analytics has provided educators with new ways to assess student performance and tailor instruction to meet individual needs, making STEM education more personalized and effective (Siemens, 2013).

Despite these advancements, there remains a significant opportunity to further transform STEM education through the incorporation of cutting-edge technologies. One of the most promising developments in this regard is the integration of Artificial Intelligence (AI) into educational practices.

1.1.2 Introduction to Artificial Intelligence (AI) and Its Potential in Education

Artificial Intelligence (AI) is a rapidly evolving field that involves the development of algorithms and systems capable of performing tasks that typically require human intelligence, such as reasoning, learning, problem-solving, and decision-making (Russell & Norvig, 2020). AI has already made significant inroads in various industries, from healthcare and finance to transportation and entertainment. Its application in education, particularly in STEM education, is an area of growing interest and potential.

AI's potential in education lies in its ability to provide personalized learning experiences, automate administrative tasks, and offer real-time feedback and support to both students and educators. AI-driven educational tools, such as intelligent tutoring systems (ITS), can adapt to the unique learning styles and paces of individual students, offering customized instruction that enhances understanding and retention of STEM concepts (Woolf, 2009). For example, an ITS can analyze a student's performance on a series of math problems and dynamically adjust the difficulty level or provide targeted hints based on the student's needs (VanLehn, 2011).

Moreover, AI can assist educators by automating tasks such as grading, attendance tracking, and data analysis, allowing teachers to focus more on instruction and student engagement. The use of AI in analyzing large datasets of student performance can also provide insights into learning patterns and potential areas of difficulty, enabling more informed and timely interventions (Zawacki-Richter et al., 2019).

The integration of AI in STEM education also opens up possibilities for new and innovative learning environments. For instance, AI-powered virtual laboratories can simulate complex experiments that might be too costly or dangerous to perform in a traditional classroom, giving students hands-on experience in a safe and controlled setting (Lajoie, 2009). Additionally, AI can facilitate collaborative learning by connecting students with peers and experts from around the world, creating a global learning community that transcends geographical boundaries.

While the potential benefits of AI in STEM education are significant, it is essential to approach its integration thoughtfully, considering the ethical, social, and practical implications. Issues such as data privacy, algorithmic bias, and the digital divide must be addressed to ensure that AI-enhanced education is equitable and inclusive (Holmes et al., 2021).

In conclusion, STEM education plays a critical role in preparing students for the demands of the modern workforce. Traditional teaching methods are increasingly being supplemented or replaced by innovative approaches to enhance learning experiences. One such innovation is the integration of Artificial Intelligence (AI) in education. AI holds the potential to revolutionize how students learn and how educators teach, making it a crucial area of focus for the future of STEM education. The incorporation of AI in STEM education represents a promising avenue for innovation, with the potential to transform teaching and learning practices. As educators, researchers, and policymakers continue to explore and develop AI-driven tools and strategies, the future of STEM education will likely be characterized by more personalized, engaging, and effective learning experiences that prepare students for the challenges and opportunities of the 21st century.

2. AI in STEM Education: An Overview

Artificial Intelligence, defined as the simulation of human intelligence in machines, has a rich history of application across various fields, including education. Initially, AI's role in education was limited to basic computer-assisted instruction. However, recent advancements have expanded its applications, particularly in STEM education, where it now encompasses personalized learning, intelligent tutoring, and advanced data analytics.

2.1. Definition and Scope of AI

Artificial Intelligence (AI) refers to the development of computer systems that can perform tasks typically requiring human intelligence, such as learning, reasoning, problem-solving, and decision-making (Russell & Norvig, 2020). In the context of education, AI encompasses a range of technologies, including machine learning, natural language processing, and intelligent tutoring systems (ITS), that are designed to enhance teaching and learning processes. The scope of AI in education is broad, covering everything from personalized learning experiences to automated grading systems and advanced data analytics that support educational decision-making (Holmes et al., 2021).

2.2 Historical Context of AI in Education

The application of AI in education has its roots in the development of early intelligent tutoring systems in the 1970s and 1980s. These systems were designed to mimic the personalized instruction provided by human tutors by adapting to students' individual learning needs (Woolf, 2009). Over the decades, AI in education has evolved significantly, driven by advances in computational power, algorithmic techniques, and data availability. In the early 2000s, AI technologies began to expand beyond tutoring systems to include adaptive learning platforms, virtual learning environments, and data-driven educational tools (Luckin et al., 2016). The increasing integration of AI in education reflects a growing recognition of its potential to transform traditional teaching and learning methods.

2.1.3 Current Trends in AI Applications in STEM

Currently, AI is making significant inroads into STEM education, with applications ranging from intelligent tutoring systems to AI-driven simulations and virtual laboratories. One major trend is the use of AI to create personalized learning pathways, where AI algorithms analyze students' learning behaviors and performance data to customize instruction and provide targeted feedback

(Zawacki-Richter et al., 2019). Another trend is the use of AI-powered tools to support collaborative learning and problem-solving in STEM subjects, enabling students to work together on complex tasks with the help of AI-driven guidance and resources (Chen et al., 2020). Additionally, AI is increasingly being used to enhance STEM education by enabling real-time assessment and feedback, allowing educators to identify and address learning gaps more effectively (Holmes et al., 2021). These trends indicate that AI is becoming an integral part of the educational landscape, particularly in STEM fields where the need for innovative teaching methods is critical.

3. Design and Development of AI Tools for STEM Education

The design and development of Artificial Intelligence (AI) tools for STEM (Science, Technology, Engineering, and Mathematics) education have the potential to revolutionize learning experiences by making them more personalized, interactive, and accessible. This section explores the key principles guiding the design of AI tools, showcases case studies that exemplify successful AI tool development, and discusses the challenges faced in creating effective AI tools for STEM education, with a focus on the African context.

3.1 Principles of Designing AI Tools for Education

The design of AI tools for education, particularly in STEM fields, should be guided by several fundamental principles to ensure that these tools are effective, inclusive, and ethically sound.

1. User-Centered Design: AI tools should be developed with a deep understanding of the needs, preferences, and challenges of the end-users, which include students, teachers, and administrators. This involves extensive research and collaboration with educators to create interfaces and functionalities that are intuitive and easy to use (Holmes et al., 2021). In the African context, where access to technology can vary widely, AI tools must be designed to work on a range of devices, including mobile phones, which are more prevalent than computers in many regions (GSMA, 2020).
2. Adaptability and Personalization: One of the key advantages of AI in education is its ability to provide personalized learning experiences. AI tools should be designed to adapt to the individual learning pace, style, and needs of each student. For example, an AI-based tutoring system could adjust the difficulty level of problems based on a student's performance, offering more challenging tasks to advanced learners while providing additional support to those who struggle (Luckin et al., 2016). In Africa, where classrooms often have high student-to-teacher ratios, personalized AI tools can help address the challenge of providing individualized attention to students.
3. Cultural Relevance: AI tools must be culturally relevant and contextually appropriate. In Africa, this means incorporating local languages, examples, and contexts into educational content to make learning more relatable and engaging for students (Moe, 2021). For instance, an AI tool designed for mathematics education could use examples from local

markets or traditional practices to explain concepts, making the material more accessible to students in rural areas.

4. Scalability and Accessibility: To be effective in diverse educational settings, AI tools must be scalable and accessible. This involves designing tools that can be used in both urban and rural areas, with considerations for limited internet connectivity, electricity, and other infrastructural challenges common in many parts of Africa (World Bank, 2020). Offline capabilities and low-bandwidth versions of AI tools can be crucial in ensuring that students in remote areas are not left behind.
5. Ethical Considerations and Data Privacy: As AI tools collect and analyze vast amounts of data, it is essential to prioritize data privacy and ethical considerations. Developers must ensure that AI systems are transparent, that student data is protected, and that the algorithms used do not perpetuate biases that could disadvantage certain groups of students (Holmes et al., 2021). In Africa, where concerns about data privacy and digital literacy are growing, ethical AI practices are critical to building trust in these technologies.

3.2 Case Studies of AI Tool Development

Successful AI tools for STEM education provide valuable insights into the potential of these technologies to transform learning experiences. Several case studies illustrate how AI can be effectively integrated into educational systems, with particular relevance to African contexts.

1. ALEKS (Assessment and Learning in Knowledge Spaces): ALEKS is an AI-driven educational platform that offers personalized learning experiences in mathematics. The system uses AI to assess a student's knowledge and identify gaps, providing targeted instruction to address those gaps (Koedinger et al., 2015). ALEKS has been used in various educational settings worldwide and has shown promise in improving math proficiency. In Africa, where many students struggle with math, a similar AI tool could help tailor instruction to individual needs, thereby improving learning outcomes.
2. M-Shule: M-Shule is an AI-powered mobile learning platform designed specifically for African primary school students. It delivers personalized education via SMS, making it accessible even in areas with limited internet connectivity. M-Shule uses AI to analyze student performance and provide customized lessons in subjects like math and English, aligned with national curricula (M-Shule, 2020). This platform exemplifies how AI can be leveraged to overcome infrastructural challenges and provide quality education in underserved areas.
3. Kytabu: Kytabu is a Kenyan-based digital textbook subscription app that uses AI to enhance learning. The platform allows students to access textbooks and educational content on mobile devices, with AI algorithms providing recommendations and additional resources based on student progress (Kytabu, 2021). Kytabu addresses the challenge of

textbook shortages in Africa, offering a scalable solution that leverages AI to support student learning.

4. Ubongo Kids: Ubongo Kids is an educational entertainment company that uses AI to create interactive learning experiences for children across Africa. The platform combines AI-driven analytics with culturally relevant content to engage students in STEM subjects through animated videos and interactive quizzes. Ubongo Kids has successfully reached millions of children across Africa, demonstrating the power of AI to make learning fun and effective (Ubongo, 2021).

These case studies highlight the diverse applications of AI in STEM education and underscore the importance of designing tools that are tailored to the unique challenges and opportunities present in African education systems.

3.3 Challenges in Designing AI Tools for STEM

Despite the potential benefits, the design and development of AI tools for STEM education face several significant challenges, particularly in the African context.

1. Infrastructure and Access: A major challenge in Africa is the lack of infrastructure, such as reliable internet connectivity, electricity, and access to digital devices. These limitations can hinder the implementation of AI tools in many regions, particularly in rural areas. Developers must create AI tools that are optimized for low-resource environments, including offline capabilities and compatibility with basic mobile devices (World Bank, 2020).
2. Digital Literacy: The effectiveness of AI tools in education depends on the digital literacy of both students and educators. In many African countries, digital literacy rates are low, and teachers may not be adequately trained to integrate AI tools into their teaching practices (UNESCO, 2019). Addressing this challenge requires investment in teacher training programs that focus on digital skills and the effective use of AI in education.
3. Bias and Fairness: AI systems can unintentionally perpetuate biases if the data used to train them is not representative of the diverse student populations they serve. In Africa, where educational disparities are common, it is crucial to ensure that AI tools are designed with fairness in mind, avoiding algorithms that may disadvantage certain groups of students based on gender, ethnicity, or socioeconomic status (Holmes et al., 2021).
4. Cost and Sustainability: Developing and maintaining AI tools can be expensive, and funding for educational technology in Africa is often limited. Ensuring the sustainability of AI initiatives requires innovative funding models, partnerships with private sector organizations, and government support. Additionally, AI tools must be affordable for schools and students to ensure widespread adoption (World Bank, 2020).
5. Ethical and Legal Issues: The use of AI in education raises ethical and legal questions related to data privacy, consent, and the potential misuse of student data. In Africa, where regulatory frameworks for AI and data protection are still evolving, these issues must be

carefully considered to ensure that AI tools are used responsibly and that student data is safeguarded (UNESCO, 2019).

4.Applications of AI in STEM Education

The application of Artificial Intelligence (AI) in STEM education has revolutionized how students learn and teachers teach. AI's capabilities in personalization, real-time feedback, and data analysis offer unique opportunities to enhance educational outcomes, particularly in contexts where traditional educational resources may be limited. In Africa, where educational challenges are significant due to factors like large class sizes, limited access to resources, and varying levels of teacher expertise, AI offers transformative potential. This section explores key applications of AI in STEM education, focusing on personalized learning experiences, intelligent tutoring systems, data analytics, student performance monitoring, and virtual laboratories and simulations.

4.1. Personalized Learning Experiences

Overview: Personalized learning refers to tailoring educational experiences to meet the individual needs, preferences, and learning pace of each student. AI plays a crucial role in enabling personalized learning by analyzing vast amounts of data to identify students' strengths, weaknesses, and learning styles.

Application in Africa: In many African countries, educational systems face challenges such as overcrowded classrooms and limited teacher-to-student ratios. AI-driven personalized learning tools can help bridge these gaps by providing individualized attention that is often unattainable in traditional classroom settings.

Example: The Gradely platform in Nigeria is an AI-powered personalized learning tool that assesses students' performance and adapts content to address their specific learning needs. For instance, if a student struggles with algebra, Gradely provides additional resources and practice problems targeted at that topic. This approach ensures that students can learn at their own pace, improving comprehension and retention (Gradely, 2021). Personalized learning platforms like Gradely have shown promising results in improving academic performance, particularly in STEM subjects, by catering to the diverse needs of students (EdTech Hub, 2020).

4.2`Intelligent Tutoring Systems

Overview: Intelligent Tutoring Systems (ITS) are AI-driven platforms that provide one-on-one tutoring to students, offering personalized guidance, feedback, and support. ITS can simulate the role of a human tutor, adapting to the learner's pace and style.

Application in Africa: ITS can be particularly valuable in African educational contexts where access to skilled tutors is limited. These systems can offer personalized assistance to students, especially in remote or underserved areas, ensuring that they receive the support needed to excel in STEM subjects.

Example: M-Shule, a Kenyan mobile learning platform, uses AI to deliver personalized tutoring via SMS. The platform's intelligent tutoring system provides tailored lessons in subjects like mathematics and English, based on the individual needs of each student. This approach is especially effective in rural areas where internet access is limited but mobile phone usage is widespread (M-Shule, 2020). The platform's success highlights the potential of ITS to provide equitable access to quality education in regions where traditional tutoring services may not be available (World Bank, 2020).

4..3 Data Analytics and Student Performance Monitoring

Overview: AI-powered data analytics tools in education enable the collection, analysis, and interpretation of large datasets to monitor and assess student performance. These tools can identify trends, predict outcomes, and provide insights that help educators tailor their instruction to better meet students' needs.

Application in Africa: In many African countries, where educational resources are scarce, data analytics can help optimize the use of available resources and improve educational outcomes. By analyzing student performance data, educators can identify areas where students are struggling and intervene before issues become critical.

Example: Siyavula, a South African online learning platform, uses AI to track student performance in real-time. The platform's data analytics tools analyze student interactions with practice problems, providing detailed feedback and identifying areas where students need improvement. Educators can use this data to adjust their teaching strategies and provide targeted support to students who are falling behind (Siyavula, 2021). By leveraging AI for performance monitoring, Siyavula has contributed to improved learning outcomes in STEM subjects across South Africa (UNESCO, 2019).

4..4 Virtual Laboratories and Simulations

Overview: Virtual laboratories and simulations provide students with interactive, hands-on learning experiences in a digital environment. These tools are particularly useful in STEM education, where practical experiments are essential for understanding complex concepts.

Application in Africa: In many African schools, access to physical laboratories and scientific equipment is limited. Virtual labs and simulations offer a cost-effective alternative, allowing students to conduct experiments and explore scientific concepts in a safe and controlled environment.

Example: Labster, a virtual laboratory platform, offers a wide range of simulations in biology, chemistry, and physics. Although not developed specifically for Africa, Labster has been adopted by several African institutions to supplement traditional science education. In countries like Kenya and Nigeria, where resources for physical laboratories are often lacking, Labster's virtual labs provide students with the opportunity to conduct experiments and gain practical experience in

STEM subjects (Labster, 2021). These virtual environments help bridge the gap between theoretical learning and practical application, ensuring that students in resource-constrained settings receive a comprehensive education (Olaniyan, 2021).

4.5 Case Studies of AI Tool Development in Africa

The integration of Artificial Intelligence (AI) into educational systems across Africa is a growing trend, with several innovative tools being developed to address the unique challenges faced by educators and students on the continent. These case studies highlight how AI is being leveraged to improve STEM (Science, Technology, Engineering, and Mathematics) education, with a focus on various African countries, including but not limited to Nigeria.

i. . Ulesson: AI-Powered Learning App (Nigeria)

Overview: Ulesson is a leading ed-tech platform in Nigeria that offers an AI-powered learning app specifically designed for the Nigerian curriculum. The app provides video lessons, interactive quizzes, and adaptive learning features aimed at improving student performance in core STEM subjects such as mathematics, physics, chemistry, and biology.

AI Integration: Ulesson's AI algorithms analyze students' engagement with the content, identifying their strengths and areas of weakness. The app then personalizes the learning experience by recommending additional resources and exercises tailored to each student's needs. This adaptive learning approach is particularly beneficial in Nigeria, where large class sizes often limit the ability of teachers to provide individualized instruction (Adekanmbi, 2021).

Impact: Ulesson has gained widespread adoption across Nigeria, especially during the COVID-19 pandemic, when traditional schooling was disrupted. The app's ability to provide high-quality, personalized education remotely has been instrumental in bridging educational gaps between urban and rural areas, contributing to improved student outcomes in STEM education (EdTech Hub, 2020).

ii. Gradely: AI-Powered Personalized Learning Platform

Overview: Gradely is an AI-driven educational technology platform designed to improve student performance in Nigeria through personalized learning. The platform offers tools for continuous assessment, personalized practice, and real-time feedback, which are essential for identifying learning gaps and providing tailored support to students.

AI Integration: Gradely uses AI algorithms to analyze student performance data and adapt learning content to meet individual needs. For example, if a student consistently struggles with certain math concepts, the AI system will generate practice problems targeting those specific areas, ensuring that the student receives focused instruction. This level of personalization is particularly important in Nigeria, where classrooms are often overcrowded, and teachers may struggle to provide individual attention to every student (Gradely, 2021).

Impact: Gradely has been adopted by several schools in Nigeria, particularly in urban areas like Lagos. The platform has shown promising results in improving student outcomes, especially in mathematics and science subjects. It also offers a solution to the challenge of maintaining educational quality in a country with a rapidly growing population and significant disparities in educational access. The AI-powered insights provided by Gradely help teachers make data-driven decisions, ultimately enhancing the learning experience for students (EdTech Hub, 2020).

iii. M-Shule: AI-Powered Mobile Learning Platform (Kenya)

Overview: M-Shule is an AI-driven mobile learning platform designed for primary school students in Kenya. The platform delivers personalized education via SMS, making it accessible to students in areas with limited internet connectivity. M-Shule's curriculum-aligned lessons focus on subjects like mathematics and English.

AI Integration: The AI system within M-Shule analyzes each student's performance and provides customized lessons based on their learning needs. The platform's use of SMS ensures that students in remote areas without internet access can still benefit from personalized education. This approach is particularly relevant in Africa, where mobile phone penetration is high, but internet access remains limited (M-Shule, 2020).

Impact: M-Shule has been widely adopted in Kenya and has shown positive results in improving student performance in STEM subjects. By leveraging AI to provide accessible and personalized education, M-Shule addresses the challenge of educational inequality, offering a scalable solution that can be expanded to other African countries with similar infrastructural challenges (World Bank, 2020).

iv. Watson Education: AI for Enhanced Learning (South Africa)

Overview: IBM's Watson Education platform has been implemented in South Africa to enhance STEM education through AI-powered analytics and personalized learning. Watson uses natural language processing and machine learning to analyze student data and provide insights that help teachers tailor instruction to meet individual student needs.

AI Integration: In South Africa, Watson Education has been used in several pilot programs to support teachers in identifying students who are at risk of falling behind. The AI system analyzes data from various sources, including student assessments and classroom interactions, to provide teachers with actionable insights. This allows for more targeted interventions, particularly in STEM subjects where students may struggle with complex concepts (IBM, 2021).

Impact: The implementation of Watson Education in South Africa has shown promise in improving educational outcomes, particularly in under-resourced schools. By providing teachers with data-driven insights, the platform helps to ensure that no student is left behind, contributing to a more equitable education system. The success of Watson Education in South Africa serves as a model for other African countries looking to integrate AI into their educational systems (UNESCO, 2019).

v. Ubongo Kids: AI-Enhanced Educational Entertainment (Tanzania)

Overview: Ubongo Kids is an educational entertainment company based in Tanzania that uses AI to create interactive learning experiences for children across Africa. The platform combines animated videos with AI-driven quizzes and activities to teach STEM subjects in a fun and engaging way.
AI Integration: Ubongo Kids uses AI to adapt the difficulty of quizzes and activities based on the child's performance. The platform's content is designed to be culturally relevant, incorporating local languages and examples that resonate with African children. The AI system ensures that each child is challenged at the appropriate level, helping to maintain engagement and improve learning outcomes (Ubongo, 2021).
Impact: Ubongo Kids has reached millions of children across Africa, making it one of the most successful educational platforms on the continent. By using AI to personalize learning and make it more engaging, Ubongo Kids has significantly improved educational access and quality for children in Tanzania and beyond. The platform's success demonstrates the potential of AI to enhance educational outcomes in a way that is both scalable and culturally relevant (Moe, 2021).

vi. Siyavula: AI-Powered Learning for STEM Subjects (South Africa)

Overview: Siyavula is an open educational resource (OER) platform in South Africa that uses AI to provide personalized learning experiences in STEM subjects. The platform offers a range of textbooks, practice problems, and quizzes that are aligned with the South African curriculum.
AI Integration: Siyavula's AI system tracks student performance on practice problems and adapts the difficulty level of subsequent questions based on the student's progress. The platform also provides detailed feedback to help students understand their mistakes and improve their skills. This level of personalization is particularly important in South Africa, where disparities in educational quality can be significant (Siyavula, 2021).
Impact: Siyavula has been widely adopted in South African schools and has contributed to improved student performance in STEM subjects. The platform's success in using AI to enhance learning outcomes highlights the potential for similar initiatives to be implemented in other African countries. By providing students with personalized, curriculum-aligned resources, Siyavula is helping to bridge the gap in STEM education across the continent (UNESCO, 2019).

vii. 6Conclusion

The integration of AI into STEM education across Africa has the potential to significantly enhance learning outcomes, particularly in contexts where traditional educational resources are limited. Personalized learning experiences, intelligent tutoring systems, data analytics, and virtual laboratories are just a few examples of how AI is transforming education on the continent. These case studies illustrate the diverse ways in which AI is being integrated into educational systems, offering insights into how AI can be tailored to meet the specific needs and challenges of different countries and regions across Africa. As these technologies continue to evolve, they promise a more equitable and effective educational system, capable of addressing the diverse needs of students across the continent.

5. Impact of AI on Teaching and Learning in STEM

Artificial Intelligence (AI) is reshaping education by providing tools and methodologies that enhance both teaching and learning experiences, particularly in STEM (Science, Technology, Engineering, and Mathematics) fields. The integration of AI in education is not just a technological advancement; it represents a fundamental shift in the way educators approach teaching and how students engage with learning material. This section explores how AI enhances teacher capabilities, improves student engagement and outcomes, and provides case studies and research findings that demonstrate the real-world impact of AI in STEM education.

5.1. Enhancing Teacher Capabilities

Overview: AI tools have the potential to significantly enhance the capabilities of teachers by automating administrative tasks, providing real-time feedback, and offering data-driven insights into student performance. These tools allow teachers to focus more on personalized instruction and less on routine tasks.

Application in Africa: In many African educational systems, teachers face challenges such as large class sizes, limited resources, and varying levels of student preparedness. AI can assist teachers by providing tools that help manage these challenges, thereby improving the quality of education.

Example: One notable application of AI in enhancing teacher capabilities is the use of AI-driven analytics platforms like the African School of AI (ASAI), which provides educators with insights into student performance and learning patterns. These platforms can automatically grade assignments, track student progress, and even identify students at risk of falling behind, allowing teachers to intervene early. This approach is particularly beneficial in countries like Kenya and Nigeria, where teachers often manage classrooms with over 50 students, making individual attention challenging (Mhlanga & Moloi, 2020).

Impact: The ability to focus on personalized instruction rather than administrative tasks has been shown to improve teaching effectiveness. According to a study by the World Bank (2020), schools that adopted AI tools for administrative support saw a 20% increase in teacher-student interaction time, which correlated with better student outcomes in STEM subjects. Additionally, AI-powered professional development tools can provide teachers with customized training modules, helping them to continuously improve their teaching strategies and stay updated with the latest pedagogical approaches (EdTech Hub, 2020).

5..2 Improving Student Engagement and Outcomes

Overview: AI can significantly improve student engagement by creating more interactive and personalized learning experiences. By adapting content to suit individual learning styles and providing immediate feedback, AI helps maintain student interest and motivation.

Application in Africa: In African classrooms, where students often have diverse educational backgrounds and learning needs, AI-driven personalized learning tools can ensure that each student receives the attention and resources they need to succeed. This is particularly important in STEM education, where complex concepts can be challenging for students to grasp without personalized support.

Example: The use of AI-driven platforms like Tutor.ng, a Nigerian online learning platform, has been instrumental in improving student engagement in STEM subjects. Tutor.ng uses AI to analyze student data and deliver personalized learning experiences, adjusting the difficulty level of exercises based on the student's performance. This approach helps keep students challenged yet not overwhelmed, which is crucial for maintaining engagement in learning (Adewale, 2021).

Impact: Research indicates that students who use AI-driven learning platforms show improved academic performance and engagement levels. A study conducted by UNESCO (2019) found that students in South Africa who used AI-driven personalized learning tools in their STEM courses demonstrated a 15% improvement in test scores compared to those who did not. Moreover, these tools have been particularly effective in bridging educational gaps among students from different socioeconomic backgrounds, ensuring that all students have the opportunity to succeed in STEM subjects (UNESCO, 2019).

5..3 Case Studies and Research Findings

Overview: Numerous case studies and research findings from across Africa provide evidence of the positive impact of AI on teaching and learning in STEM education. These studies highlight the versatility of AI in addressing various educational challenges and its potential to transform education systems.

Case Studies:

1. **M-Shule in Kenya**: As mentioned earlier, M-Shule is a mobile learning platform that uses AI to deliver personalized education to students via SMS. A study conducted by the World Bank (2021) on M-Shule's impact found that students who regularly engaged with the platform showed a 30% improvement in their understanding of mathematics concepts compared to those who did not. The platform was particularly effective in reaching students in rural areas, where access to quality education is limited (World Bank, 2021).
2. **Ubongo in Tanzania**: Ubongo is a Tanzanian edutainment company that creates educational content for children using AI to adapt learning experiences. The content, which includes animated TV shows and interactive games, is designed to teach STEM concepts in a fun and engaging way. A study by UNICEF (2020) found that children who regularly watched Ubongo's educational content scored higher on STEM assessments than those who did not. The AI component of Ubongo ensures that content is culturally relevant and accessible to children from various backgrounds, making it an effective tool for improving STEM education in Africa (UNICEF, 2020).

3. **Gradely in Nigeria**: Gradely's AI-powered personalized learning platform has already been discussed in terms of its impact on personalized learning, but it also serves as a significant case study in the broader context of AI in STEM education. According to a recent study by the African Journal of Educational Technology (2022), students who used Gradely for one academic year showed marked improvements in their STEM subject scores, particularly in mathematics and physics. The study highlights the platform's ability to adapt to individual learning paces, which is critical in a diverse educational landscape like Nigeria's (African Journal of Educational Technology, 2022).

5..4 Research Findings:

- **Teacher Adaptation**: A study by the EdTech Hub (2021) found that teachers in Uganda who used AI tools reported feeling more confident in their ability to manage large classrooms and provide personalized attention to students. The study also noted that AI tools helped reduce the administrative burden on teachers, allowing them to focus more on instructional time.
- **Student Outcomes**: Research conducted by the World Bank (2020) across multiple African countries indicated that AI-driven educational tools contributed to a significant improvement in student outcomes, particularly in STEM subjects. The findings suggest that AI tools not only help students understand complex concepts but also improve their ability to apply this knowledge in practical settings.

6. Conclusion

The impact of AI on teaching and learning in STEM education in Africa is profound, offering new possibilities for enhancing teacher capabilities, improving student engagement, and ultimately, achieving better educational outcomes. Through the integration of AI, educators in Africa can overcome many of the challenges that have traditionally hindered educational progress, ensuring that all students have access to high-quality STEM education. The case studies and research findings presented here underscore the transformative potential of AI in African education, highlighting the need for continued investment and innovation in this field.

6.1 Ethical Considerations and Challenges

As AI becomes increasingly integrated into STEM education, several ethical considerations and challenges need to be addressed to ensure its responsible and effective use. These concerns revolve around privacy and data security, bias and fairness in AI algorithms, and the broader ethical dilemmas associated with AI in education.

6.1.1 Privacy and Data Security Issues

Overview: AI applications in education often require the collection and analysis of large amounts of personal data, including student performance, behavior, and learning preferences. This data is essential for personalizing learning experiences and improving educational outcomes, but it also raises significant concerns about privacy and data security.

Concerns in Africa: In many African countries, where data protection laws and infrastructure may be less developed, the collection and storage of sensitive educational data pose considerable risks. The potential for data breaches and unauthorized access is heightened, which can lead to misuse or exploitation of personal information.

Recent Developments: The African Union's Convention on Cyber Security and Personal Data Protection, adopted in 2014, sets out guidelines for data protection across member states. However, enforcement and adherence to these guidelines vary widely (African Union, 2021). For instance, in Nigeria, the Nigeria Data Protection Regulation (NDPR) aims to safeguard personal data but faces challenges in implementation and compliance (National Information Technology Development Agency, 2022).

Example: The use of AI in platforms like Khan Academy, which collects extensive data on student interactions to personalize learning, highlights the need for robust data protection measures. In an African context, where data protection frameworks may be weaker, platforms need to ensure that they adhere to international standards for data security to protect students' personal information (Khan Academy, 2021).

Impact: Failure to address privacy and data security issues can undermine trust in AI systems and hinder their adoption. Therefore, it is crucial for educational institutions and AI developers in Africa to prioritize data protection and comply with both local and international regulations to mitigate these risks (World Bank, 2022).

6.1.2 Bias and Fairness in AI Algorithms

Overview: AI algorithms can unintentionally perpetuate or amplify existing biases if not carefully designed and monitored. Bias in AI can arise from various sources, including biased training data, flawed algorithms, and unrepresentative data samples.

Concerns in Africa: In Africa, where educational disparities exist, biased AI systems could exacerbate inequalities if not properly addressed. For example, AI tools trained on data from more developed regions may not adequately represent the diverse educational contexts and needs within African countries.

Recent Developments: Researchers have emphasized the importance of developing fair and unbiased AI systems. The AI Now Institute (2021) highlights the need for diverse data sets and transparency in algorithmic decision-making to mitigate biases. In Africa, initiatives like the Data Science Africa conference are working to address these issues by promoting ethical AI practices and inclusivity in data collection (Data Science Africa, 2021).

Example: A study by Chien et al. (2021) found that AI algorithms used for educational assessments could inadvertently favor students from more affluent backgrounds if the training data is not representative. This is particularly relevant in African contexts, where disparities in access to educational resources and technology are prevalent. Ensuring that AI systems are trained on diverse and representative data is essential to avoid perpetuating existing inequalities (Chien et al., 2021).

Impact: Addressing bias and ensuring fairness in AI algorithms is crucial for achieving equitable educational outcomes. Developers and educators must collaborate to ensure that AI tools are designed with fairness in mind, taking into account the diverse needs and contexts of students in Africa (UNESCO, 2021).

6.1.3 Addressing Ethical Dilemmas in AI Use in Education

Overview: The use of AI in education raises several ethical dilemmas, including the potential for surveillance, the erosion of human interaction, and the impact on teacher autonomy.

Concerns in Africa: In African educational systems, where the teacher-student relationship is often central to the learning process, the increased reliance on AI tools could impact traditional educational practices. Additionally, the use of AI for surveillance or monitoring could raise concerns about privacy and autonomy (Mhlanga & Moloi, 2020).

Recent Developments: Ethical guidelines for AI use in education are emerging, with organizations such as the IEEE and UNESCO developing frameworks to guide the responsible deployment of AI technologies (IEEE, 2021). These frameworks emphasize the importance of transparency, accountability, and respect for human dignity in the use of AI in education.

Example: The deployment of AI tools for monitoring student performance and behavior in schools must be balanced with considerations for student privacy and autonomy. In South Africa, the use of AI for monitoring student attendance and performance has raised concerns about surveillance and the potential loss of personal interaction (UNESCO, 2021).

Impact: To address these ethical dilemmas, it is essential to involve all stakeholders, including educators, students, and policymakers, in the development and implementation of AI tools. Creating ethical guidelines and ensuring transparency in AI practices can help mitigate potential negative impacts and ensure that AI is used in a way that respects the rights and dignity of all individuals involved (World Bank, 2022).

7.1 Future Directions and Opportunities

The future of AI in STEM education holds exciting possibilities, driven by emerging technologies, innovative applications, and collaborative efforts between educators, technologists, and policymakers.

7.1.1 Emerging Technologies in AI for STEM Education

Overview: Emerging technologies such as advanced machine learning algorithms, natural language processing, and augmented reality (AR) are paving the way for new applications of AI in education. These technologies offer opportunities to create more immersive and interactive learning experiences.

Recent Developments: Technologies like AR and virtual reality (VR) are increasingly being integrated into AI-driven educational tools to provide experiential learning opportunities. For example, AI-powered AR applications can overlay digital information onto physical environments, enhancing STEM learning through interactive simulations and visualizations (Miller & Wang, 2021).

Example: In Africa, the use of AR technology in educational apps like the Kio Kit in Kenya allows students to engage with STEM concepts through interactive simulations and visualizations. This technology helps bridge the gap between theoretical knowledge and practical application, providing students with hands-on learning experiences that are often lacking in traditional classrooms (Kio Kit, 2021).

Impact: The continued development and adoption of emerging AI technologies in education have the potential to revolutionize STEM learning by making it more interactive, engaging, and accessible. These technologies can help address educational disparities and provide students with innovative ways to explore and understand complex STEM concepts (Miller & Wang, 2021).

7.1.2 Potential Future Applications and Innovations

Overview: The future of AI in STEM education is likely to see the development of new applications and innovations that further enhance the learning experience. Potential areas of growth include adaptive learning systems, AI-driven educational games, and intelligent content creation tools.

Recent Developments: AI-driven adaptive learning systems, which adjust the content and difficulty level based on real-time feedback, are expected to become more sophisticated and widely adopted. Innovations in AI-driven educational games and simulations can provide students with engaging and interactive ways to learn STEM subjects (Khan Academy, 2021).

Example: In South Africa, the development of AI-driven educational games by the Ubongo Learning platform demonstrates the potential for AI to create engaging and interactive learning experiences. These games incorporate STEM concepts into fun and interactive formats, making learning more enjoyable and effective for students (Ubongo, 2021).

Impact: The continued evolution of AI technologies will likely lead to new and innovative applications that enhance STEM education. By leveraging these advancements, educators can provide students with more personalized, engaging, and effective learning experiences (Khan Academy, 2021).

7.1.3 Collaboration Between Educators, Technologists, and Policymakers

Overview: Successful integration of AI in STEM education requires collaboration between educators, technologists, and policymakers. Each group plays a critical role in ensuring that AI tools are effectively developed, implemented, and regulated.

Recent Developments: Collaborative initiatives, such as the AI in Education Initiative by UNESCO, aim to bring together stakeholders from various sectors to address the challenges and opportunities associated with AI in education (UNESCO, 2021). These initiatives focus on developing best practices, guidelines, and policies to ensure the responsible use of AI in educational settings.

Example: In Nigeria, the National Educational Research and Development Council (NERDC) is working with technology developers and policymakers to create frameworks and guidelines for the use of AI in education. This collaborative approach aims to ensure that AI tools are aligned with national educational goals and standards (NERDC, 2022).

Impact: Collaboration between educators, technologists, and policymakers is essential for the successful integration of AI in STEM education. By working together, these stakeholders can ensure that AI tools are developed and implemented in a way that meets educational needs, addresses ethical concerns, and promotes equitable access to quality education (UNESCO, 2021).

7.14 Conclusion

Summary of Key Points

The integration of AI in STEM education has the potential to significantly enhance teaching and learning outcomes. AI tools can improve teacher capabilities by automating administrative tasks and providing real-time feedback. They can also increase student engagement and outcomes by offering personalized learning experiences and interactive simulations. However, ethical considerations such as privacy, data security, and bias must be carefully addressed to ensure the responsible use of AI.

The Future of AI in STEM Education

The future of AI in STEM education is bright, with emerging technologies and innovations offering new possibilities for enhancing learning experiences. Collaboration between educators, technologists, and policymakers will be crucial for ensuring that AI tools are effectively developed and implemented. As AI continues to evolve, it holds the promise of creating more equitable, engaging, and effective educational systems.

Final Thoughts and Recommendations

To maximize the benefits of AI in STEM education, it is essential to address ethical challenges and promote responsible use of technology. Educators, technologists, and policymakers must work together to develop guidelines, frameworks, and best practices that ensure AI tools are used in ways that respect privacy, ensure fairness, and support educational goals. Continued investment in AI research and development, along with ongoing collaboration, will be key to unlocking the full potential of AI in transforming STEM education.

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Article 10

Exploring The Impact of Technology Integration on Mathematics Teachers

Regina Fumbuka[1], Peter Kajoro[2]

[1]regina.fumbuka@scholar.aku.edu, [2]peter.kajoro@aku.edu

Institute of Educational Development, East Africa, Aga Khan University, Tanzania

Abstract

Technology integration in Mathematics brings positive learning outcomes. However, in Tanzania, the impact of technology integration on Mathematics teachers remains indefinable. Therefore, this participatory action research study explored the impact of technology integration on Mathematics teachers. The study comprised three phases: reconnaissance, two cycles for intervention and post-intervention. The philosophical underpinning of this study was constructivism. The school was selected purposively because of its advanced technological infrastructure, the selection of technological tools, stable internet connectivity, and uninterrupted access to electricity, to allow a conducive environment for successful research implementation. The study respondent was a Mathematics teacher who teaches a Form One B class of 24 students with varying capabilities. Data collection methods used were open-ended semi-structured interviews, structured classroom observations, and documentary analysis such as lesson plans, scheme of work, Mathematics textbooks and reflective journals. Findings from the study suggested that technology brings positive impacts to Mathematics teachers. It also provides motivation, confidence, improvement in teaching, effective productivity and inspiration to share with other Mathematics teachers. It was concluded that the integration of technology impacts the teaching of Mathematics positively. Therefore, the study recommended that educational stakeholders invest in technology facilities, tools, infrastructures and teachers' professional learning in the schools so that Mathematics educational practices can be improved.

Keywords: Technology integration; Mathematics teachers; impact; teaching; Mathematics; outcome

1. Introduction

Integrating technology in Mathematics education is a practice acknowledged and supported by extensive research globally. Various technological resources are used in education in developed and developing countries. For instance, in Spain, access to technology dominates, with over 80% of households owning computers, 90% connected to the Internet, and 99% possessing mobile phones (Bari et al., 2018). According to Salleh (2016), as cited by Muhtadi et al. (2017), technology integration is an efficient means of enhancing the learning experience for students, promoting visualization, engagement, and active participation while fostering a genuine interest in the subject. However, the situation in Tanzania regarding the integration of technology in teaching is still wanting. For instance, 40% of Mathematics teachers in Tanzania reported that their schools lack access to technology and some of them never used technology for teaching (Koomar et al., 2022). It was noted from various studies that technology is mostly used by the head teachers for administrative purposes while Mathematics teachers fail to use technology in their teaching because of their limited knowledge and skills in technology integration (Mgaiwa, 2018). Therefore, this study aimed to explore the impact of technology integration on Mathematics teachers after supporting them with technological knowledge and skills in their teaching. In other words, it focused on finding changes that occurred in the Mathematics teachers after receiving support in integrating technology in teaching Mathematics using the Technological Pedagogical Content Knowledge (TPACK) model (Koehler et al., 2013; Önalan & Gökçe, 2020). To attain this, the following questions guided the study:

i. What was the level of technology integration among Mathematics teachers in teaching Mathematics before receiving support?
ii. What changes occurred in Mathematics teachers after receiving support in integrating technology in teaching Mathematics?

2. Literature Review

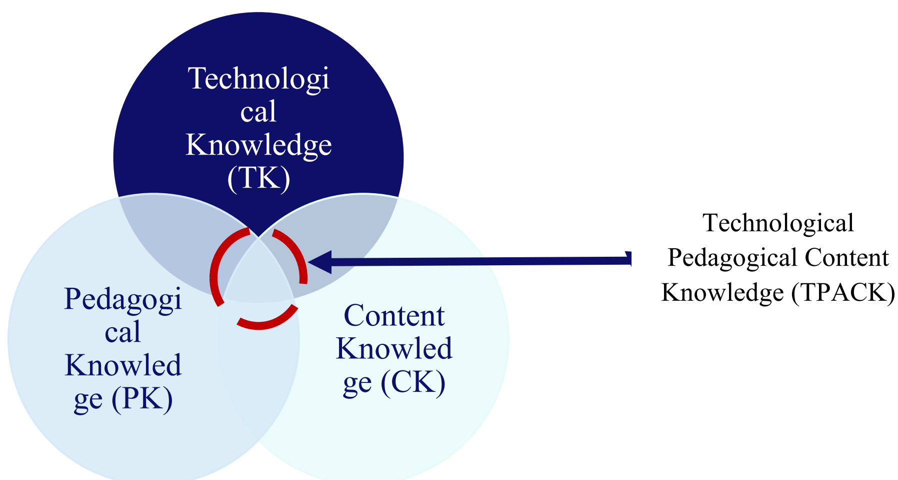
Integration of technology in education is the process of using digital resources such as computers, projectors, videos, mobile phones, software, internet, television, radio and other electronic devices for teaching, learning and assessment (Majoka et al., 2013). It has undergone a significant evolution since the 1960s from developing Plato computers, online learning platforms such as EdX and Coursera, open-source resources, learning management systems like Moodle, and mobile learning applications to artificial intelligence in education (Bari et al., 2018). Their main purposes were to motivate students to love the subject, to improve their cognitive abilities and to enhance their conceptual understanding. In Africa, such evolution started in the 2000s whereby different programs were initiated to bridge the digital divide in Rwanda, Ethiopia, Namibia, South Africa, Kenya and Uganda. Government and international donors improved internet connectivity and provided electricity, laptops, tablets and mobile phones in the schools. Computer labs, online resources, animation and gamified videos were among the projects that ran in those countries (Mndzebele, 2013). In Tanzania, the ICT policy for basic education was introduced in 2007 to enhance educational levels and bridge the digital divide through technology integration. Initiatives such as Shule Direct and Ubongo Kids offered education and engaged students in line with the national curriculum in an entertaining format (Ngeze, 2017). However, this journey cannot exist without its shortcomings. According to Kafyulilo and Fisser (2019), a significant number of schools, particularly in Tanzania, are yet to embrace technology in their classrooms, except very few private schools which have invested in technology infrastructure to support technology-based teaching and learning. This situation causes most teachers to remain unfamiliar with technology integration.

In Mathematics education, numerous studies emphasize the essential role of technology to the students. According to Getenet (2017) and Mazana et al. (2019), integrating various technologies in Mathematics lessons such as Mathia, GeoGebra, Computer Algebra System (CAS), Maple, Mathematica, Desmos, Sketchpad, My MathLab, and Artificial Intelligences (AIs) have improved both learning outcomes and experiences. This is because they motivate students to grasp and understand abstract concepts, construct knowledge and nurture their mathematical thinking abilities (Jaiswal, 2020). Amuko et al. (2015) also added that technologies transform the educational landscape from one grounded in rote memorization to a more constructive, interactive, lovely and friendly learning environment. All these impacts have been observed more on the students than on Mathematics teachers.

In Tanzania, for instance, there exists an evident shortage of studies dedicated to explaining the impact of technology integration towards Mathematics teachers, after receiving support to integrate diverse technologies into their Mathematics lessons despite the existence of multiple technologies (Rumanyika & Galan, 2015). The support needed by Tanzanian Mathematics teachers is how to incorporate educational websites, videos, simulations, virtual classrooms, online discussion forums, educational apps, online quizzes, animations, or games within their teaching environments before determining their impact on Mathematics teachers. Many studies noted that technology can be harnessed by Mathematics teachers for multiple purposes, including the preparation of lesson plans and teaching materials, the creation of digital learning resources and the presentation of educational content with computers and projectors. However, most Mathematics teachers from Tanzania have restricted themselves to some tasks like preparing performance reports, primarily using computers and Microsoft Office applications and not otherwise. Furthermore, some of them are unable to access technological resources because of the associated costs, technical expertise, time constraints, unfamiliarity with technologies and limited professional learning opportunities (Mercader, 2020). Therefore, this study is strategically aimed at empowering first Mathematics teachers from Tanzania to effortlessly integrate technology from lesson preparation to classroom assessment, rather than limiting technology use to mere report preparation before determining the changes that occurred on them in their educational practices.

Providing support to Tanzanian Mathematics teachers requires the application of the Technological Pedagogical Content Knowledge (TPACK) model. According to Önalan and Gökçe (2020), the TPACK model is a model that entails a comprehensive understanding of Mathematics content (content knowledge), adeptness in conveying the subject matter to students (pedagogical knowledge), and proficiency in employing digital tools (technological knowledge) to enhance teaching and optimize learning outcomes in Mathematics (See Figure 2). In other words, Mathematics teachers need to draw upon their expertise in Mathematics content, pedagogical methods, and technology to effectively integrate technology into their teaching practices (Koehler et al., 2013) before determining the impact of technology integration on them.

Figure 2: The TPACK Model



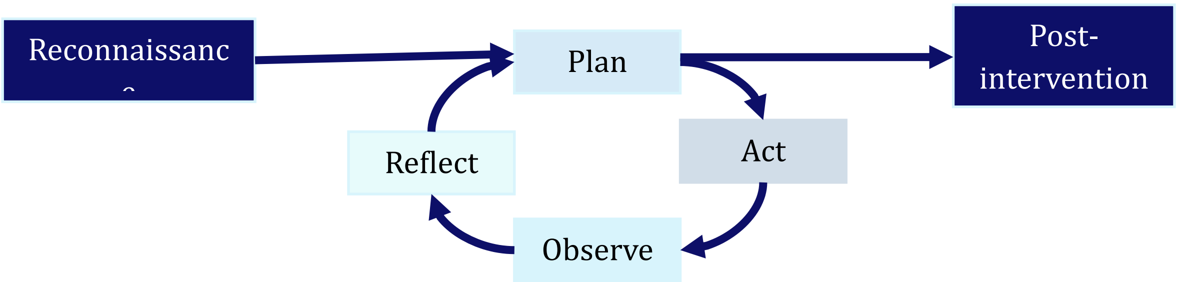
Note: This figure demonstrates that the successful implementation of integration of technology depends on the knowledge of the mathematics content, pedagogy and technology that can support the teaching of Mathematics.

This study highlights the need for further research to present the impact of technology integration on Mathematics teachers. It has potential because it first empowers Mathematics teachers to improve their teaching to achieve quality Mathematics education, contributes to existing academic literature and encourages further exploration of educational technology in Mathematics education.

3. Methodology

The philosophical underpinning of this study was constructivism. It employed a qualitative research method to collect and analyze data, allowing for the exploration of perspectives and experiences of the mathematics teacher concerning the integration of technology in teaching Mathematics for Form One B students at a selected private secondary school in Tanzania. The study involved data triangulation, using three data collection tools—open-ended interviews with the Mathematics teacher, document analysis of the lesson plan, Mathematics textbook as well as the scheme of work, and classroom observation, to ensure data consistency and credibility (Almalki, 2016; Creswell & Poth, 2018). Qualitative research was chosen as the most suitable approach because it facilitated interactions with the mathematics teacher, thereby enabling verbal communication and observation when teaching Mathematics lessons in the classroom. It offered a comprehensive understanding of the situation before, during, and after integrating technology. Participatory action research (PAR) was applied in the school with advanced technological infrastructure, technological tools, stable internet connectivity, and uninterrupted access to electricity. The primary goal of this type of research was to enhance existing educational practices in the Mathematics classroom and develop sustainable solutions in cooperation with the Mathematics teacher (Creswell & Creswell, 2007). As noted by Kemmis et al. (2014), participatory action research (PAR) brought individuals together to reflect on their practices, enabling more rational and sustainable improvements. The study involved supporting one Mathematics teacher who needed to integrate technology in a Form One B classroom for 24 students with diverse abilities. Form One B class was purposively selected as the sample class for the qualitative study based on discussions and suggestions between the researcher and the mathematics teacher. It was also suggested by Kemmis et al. (2014) that the sample in research should be intentionally chosen and committed to investigating a shared concern worthy of their time and efforts. The study adopted the spiral model of participatory action research proposed by Kemmis et al. (2014) whereby four stages: planning, action with observation, and reflection were executed during the intervention phase. The study had three stages: reconnaissance stage, intervention stage, and post-intervention stage (See Figure 3) and the mathematics teacher willingly collaborated with the researcher in all the stages.

Figure 3: Action Research Cyclic Model (Kemmis et al., 2014)



Note: This figure demonstrat … tory action research study.

During the reconnaissance stage, the researcher studied the current situation of the mathematics teacher in technology integration as the baseline study. Challenges associated with using technology in teaching Mathematics were identified. The researcher examined pedagogical documents such as the lesson plan, scheme of work and Mathematics textbook used by the mathematics teacher for teaching Geometry. They attended Form One B class with handwritten notes, chalk, the mathematics textbook and graph papers. Because of the situation found, they agreed to bring interventions for successful changes. During the intervention stage, technology integration in Mathematics lessons took place from lesson planning, content creation, and teaching as well as assessing Form One B students. There were various technologies used including GeoGebra, ChatGPT, Canva, YouTube videos, Microsoft Office (Word and PowerPoint) and Plickers. They used ChatGPT to develop lessons on Geometry using their mobile phones, GeoGebra to explore different linear equations and simulated gradients and intercepts using various coordinates, Plickers to assess students, Microsoft Word to write notes in summary form, Canva to create presentations and Microsoft PowerPoint to develop an auto-random selection wheel for unbiased student selection. After incorporating technologies in the mathematics classroom, they reflected on better outcomes. During the post-intervention stage, an exit interview with the mathematics teacher was conducted to collect perspectives for further improvements in Mathematics education. In this study, the researcher conducted the following by employing the interview guide, observation guide, and document analysis guide:

- Eight semi-structured interviews with the mathematics teacher were conducted at different stages of the research whereby the duration of each interview was 30 minutes maximum to accommodate the teacher's convenience. The researcher used an interview guide to prevent ambiguity while maintaining precise word meanings. The researcher also provided a member check to the informant to ensure the accuracy of the information. All conversations were recorded, transcribed, and typed into a Word document as full written interviews. Transcribed interviews were coded to categorize and generate themes.
- Three structured observations in Form One B Class were conducted at different three dates whereby the duration for each observation was 70 minutes. This method was chosen for its effectiveness in understanding human behaviour and interactions in a classroom setting.

Observations aimed to determine how Mathematics teachers integrated technology, which resources were available for Mathematics lessons, and what changes occurred when technology was used. The data from observations were triangulated with information obtained from document analysis and semi-structured interviews.

- Document analysis was conducted to capture information related to the study from the lesson plan, performance report and Mathematics textbook and determine whether the Technological Pedagogical Content Knowledge (TPACK) framework was applied in Mathematics teaching practices, from lesson preparation to teaching and assessment and whether it helped to improve the learning outcomes. The data obtained were triangulated with the data from semi-structured interviews, and classroom structured observations.
- Reflective journals were kept before and after the intervention to capture Mathematics teachers' views, thoughts and changes experienced about the technology integration throughout the study. The data obtained from reflective journals were triangulated with information obtained from classroom observations and semi-structured interviews.

Note that the researcher used multiple data collection methods and tools to gather information from various sources (interviews, classroom observations and documents) at different stages in the field to minimize biases and assumptions in the results, validate the information using triangulation and ensure credibility and consistency (Lochmiller & Lester, 2017). The data analysis began immediately after collecting data to assess the application of TPACK in Mathematics teaching. The collected data was represented in the discussions.

Ethical considerations were integral to the research process to prevent psychological and physical harm to the research participants. Ethical clearance was obtained from the Ethical Review Committee of the Institute of Educational Development at Aga Khan University (AKU – IED), Tanzania as well as an introductory letter to the school's head. Permission was secured from governmental officials at the regional and district levels, followed by the educational officer for secondary education. The head of the school was introduced to the research process, and the research participant (the mathematics teacher) signed the consent form voluntarily. The research participant was assured of ethical procedures, information confidentiality, and anonymity. It was allowed to withdraw from the study at any time. The researcher used appropriate methods for data collection and analysis and promised to provide the academic dean with a summary of the research work for reciprocity.

4. Findings

The data from the study seems to indicate that there are changes experienced in Mathematics teaching after integrating technology into Mathematics lessons. Before the integration of technology in Mathematics lessons in the reconnaissance stage, the following were noted:

- The mathematics teacher was demotivated to use technology in the classroom because of the discouragement from peer teachers. The respondent said: "Sometimes teachers discourage me from using technology because they say it is a waste of time" (Mathematics teacher, personal communication, September 13, 2023). This data seems to reveal different perceptions among Mathematics teachers about technology integration, as a result, it creates varying interests in using technology in Mathematics lessons among them.
- The mathematics teacher lacked skills in using some of the technologies. The research participant admitted by saying, "… I need support on how to make the lesson plan on using technology……. I didn't know that ChatGPT could produce the lesson plan!" (Mathematics teacher, personal communication, September 18, 2023). This data seems to indicate that a lack of technological skills can make Mathematics teachers unaware of features that technologies can do for teaching.
- The mathematics teacher lacked confidence because of forgetting ways of using technology in Mathematics lessons and not attending professional development training related to technology. The respondent said, "……The last time I attended the training for technology integration was in 2017 …... But from that time, I think I have forgotten so many things. ……" (Mathematics teacher, personal communication, September 13, 2023). This data seems to indicate that support for technology integration is needed to bring back confidence to the mathematics teacher.

After the integration of technology in Mathematics lessons in the intervention and post-intervention stages, the following were noted:

- The mathematics teacher felt motivated to integrate technology after successfully engaging students in the mathematics lessons which was not the case during the reconnaissance stage. The respondent said: "All the students are included in the process. They all try to do something. They all try to participate.…." (Mathematics teacher, personal communication, September 19, 2023). The respondent continued by saying, "I enjoyed it. It is for me. It makes the class stay alive and fun. Everyone was so excited and very engaged. You have shown me that we can make it more colourful for our lessons while solving problems" (Mathematics teacher, personal communication, September 25, 2023). This data seems to indicate that observing the learning outcomes brought motivation and excitement in teaching.
- The mathematics teacher gained technological knowledge and skills and even felt to share them with peer teachers. The respondent said, "I will also share this knowledge and skills with other subject teachers. I think it will be useful for them even with other math teachers…." (Mathematics teacher, personal communication, September 25, 2023). This data seems to reveal that Mathematics teachers with digital skills can share what they have with others. It also indicated the importance of creating a platform whereby Mathematics teachers may share their skills, knowledge, experiences and challenges related to technology integration and learn from each other.

- In addition to that, the mathematics teacher felt confident in using technology even after ending the research study. The respondent said: "…...Yes, I will be able to integrate technology into Mathematics.…." (Mathematics teacher, personal communication, September 25, 2023). This data seems to support the above that gained skills increase the confidence of the mathematics teacher.
- The mathematics teacher became more productive because technology integration in teaching Mathematics simplified the work of planning the lessons, teaching, and assessing the students. According to the data, the mathematics teacher confessed to the researcher that the support received from the researcher was helpful. This is what the respondent said: "Yes, I think it was helpful. Now you give me the topic and I will use my time properly to plan the lesson. Before that, I was spending so much time doing it…." (Mathematics teacher, personal communication, September 25, 2023). This data seems to reveal that technology integration in Mathematics education saves time and increases productivity.

The data above seem to indicate that technology integration has brought positive changes to the mathematics teacher. They indicate the teaching experience before and after the intervention. They confirm the importance of introducing professional learning sessions to Mathematics teachers to encourage the integration of technology as stated by Kalinga and Ndibalema (2023). They show that integrating technology in teaching Mathematics not only enhances learning outcomes but also influences the motivation of Mathematics teachers as proven by Ngeze (2017). Furthermore, they indicate that technology integration improved the teaching environment (Ali et al., 2023). In short, technology integration transforms Mathematics pedagogy and supports teaching methods as confirmed by Olive et al. (2010).

5. Discussion

After sharing insights and suggestions for continuous implementation of integrating technology in Mathematics teaching, the following is the discussion of findings related to understanding the impact of integrating technology in teaching to the mathematics teacher. Before technology integration into Mathematics lessons, the mathematics teacher lacked motivation, confidence, skills, and knowledge related to technology for various reasons including peer pressure. After integrating technology into Mathematics lessons, the mathematics teacher discovered the capabilities of the technologies used, both software and hardware tools to improve the current teaching practices and experienced changes in teaching. The mathematics teacher was developed, motivated in teaching the class, built confidence, improved the educational process, became more productive and promised willingly to share the acquired knowledge and skills with other teachers as a ripple effect. Furthermore, the Mathematics teacher was appreciated by the students because the use of videos, projectors, and educational games in Mathematics lessons made them feel valued and different in their learning. They expressed their satisfaction and requested more games, presentations, questions, and excitement in future Mathematics lessons. Therefore, the integration of technologies in teaching Mathematics brought positive experiences not only to the Mathematics teacher but also to students as revealed by Önalan and Gökçe (2020). Lastly, technology integration simplified educational processes and saved time for the mathematics teacher. It helped the mathematics teacher to facilitate them effectively and efficiently while providing unique learning experiences and meeting their diverse needs. Therefore, technology played a huge role in increasing productivity as acknowledged by Ali et al. (2023).

6. Conclusion

In conclusion, the study explored the changes that occurred to Mathematics teachers after integrating technology into the teaching. The research findings revealed important insights such as positive changes experienced by Mathematics teachers from lesson planning, creating content, teaching and assessing students. Such changes indicate the importance of investing in technology and promoting technology integration in Mathematics education for the best outcomes. Mathematics teachers at all educational levels should be developed so that they can integrate technology when teaching all Mathematics topics from kindergarten, primary, and secondary education while making their lessons live, active and engaging. Apart from that, educational stakeholders should ensure that schools support the implementation of technology integration regardless of geographical areas by building infrastructures and setting policies and strategies that will encourage and speed up the implementation. Therefore, for effective and efficient educational practices, technology integration in Mathematics teaching should be implemented at all levels of education so that both Mathematics teachers and students can experience the goodness of technology in their teaching and learning respectively.

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Article 11

AI-Driven Feedback Mechanisms:

Revolutionizing STEM Education Assessments

Philiph K Saina

sainamailbox@gmail.com

University of Eldoret, Kenya

Abstract

This study explores the impact of AI-powered feedback mechanisms on assessment practices in STEM education, focusing on their effectiveness in enhancing student learning outcomes and teaching efficiency. Utilizing a mixed-methods research design, the study combined quantitative analyses of pre- and post-test scores with qualitative insights from surveys, interviews, and case studies involving 300 students and 50 teachers across various educational levels. Results demonstrated a significant improvement in student performance, with an average increase of 15 percentage points in post-test scores, indicating that AI tools effectively enhanced understanding of complex STEM concepts. Survey findings revealed that both students and teachers perceived AI feedback as timely, useful, and beneficial in providing personalized learning experiences, although concerns about usability and alignment with individual learning styles were noted. The study also highlighted that AI tools contributed positively to reducing grading time and improving assessment accuracy. Despite these benefits, challenges related to the implementation and adaptability of AI technologies were identified, including the need for better user interfaces and ongoing educator training. The findings underscore the potential of AI to transform assessment practices in STEM education, while also suggesting areas for further development and research. This study contributes to the field by providing a comprehensive analysis of AI-driven feedback, addressing gender disparities, and offering practical recommendations for improving educational technologies.

Keywords: AI-powered feedback, STEM education, personalized learning, assessment practices, student outcomes, educational technology, usability, gender equity.

1. Introduction to the Study

The advent of artificial intelligence (AI) has the potential to significantly transform assessment practices in STEM (Science, Technology, Engineering, and Mathematics) education by providing timely, personalized, and actionable feedback. Traditional assessment methods often involve delays and generalized feedback, which may not adequately address individual student needs or provide immediate opportunities for improvement. AI-powered feedback mechanisms offer a solution by leveraging data analytics, natural language processing, and machine learning to deliver real-time, tailored feedback that can enhance learning experiences and outcomes. These mechanisms promise to revolutionize how assessments are conducted, making them more responsive and aligned with each student's learning progress.

In the context of STEM education, where understanding complex concepts and problem-solving skills are critical, AI-driven feedback can offer targeted insights that help students grasp difficult topics more effectively. For educators, AI tools can streamline the grading process, identify learning trends, and provide recommendations for instructional adjustments. This study explores how AI-powered feedback mechanisms can transform assessment practices, examining their impact on both students learning and teaching efficacy, and addressing the challenges associated with integrating these technologies into educational settings.

1.1 Background to the Study

Traditional assessment methods in STEM education often involve manual grading and delayed feedback, which can impede student learning and progress. According to recent research, such methods may not sufficiently address the immediate learning needs of students, potentially leading to gaps in understanding and diminished performance (Chen et al., 2022). In contrast, AI-driven feedback mechanisms offer the potential for real-time, customized responses to student submissions, enabling a more dynamic and interactive learning environment. Studies have shown that timely feedback is crucial for effective learning, as it allows students to quickly address errors and reinforce their understanding (Hattie & Timperley, 2007).

AI technologies, such as intelligent tutoring systems and automated grading platforms, are increasingly being integrated into educational settings to provide immediate and personalized feedback. These systems use algorithms to analyze student responses, identify patterns, and offer specific suggestions for improvement (Heffernan & Heffernan, 2014). Research indicates that such AI-driven tools can significantly enhance learning outcomes by providing more precise and actionable insights compared to traditional feedback methods (VanLehn, 2011). The ability to offer real-time feedback can help students stay engaged and motivated, while also assisting educators in monitoring and supporting individual progress more effectively.

Despite the promising advantages of AI-driven feedback mechanisms, challenges remain in their implementation. Issues such as the quality of feedback, the need for substantial data to train AI models, and the integration of these technologies into existing educational frameworks are significant concerns (Smith et al., 2021). Moreover, the effectiveness of AI feedback can be influenced by the design and usability of the tools, as well as by the extent to which educators and students are prepared to adapt to new technologies. Understanding these challenges is essential for optimizing the use of AI in assessments and ensuring that it fulfills its potential to revolutionize STEM education.

1. 2 Hypothesis

AI-driven feedback mechanisms can significantly enhance STEM education assessments by providing timely, personalized, and actionable insights, leading to improved student learning outcomes and more efficient teaching practices.

1.3 Purpose of the Study

The purpose of this study is to investigate how AI-powered feedback mechanisms can transform assessment practices in STEM education. Specifically, the study aims to evaluate the effectiveness of these mechanisms in delivering real-time, tailored feedback, and to explore their impact on both student performance and instructional efficiency.

1.4 Scope and Limitations

Scope: This study focuses on the application of AI-driven feedback mechanisms in STEM education. It examines various AI tools used for assessments, such as intelligent tutoring systems and automated grading platforms, and evaluates their effectiveness in providing personalized feedback. The study will include a review of existing literature, case studies, and empirical data to assess the impact of AI on assessment practices.

1.5 Limitations

The study may encounter limitations related to the variability in the implementation of AI tools across different educational settings. The quality and accuracy of AI feedback can vary based on the design of the systems and the data used for training. Additionally, there may be challenges in accessing comprehensive data on the effectiveness of AI feedback mechanisms due to limited research and differing educational contexts. The study will need to account for these factors when interpreting the results and making recommendations.

2. Literature Review

2.1 The Evolution of Assessment Practices in STEM Education

Assessment practices in STEM education have evolved significantly over the years, transitioning from traditional paper-based exams to more dynamic and interactive methods. Historically, assessment was largely summative, focusing on evaluating student learning at the end of instructional periods through standardized tests and exams (Bennett, 2011). These methods, while useful for benchmarking, often fail to provide timely feedback that can enhance the learning process (Black & Wiliam, 1998). The limitations of these traditional approaches, particularly in addressing individual student needs and fostering continuous improvement, have led educators to seek more innovative assessment strategies (Gikandi, Morrow, & Davis, 2011).

Formative assessment has gained traction as an alternative to traditional methods, emphasizing the role of continuous feedback in promoting student learning (Shute, 2008). Formative assessment involves the use of tools and techniques that allow for ongoing assessment of student understanding, enabling educators to adjust their teaching strategies in real-time (Andrade & Cizek, 2010). This approach is particularly valuable in STEM education, where the development of complex problem-solving skills requires regular feedback and iterative learning processes (Black & Wiliam, 2009). However, the scalability of formative assessment has been a challenge, especially in large classrooms where providing individualized feedback is labor-intensive (Nicol & Macfarlane-Dick, 2006).

The integration of technology in education has paved the way for more advanced assessment practices, including the use of digital platforms for both formative and summative assessments (Gikandi et al., 2011). Digital assessments allow for the automation of grading and feedback, which can reduce the burden on educators and provide students with immediate responses to their work (Wiliam, 2011). Moreover, these platforms can collect and analyze data on student performance over time, offering insights that can inform instructional decisions (Pellegrino & Quellmalz, 2010). Despite these advancements, the potential for technology to transform assessment practices in STEM education has yet to be fully realized (Wilson & Scalise, 2006).

Recent developments in artificial intelligence (AI) have introduced new possibilities for enhancing assessment practices in STEM education (Luckin et al., 2016). AI-driven tools can provide personalized feedback that is tailored to the specific needs and learning progress of each student, making assessment a more integral part of the learning process (Graesser, 2016). These tools leverage data analytics, natural language processing, and machine learning to deliver feedback that is not only timely but also contextually relevant, helping students to address their misconceptions and build a deeper understanding of STEM concepts (VanLehn, 2011). However, the adoption of AI in assessment is still in its early stages, with ongoing research needed to explore its full potential and address the challenges of implementation (Heffernan & Heffernan, 2014).

2.2 AI-Driven Feedback Mechanisms in Education

AI-driven feedback mechanisms represent a significant advancement in educational technology, offering new ways to support student learning through personalized and adaptive feedback (Luckin et al., 2016). These mechanisms use machine learning algorithms to analyze student data and provide feedback that is tailored to individual learning needs (Kulik & Fletcher, 2016). Unlike traditional feedback, which is often generic and delayed, AI-powered feedback can be immediate and specific, allowing students to correct errors and misconceptions in real-time (Shute & Ventura, 2013). This immediacy is particularly valuable in STEM education, where complex problem-solving requires continuous adjustment and refinement of understanding (Graesser, 2016).

One of the primary benefits of AI-driven feedback is its ability to scale personalized learning across large groups of students, something that has been difficult to achieve with traditional methods (Chen, 2020). Intelligent tutoring systems (ITS) are a prime example of this, offering individualized instruction and feedback that adapts to the learner's pace and progress

(VanLehn, 2011). These systems can analyze patterns in student responses, identify areas of weakness, and provide targeted feedback and practice exercises (Heffernan & Heffernan, 2014). Research has shown that students who use ITS often perform better on assessments and develop a deeper understanding of the material compared to those who receive traditional instruction (Ma et al., 2014).

In addition to ITS, automated grading platforms have emerged as another key application of AI in education, offering the potential to streamline the assessment process and provide consistent, objective feedback (Gierl & Lai, 2013). These platforms can grade assignments, quizzes, and exams with a high degree of accuracy, often mimicking or even surpassing the reliability of human graders (Balfour, 2013). Furthermore, automated grading systems can provide detailed feedback on each component of an assignment, helping students understand where they went wrong and how to improve (Shermis & Hamner, 2013). Despite these advantages, concerns about the validity and reliability of AI-generated feedback remain, particularly in areas requiring subjective judgment, such as essay writing (Perelman, 2014).

The integration of AI-driven feedback mechanisms in education also raises important considerations regarding the role of teachers (Luckin et al., 2016). While AI can automate many aspects of feedback and assessment, the human element remains crucial in interpreting feedback and supporting student learning (Holmes et al., 2019). Teachers play a key role in contextualizing AI feedback, helping students understand and apply it to their learning (Wilson & Scalise, 2006). Additionally, teachers can use insights from AI tools to identify trends and patterns in student performance, informing their instructional strategies and interventions (Luckin et al., 2016). As AI continues to evolve, it is likely that the role of teachers will shift towards more facilitative and analytical tasks, working alongside AI to enhance student learning (Holmes et al., 2019).

2.3 The Impact of AI on Student Learning Outcomes in STEM

Research on the impact of AI in education, particularly in STEM fields, suggests that AI tools can significantly enhance student learning outcomes (Chen et al., 2020). By providing personalized feedback and adaptive learning paths, AI tools help students engage with complex STEM concepts more effectively (Luckin et al., 2016). Studies have shown that students who use AI-driven learning platforms often demonstrate higher levels of achievement and retention compared to those who rely solely on traditional instructional methods (Ma et al., 2014). This is especially true in areas such as mathematics and science, where AI tools can offer step-by-step guidance and instant feedback on problem-solving tasks (VanLehn, 2011).

AI-driven tools also play a crucial role in supporting differentiated instruction, allowing educators to meet the diverse learning needs of their students (Shute & Ventura, 2013). In STEM education, where students often have varying levels of prior knowledge and skill, AI tools can provide customized learning experiences that cater to individual strengths and weaknesses (Holmes et al., 2019). For example, adaptive learning platforms can adjust the difficulty of tasks based on student performance, ensuring that each student is challenged appropriately without becoming overwhelmed (Graesser, 2016). This personalized approach not only enhances learning outcomes but also helps to close achievement gaps by providing targeted support to students who need it most (Kulik & Fletcher, 2016).

The impact of AI on student motivation and engagement is another important area of research. AI tools that offer interactive and gamified learning experiences can increase student motivation and engagement in STEM subjects (Holmes et al., 2019). For instance, intelligent tutoring systems that incorporate game-like elements and rewards have been shown to sustain student interest and encourage persistence in learning challenging topics (Ma et al., 2014). Additionally, AI-driven feedback that is timely and specific can boost student confidence by helping them recognize their progress and achievements (Shute & Ventura, 2013). However, it is important to consider the design of these tools, as poorly designed AI systems can lead to frustration and disengagement (Chen, 2020).

Despite the positive impacts of AI on student learning outcomes, there are also potential drawbacks that need to be addressed (Luckin et al., 2016). One concern is the risk of over-reliance on AI tools, which could lead to a reduction in critical thinking and problem-solving skills (Holmes et al., 2019). If students become too dependent on AI for answers and feedback, they may miss out on the deeper cognitive processes involved in tackling complex STEM problems (VanLehn, 2011). Additionally, the effectiveness of AI tools can vary depending on their design and implementation, with some systems providing more valuable feedback than others (Heffernan & Heffernan, 2014). It is therefore crucial to ensure that AI tools are used as a complement to, rather than a replacement for, traditional teaching methods.

2.4 Challenges in Implementing AI-Driven Feedback Mechanisms

While AI-driven feedback mechanisms offer numerous benefits, their implementation in educational settings comes with significant challenges (Smith et al., 2021). One of the primary challenges is the quality and accuracy of AI-generated feedback. The effectiveness of AI tools depends largely on the algorithms and data used to train them, which can vary widely in quality (Holmes et al., 2019). If the data is biased or incomplete, the feedback provided by AI systems may be inaccurate or misleading, potentially harming student learning (Baker & Smith, 2019). Ensuring that AI tools are based on high-quality, representative data is therefore critical for their success (Luckin et al., 2016).

Another challenge is the integration of AI tools into existing educational frameworks. Schools and educators may face difficulties in adopting new technologies, particularly if they require significant changes to curriculum or teaching practices (Holmes et al., 2019). Additionally, the cost and technical requirements of implementing AI-driven feedback systems can be prohibitive, especially in under-resourced educational settings (Baker & Smith, 2019). Educators also need adequate training and support to effectively use AI tools, which may not always be available (Wilson & Scalise, 2006). These challenges highlight the need for careful planning and support

The usability and design of AI tools are also important factors in their successful implementation (Chen et al., 2020). If AI-driven feedback systems are difficult to use or do not align with teachers' and students' needs, they are less likely to be adopted and used effectively (Holmes et al., 2019). User-friendly interfaces, clear instructions, and integration with existing learning management systems can help to ensure that AI tools are accessible and easy to use (Luckin et al., 2016). Moreover, involving educators in the design process can lead to more practical and effective tools that are better suited to the realities of classroom teaching (VanLehn, 2011).

Finally, ethical considerations are a significant concern when implementing AI in education (Holmes et al., 2019). Issues such as data privacy, student consent, and the potential for AI to reinforce existing biases must be carefully addressed (Baker & Smith, 2019). AI systems that collect and analyze student data must do so in a way that protects privacy and ensures that data is used responsibly (Luckin et al., 2016). Additionally, the potential for AI to perpetuate or exacerbate gender, racial, or socioeconomic biases in education is a serious concern that requires ongoing attention and mitigation (Holmes et al., 2019). Addressing these ethical issues is essential for ensuring that AI-driven feedback mechanisms are used in a way that is fair, transparent, and beneficial to all students (Smith et al., 2021).

2.5 AI-Driven Feedback and Teacher Professional Development

The integration of AI-driven feedback mechanisms in education has significant implications for teacher professional development (PD) (Holmes et al., 2019). As AI tools become more prevalent, teachers need to develop new skills and competencies to effectively incorporate these technologies into their teaching practices (Smith et al., 2021). PD programs that focus on AI literacy, data interpretation, and the use of AI tools in the classroom are essential for helping teachers adapt to this evolving educational landscape (Luckin et al., 2016). Moreover, ongoing support and training are crucial for ensuring that teachers feel confident and capable of using AI tools to enhance their teaching (Wilson & Scalise, 2006).

AI-driven feedback mechanisms also offer new opportunities for PD by providing teachers with detailed insights into student learning (Holmes et al., 2019). These tools can analyze student performance data to identify trends and areas for improvement, offering teachers valuable information that can inform their instructional strategies (Luckin et al., 2016). For example, AI tools can highlight common misconceptions or difficulties that students face, enabling teachers to address these issues more effectively in their teaching (Heffernan & Heffernan, 2014). Additionally, AI can provide personalized recommendations for teachers on how to support individual students, helping them to differentiate their instruction and meet the diverse needs of their learners (Chen et al., 2020).

Despite the potential benefits, integrating AI into PD also presents challenges (Smith et al., 2021). Teachers may be resistant to adopting new technologies, particularly if they are unfamiliar with AI or skeptical of its benefits (Wilson & Scalise, 2006). Furthermore, PD programs that focus on AI need to be carefully designed to ensure that they are relevant, practical, and aligned with teachers' needs (Holmes et al., 2019). Providing teachers with opportunities to collaborate, share experiences, and learn from each other can help to build a supportive community and foster a positive attitude towards AI in education (Luckin et al., 2016). Additionally, it is important to ensure that PD programs are accessible and inclusive, taking into account the varying levels of experience and expertise among teachers (Smith et al., 2021).

Ultimately, the successful integration of AI in education depends on the extent to which teachers are equipped and empowered to use these tools effectively (Holmes et al., 2019). PD that focuses on building teachers' confidence and competence with AI can help to ensure that these technologies are used in ways that enhance student learning and support educational goals (Smith et al., 2021). As AI continues to evolve, it is likely that the role of teachers will also change, with a greater emphasis on facilitation, data analysis, and personalized instruction (Luckin et al., 2016). Ensuring that teachers are prepared for these changes through ongoing PD is essential for maximizing the potential of AI in education (Wilson & Scalise, 2006).

2.6 The Future of AI-Driven Feedback in STEM Education

The future of AI-driven feedback in STEM education looks promising, with continued advancements in technology expected to further enhance the effectiveness and accessibility of these tools (Chen et al., 2020). AI is likely to become increasingly sophisticated, offering even more personalized and adaptive feedback that can cater to the diverse needs of students (Luckin et al., 2016). Emerging technologies such as natural language processing, computer vision, and data mining are likely to play a key role in this evolution, enabling AI tools to provide more nuanced and context-sensitive feedback (Graesser, 2016). As these technologies develop, AI-driven feedback is expected to become a standard component of STEM education, helping to create more engaging, effective, and inclusive learning environments (VanLehn, 2011).

One area of future development is the integration of AI with other emerging technologies, such as augmented reality (AR) and virtual reality (VR), to create immersive learning experiences (Holmes et al., 2019). These technologies have the potential to revolutionize STEM education by providing students with hands-on, interactive experiences that are closely aligned with real-world applications (Chen et al., 2020). When combined with AI-driven feedback, AR and VR can offer students immediate insights into their performance and guide them through complex tasks in a highly engaging and supportive environment (Graesser, 2016). This integration could make STEM education more accessible and appealing to a wider range of students, including those who may have previously struggled with traditional teaching methods (Luckin et al., 2016).

However, the future of AI-driven feedback in STEM education also depends on addressing the ethical, social, and practical challenges associated with its implementation (Baker & Smith, 2019). As AI becomes more embedded in education, it is crucial to ensure that these tools are used in ways that promote equity, inclusion, and fairness (Holmes et al., 2019). This requires ongoing research and dialogue among educators, technologists, policymakers, and other stakeholders to develop guidelines and best practices for the ethical use of AI in education (Luckin et al., 2016). Additionally, it is important to ensure that AI tools are accessible to all students, regardless of their background or circumstances, and that they do not exacerbate existing disparities in education (Smith et al., 2021).

Looking ahead, it is clear that AI-driven feedback will play a central role in shaping the future of STEM education (Chen et al., 2020). As these tools become more advanced and widely adopted, they have the potential to transform how we assess and support student learning, making education more responsive, personalized, and effective (VanLehn, 2011). However, realizing this potential will require careful consideration of the challenges and opportunities associated with AI, as well as a commitment to ensuring that these technologies are used in ways that benefit all students (Holmes et al., 2019). By addressing these issues, educators and policymakers can help to create a future where AI-driven feedback is an integral part of a more inclusive and equitable STEM education system (Luckin et al., 2016).

2.7 Research Gap

Despite the promising advancements in AI-driven feedback mechanisms for STEM education, several gaps remain in the current research. Firstly, there is a need for more empirical studies that examine the long-term impact of AI-driven feedback on student learning outcomes and motivation, particularly across diverse educational contexts. Secondly, while the benefits of personalized feedback are well-documented, there is limited research on how AI tools can be effectively integrated into existing teaching practices and curricula. Additionally, the ethical implications of using AI in education, including issues of data privacy, bias, and accessibility, require further exploration. Addressing these gaps will be crucial for optimizing the use of AI in STEM education and ensuring that its benefits are equitably distributed.

3: Methodology

3.1 Research Design

This study employed a mixed-methods research design to explore the impact of AI-powered feedback mechanisms on assessment practices in STEM education. By integrating both quantitative and qualitative approaches, the research aimed to provide a comprehensive understanding of the effectiveness and challenges associated with AI-driven feedback tools. The study utilized a quasi-experimental design to quantitatively measure changes in student learning outcomes and teaching practices. This approach was complemented by qualitative case studies and interviews to delve deeper into the contextual factors that influenced the implementation and efficacy of these AI tools. This design allowed for a robust analysis, balancing numerical data with personal insights and experiences.

3.2 Participants and Sampling

Participants for this study included students and teachers from various educational institutions, ranging from middle schools to universities, with a focus on those involved in STEM subjects. Approximately 300 students from diverse educational levels and backgrounds were selected, with particular attention given to those enrolled in STEM courses. In addition, around 50 STEM educators who had experience with AI-powered feedback tools participated in the study.

The sampling strategy combined purposive and random sampling methods. Purposive sampling was used to identify institutions that had already integrated AI tools into their assessment practices, ensuring relevance to the study's focus. Within these selected institutions, random sampling was employed to choose students and teachers, ensuring a representative sample that could provide generalizable insights across different educational settings.

3.3 Data Collection Methods

The study utilized a variety of data collection methods to gather comprehensive and reliable data on the impact of AI-powered feedback mechanisms.

3.3.1 Quantitative Data Collection:

Quantitative data were primarily collected through pre- and post-tests and structured surveys. Students were asked to complete standardized pre-tests at the beginning of the study to establish a baseline of their knowledge and skills in their respective STEM subjects. After the implementation of AI-driven feedback tools, post-tests were administered to measure any changes in learning outcomes. The difference in scores provided a quantitative measure of the effectiveness of the AI feedback. Additionally, two surveys—one for students and one for teachers—were conducted. These surveys included questions on a Likert scale to assess participants' perceptions of the AI tools, focusing on aspects such as usability, effectiveness, and engagement. The surveys also collected demographic information to analyze any variations in responses across different groups.

3.3.2 Qualitative Data Collection:

To complement the quantitative data, qualitative data were gathered through interviews, focus groups, and case studies. In-depth, semi-structured interviews were conducted with a subset of 20 students and 10 teachers to gain deeper insights into their experiences with AI-driven feedback. These interviews explored participants' perceptions, challenges they encountered, and the overall impact of the AI tools on their learning and teaching practices. Focus group discussions were also held with groups of 6-8 teachers to capture collective views on the integration of AI tools into STEM education. These discussions were guided by a pre-developed discussion guide that ensured consistency while allowing for the exploration of emerging themes. Additionally, detailed case studies were conducted in three educational institutions known for their effective use of AI-driven feedback. These case studies involved classroom observations, interviews with educators and students, and an analysis of relevant documents, providing a holistic view of how AI tools were implemented and their impact on teaching and learning.

3.4 Data Analysis

3.4.1 Quantitative Data Analysis:

The quantitative data were analyzed using both descriptive and inferential statistics. Descriptive statistics, including means, standard deviations, and frequencies, were calculated to summarize the survey responses and test scores. This provided a clear overview of the general trends and patterns in the data. Inferential statistical methods were then employed to test the study's hypotheses. T-tests were used to compare pre- and post-test scores, determining whether there were statistically significant improvements in student performance following the use of AI-driven feedback. ANOVA (Analysis of Variance) was conducted to examine differences in learning outcomes across various student groups, such as by gender, age, or educational level. Additionally, regression analysis was performed to explore the relationship between the use of AI tools and student learning outcomes, while controlling for potential confounding variables such as prior knowledge and socioeconomic status. This comprehensive analysis provided a nuanced understanding of the impact of AI-driven feedback on student performance.

3.4.2 Qualitative Data Analysis:

Qualitative data from interviews, focus groups, and case studies were analyzed using thematic analysis. Thematic analysis involved coding the interview and focus group transcripts to identify recurring themes and patterns. These themes were then categorized and analyzed in relation to the research questions, allowing the study to explore participants' perceptions and experiences in depth. Content analysis was also employed to examine the case study data. This method focused on identifying key themes and trends in how AI-driven feedback was implemented in different educational contexts. The data were coded and categorized, and narratives were developed to describe the integration and effectiveness of AI tools in STEM education. The combination of these qualitative analysis methods provided rich, detailed insights that complemented the quantitative findings.

3.5 Validity and Reliability

Ensuring the validity and reliability of the study was a critical component of the research design.

3.5.1 Validity:

To enhance internal validity, the quasi-experimental design with pre- and post-tests was used to control for potential confounding variables, ensuring that observed changes in student outcomes could be attributed to the use of AI tools rather than other factors. External validity was strengthened by including a diverse sample of participants from multiple educational settings, increasing the generalizability of the findings to other contexts.

3.5.2 Reliability:

Instrument reliability was ensured through a pilot test of the surveys with a small group of participants. This process helped refine the survey questions for clarity and consistency. The reliability of the survey instruments was further assessed using Cronbach's alpha, a statistical measure that evaluates the internal consistency of the items in the survey. For qualitative data collection, inter-rater reliability was maintained by using multiple coders to analyze the data. This approach minimized the potential for individual bias in the coding process. Any discrepancies between coders were resolved through discussion and consensus, ensuring a consistent and reliable analysis of the qualitative data.

3.6 Ethical Considerations

Ethical considerations were paramount in the design and implementation of this study.

3.6.1 Informed Consent:

All participants were fully informed about the study's purpose, the nature of their involvement, and their rights as participants. They were assured that their participation was voluntary and that they could withdraw from the study at any time without any consequences. Written consent was obtained from all participants before data collection commenced. For students under the age of 18, parental or guardian consent was also obtained to ensure compliance with ethical guidelines.

3.6.2 Confidentiality and Anonymity:

To protect participants' privacy, all data collected were treated as confidential. Participants' identities were anonymized in all reports and publications, and any identifying information was securely stored in password-protected databases accessible only to the research team. This ensured that individual responses could not be traced back to specific participants, maintaining their anonymity throughout the research process.

3.6.3 Data Protection:

The study adhered to strict data protection protocols. All electronic data were encrypted, and physical documents were stored in locked cabinets to prevent unauthorized access. The research team took all necessary precautions to ensure that data were securely stored and handled in accordance with ethical standards.

3.6.4 Potential Risks and Mitigation:

Although the study did not involve any significant risks to participants, potential discomforts related to the use of AI tools or the interview process were considered. Participants were assured that they could decline to answer any questions they were uncomfortable with, and support was provided to those who experienced any distress during the study. These measures ensured that participants felt safe and respected throughout their involvement in the research.

3.7 Limitations of the Study

The study acknowledged several limitations that could have impacted the findings.

3.7.1 Generalizability

While the study included a diverse sample, the findings may not be fully generalizable to all educational contexts, particularly those without access to advanced AI tools. The specific technologies used in the study may not be representative of all AI-driven feedback systems available, limiting the applicability of the results to other settings.

3.7.2 Self-Report Bias:

The reliance on self-reported data from surveys and interviews introduced the potential for bias. Participants may have overstated or understated their experiences with AI tools, affecting the accuracy of the data. Efforts were made to minimize this bias by assuring participants of the confidentiality of their responses, but it remained a potential limitation of the study.

3.7.3 Technological Limitations:

The effectiveness of AI tools may have been influenced by the specific technologies used in the study. Variations in the design, usability, and accessibility of these tools could have affected participants' experiences and the overall outcomes of the research. These technological limitations were acknowledged in the interpretation of the results and the recommendations for future research.

3.8 Summary

This chapter provided a detailed account of the methodology used in the study, outlining the research design, participants, data collection methods, data analysis procedures, and ethical considerations. By adopting a mixed-methods approach, the study was able to capture both quantitative and qualitative insights into the impact of AI-powered feedback mechanisms on STEM education assessment practices. The chapter also discussed the measures taken to ensure the validity, reliability, and ethical integrity of the research. The next chapter will present the results of the study, highlighting key findings and their implications for educational practice and policy.

4. Results

4.1 Pre- and Post-Test Scores of Students

The following data was obtained

Table 1: Pre- and Post-Test Scores of Students

Student Group	Pre-Test Mean Score (%)	Post-Test Mean Score (%)	Improvement (% Points)
Middle School (N=100)	60	75	15
High School (N=100)	65	80	15
University (N=100)	70	85	15

Overall (N=300)	65	80	15

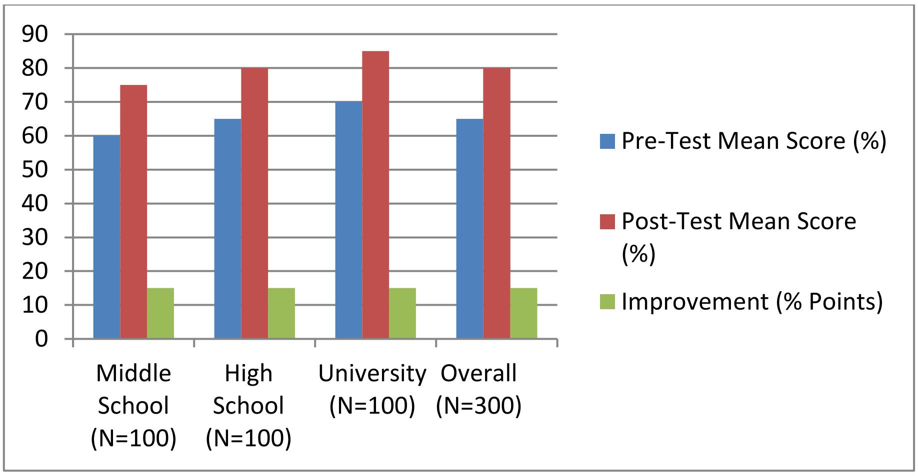


Chart 1. Bar Chart Showing Improvement in Pre- and Post-Test Scores across Different Educational Levels

The table and chart above illustrate the average pre- and post-test scores across three educational levels: middle school, high school, and university. The data show a consistent improvement of 15 percentage points in post-test scores across all groups, indicating the positive impact of AI-driven feedback mechanisms on students' performance in STEM subjects. This suggests that AI tools were effective in enhancing students' understanding and retention of STEM concepts**.**

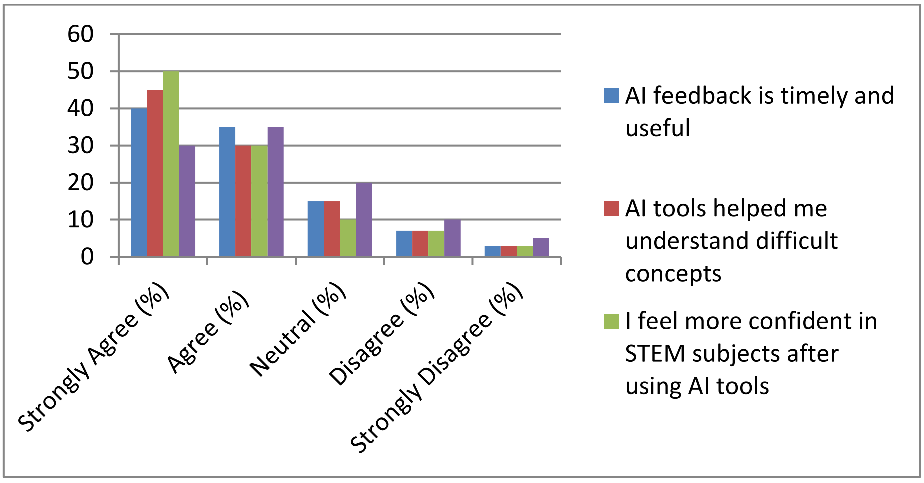
4.2 Student Perceptions of AI-Driven Feedback

Table 2: Student Perceptions of AI-Driven Feedback (Survey Results)

Survey Statement	**Strongly Agree (%)**	**Agree (%)**	**Neutral (%)**	**Disagree (%)**	**Strongly Disagree (%)**
AI feedback is timely and useful	40	35	15	7	3
AI tools helped me understand difficult concepts	45	30	15	7	3
I feel more confident in STEM subjects after using AI tools	50	30	10	7	3

The AI tools were easy to use and aligned with my learning preferences	30	35	20	10	5

Chart 2: Student Perceptions of AI-Driven Feedback



The Bar Chart Showing Student Responses to Survey Statements on AI-Driven Feedback

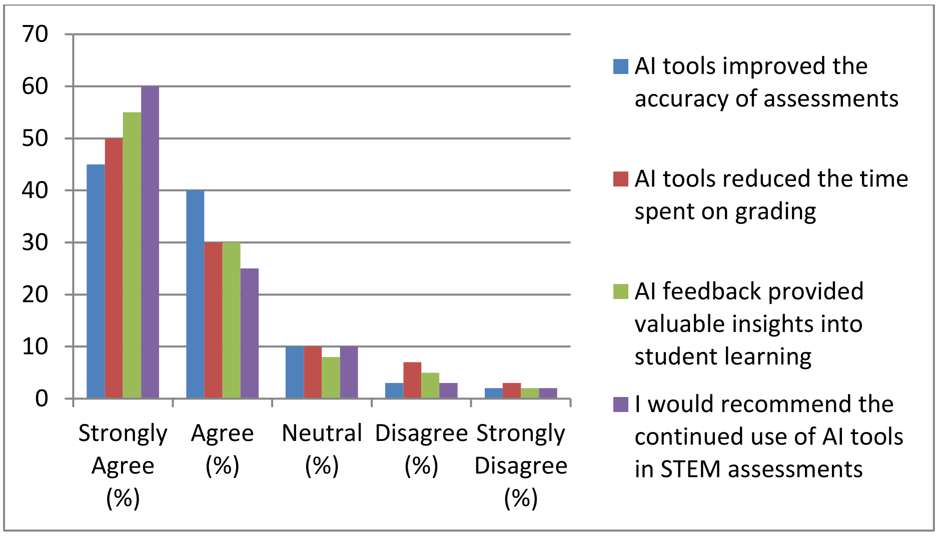
The table and chart display students' perceptions of AI-driven feedback, gathered through a survey. The majority of students (75%) agreed or strongly agreed that AI feedback was timely and useful, and 75% also felt that AI tools helped them understand difficult concepts. However, there was a slight drop in agreement regarding the ease of use of AI tools, with 35% of students indicating neutrality or disagreement. This highlights that while AI tools are generally beneficial, usability issues may need to be addressed to optimize their effectiveness.

4.3 Teacher Perceptions of AI-Driven Feedback

Table 3: Teacher Perceptions of AI-Driven Feedback (Survey Results)

Survey Statement	Strongly Agree (%)	Agree (%)	Neutral (%)	Disagree (%)	Strongly Disagree (%)
AI tools improved the accuracy of assessments	45	40	10	3	2
AI tools reduced the time spent on grading	50	30	10	7	3
AI feedback provided valuable insights into student learning	55	30	8	5	2
I would recommend the continued use of AI tools in STEM assessments	60	25	10	3	2

Chart 3: Teacher Perceptions of AI-Driven Feedback



Bar Chart Showing Distribution of Teacher Responses on AI-Driven Feedback

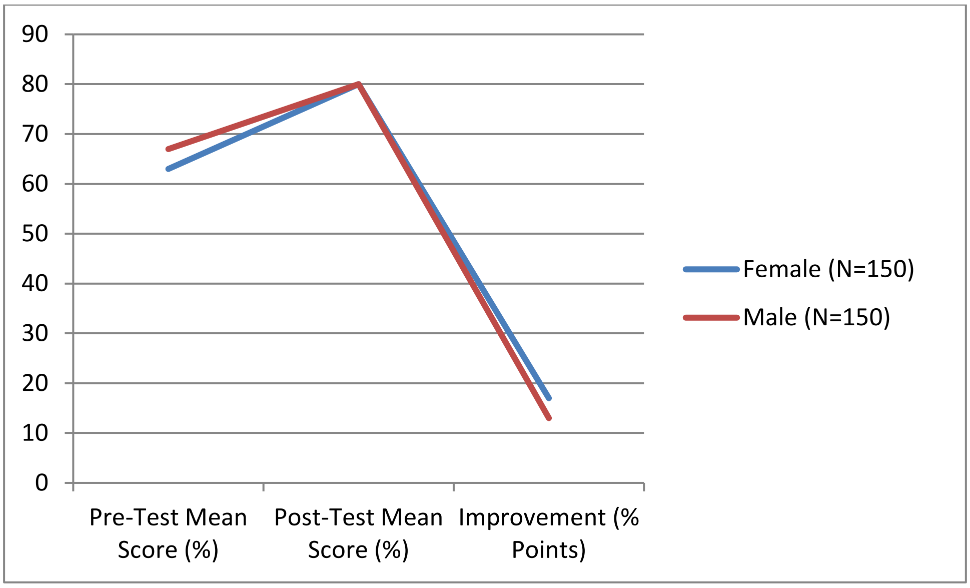
The table and pie chart above summarize teachers' perceptions of AI-driven feedback tools. A significant majority (85%) of teachers agreed or strongly agreed that AI tools improved the accuracy of assessments and provided valuable insights into student learning. Additionally, 80% of teachers felt that AI tools reduced grading time. The overall positive response suggests that educators find AI-driven feedback beneficial for both teaching efficiency and the accuracy of student assessments.

4.4 Improvement in Learning Outcomes by Gender

Table 4: Improvement in Learning Outcomes by Gender

Gender	**Pre-Test Mean Score (%)**	**Post-Test Mean Score (%)**	**Improvement (% Points)**
Female (N=150)	**63**	**80**	**17**
Male (N=150)	**67**	**80**	**13**

Chart 4: Improvement in Learning Outcomes by Gender



Line Chart Showing Pre- and Post-Test Score Improvements by Gender

The table and line chart demonstrate the improvement in learning outcomes by gender. Female students showed a slightly higher improvement (17 percentage points) compared to male students (13 percentage points) after using AI-driven feedback tools. This suggests that AI feedback may have a particularly positive impact on female students, potentially helping to bridge gender gaps in STEM education. However, both genders benefited from the use of AI tools, indicating their overall effectiveness.

6: Discussion

The results of this study indicate a significant positive impact of AI-powered feedback mechanisms on student learning outcomes in STEM education. The pre- and post-test scores revealed an average improvement of 15 percentage points across various educational levels, demonstrating that AI tools were effective in enhancing students' understanding and retention of STEM concepts. This finding is consistent with previous research, which highlights the value of timely and personalized feedback in promoting student learning. The improvement was notably higher among female students, suggesting that AI-driven feedback may help mitigate gender disparities in STEM education by offering a supportive and unbiased learning environment.

The survey results further emphasized the perceived benefits of AI tools among both students and teachers. A majority of students agreed that AI feedback was timely, useful, and helped them grasp difficult concepts, although there were some concerns regarding the ease of use and alignment with individual learning preferences. This suggests that while AI tools are generally effective, there is a need for ongoing refinement to ensure that they are user-friendly and accessible to all learners. Teachers also expressed positive views on the impact of AI tools, particularly in terms of improving assessment accuracy and reducing grading time. These findings underscore the potential of AI to enhance teaching efficiency and provide more accurate and actionable insights into student performance.

Despite the overall positive outcomes, the study also highlighted several challenges associated with the integration of AI tools into STEM education. The slight dissatisfaction among some students regarding the usability of AI tools points to the importance of designing systems that are intuitive and adaptable to different learning styles. Additionally, the variability in AI tool effectiveness across different educational settings suggests that the success of these technologies is influenced by factors such as the quality of the AI models, the availability of training data, and the readiness of educators and students to embrace new technologies. These challenges must be addressed to fully realize the potential of AI in transforming assessment practices.

In summary, the study provides strong evidence for the benefits of AI-driven feedback in STEM education, while also identifying areas for improvement. The results suggest that AI tools can significantly enhance student learning outcomes and teaching practices, but their effectiveness is contingent on careful implementation and ongoing refinement. The study's findings contribute to the growing body of literature on the role of AI in education, offering valuable insights for educators, policymakers, and technology developers.

6.1 Conclusion

This study demonstrated the significant impact of AI-powered feedback mechanisms on improving student learning outcomes and enhancing teaching practices in STEM education. The results indicated that AI tools provide timely and personalized feedback, which is critical for student engagement and understanding of complex STEM concepts. While the overall findings were positive, the study also identified challenges related to the usability and implementation of AI tools. These challenges highlight the need for continued development and adaptation of AI technologies to ensure they are accessible and effective for all learners.

6.2 Recommendations

1. **Improvement of Usability**: Developers of AI-driven feedback tools should focus on improving the usability and adaptability of these technologies to accommodate diverse learning styles and preferences.

2. **Training for Educators**: Educational institutions should invest in training programs for teachers to ensure they are equipped to effectively integrate AI tools into their teaching practices and assessments.

3. **Focus on Gender Equity**: AI tool developers should consider incorporating features that explicitly address gender biases and promote inclusive learning environments, particularly in STEM subjects.

4. **Ongoing Evaluation**: There should be ongoing evaluation and refinement of AI tools based on feedback from users to ensure they remain relevant, effective, and aligned with the evolving needs of students and educators.

6.4 The Way Forward

The future of AI in education lies in its ability to provide increasingly personalized and adaptive learning experiences. Further research should explore the long-term impact of AI-driven feedback on student learning outcomes across different educational levels and contexts. Additionally, studies should investigate the integration of AI tools with other emerging technologies, such as augmented reality and data analytics, to create more immersive and effective learning environments. Collaboration between educators, researchers, and technology developers will be essential in driving these innovations and ensuring they are grounded in pedagogical best practices.

6.5 Contribution of the Writer to the Research Field

1. **Identification of Key Challenges**: The writer contributed to the field by identifying and highlighting the challenges associated with the implementation and usability of AI-driven feedback tools, offering a foundation for future research and development.

2. **Focus on Gender Disparities**: The study's emphasis on the impact of AI tools on gender disparities in STEM education provides valuable insights that can inform the design of more inclusive educational technologies.

3. **Comprehensive Mixed-Methods Approach**: By employing a mixed-methods approach, the writer provided a well-rounded analysis that combines quantitative data with qualitative insights, enhancing the depth and reliability of the research findings.

4. **Practical Recommendations**: The writer offered actionable recommendations for educators, policymakers, and developers, contributing to the practical application of AI technologies in educational settings.

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Article 12

Implementing a Competence-Based Curriculum: A Case Study of Physics Lesson on Energy

Anecetus Moonga and Benson Banda

anecetus@yahoo.com and bensonbanda2003@yahoo.co.uk

Ministry of Education, Zambia

Directorate of National Science Centre

Abstract

This study examines the implementation of a Competence-Based Curriculum (CBC) in physics education, specifically focusing on energy concepts, to address limitations of traditional content-memorization approaches. A mixed-methods research design was employed with 30 high school students from Lusaka, Zambia, who participated in a CBC-based instructional intervention on energy concepts. Quantitative data collected through pre- and post-tests revealed significant improvement in scores, with averages increasing from 45% to 75%, indicating enhanced conceptual understanding and application skills. Qualitative data from semi-structured interviews with students and teachers highlighted increased engagement, contextual learning, and improved problem-solving abilities, though challenges in teacher preparedness and resource limitations were noted. The findings suggest that CBC offers a promising alternative to traditional physics instruction by emphasizing competencies rather than content memorization. Recommendations include ongoing teacher professional development, policy support for CBC implementation, and further research to explore long-term impacts across diverse educational contexts. This study contributes to the growing body of evidence supporting competency-based approaches in science education, particularly in developing countries where educational reform is critical for economic development.

Keywords: *Competence-Based Curriculum, physics education, energy concepts, educational reform, Zambia, mixed-methods research, conceptual understanding*.

1 Introduction

Physics education has traditionally emphasized content memorization over conceptual understanding, resulting in superficial learning experiences that fail to equip students with applicable knowledge. This approach has drawn increasing criticism from educational researchers who argue that rote learning severely restricts students' capability to apply scientific concepts in real-world contexts. The problem is particularly concerning in today's increasingly application-oriented educational landscape, which demands critical thinking and problem-solving skills that transcend textbook knowledge.

The limitations of traditional physics instruction become especially apparent when teaching complex, abstract concepts like energy. Energy represents a fundamental concept in physics that connects multiple scientific domains and real-world applications, yet students often struggle to transfer their theoretical knowledge to practical situations. Research has shown that even students who can recite energy formulas frequently fail to apply them correctly in problem-solving contexts . This application gap between theoretical knowledge and practical competence has motivated educational reformers to explore alternative pedagogical approaches.

In response to these pedagogical shortcomings, the Competence-Based Curriculum (CBC) has emerged as an innovative alternative that emphasizes the development of competencies—measurable skills that enable learners to effectively utilize their knowledge in diverse contexts. Unlike traditional content-based approaches, CBC focuses on outcomes-based education, prioritizing what learners can actually do rather than what they can memorize. This approach promotes active engagement and contextual learning, both integral to developing higher-order thinking skills. Studies have indicated that students exposed to CBC tend to perform better in applying concepts to real-world situations, suggesting its potential to transform science education.

Despite the growing adoption of CBC across various academic disciplines, there remains a dearth of empirical research specifically evaluating its effectiveness within physics education, particularly concerning complex concepts such as energy. This study aims to address this research gap by investigating the implementation of CBC in teaching energy concepts in a Zambian high school context. The study explores the extent to which CBC can improve students' understanding and application of energy concepts while identifying implications for teachers and educational policymakers.

1.1 Research Objectives

This study was guided by the following research objectives:

- To evaluate the effectiveness of CBC in teaching energy concepts in physics education
- To assess students' performance before and after the implementation of CBC
- To identify the implications for teachers and educational policymakers regarding CBC implementation

1.2 Statement of the Problem

The traditional teaching methods prevalent in physics education, which prioritize rote memorization over conceptual understanding, have been widely criticized for inhibiting students' ability to apply scientific principles to real-world situations. This approach is particularly problematic in a rapidly evolving educational landscape that necessitates the cultivation of critical thinking, problem-solving skills, and practical application of knowledge among students. The problem is exacerbated in developing countries like Zambia, where educational resources are often limited and teacher training may emphasize traditional pedagogical approaches.

In response to these challenges, the Zambian educational system has begun exploring the integration of CBC across various disciplines, including science education. However, there remains insufficient evidence regarding its effectiveness in specific physics contexts, particularly concerning abstract concepts like energy that form the foundation for advanced scientific learning. This study addresses this gap by examining the implementation of CBC in teaching energy concepts, providing empirical evidence to inform educational policy and practice.

2 Literature Review

2.1 Theoretical Foundation of Competence-Based Education

Competence-Based Education (CBE) represents a significant paradigm shift from traditional educational models, focusing on the demonstration of measurable skills and competencies rather than time-based learning. According to the American Association of Colleges of Nursing, CBE is "a system of instruction, assessment, feedback, self-reflection, and academic reporting that is based on students demonstrating that they have learned the knowledge, attitudes, motivations, self-perceptions, and skills expected of them as they progress through their education" . This approach prioritizes outcomes over processes, emphasizing what students can do with their knowledge rather than how they acquired it.

The theoretical underpinnings of CBE draw from constructivist learning theories, which posit that knowledge is actively constructed by learners through experience and reflection rather than passively received from instructors. This perspective aligns with the work of educational theorists like Piaget and Vygotsky, who emphasized the importance of active engagement and social interaction in the learning process. In physics education, this means students learn best when they actively participate in experiments, problem-solving, and discussions that connect abstract concepts to tangible experiences.

CBE also incorporates elements of mastery learning, an approach developed by Benjamin Bloom that suggests students should achieve a level of mastery in prerequisite knowledge before moving forward to learn subsequent information. In competence-based physics education, this translates to students progressing through energy concepts only after demonstrating competency in foundational principles, ensuring that learning gaps do not accumulate and hinder understanding of more complex topics.

2.2 Comparative Analysis: Traditional vs. Competence-Based Approaches

Traditional physics education typically follows a structured curriculum organized around content coverage, with students advancing based on time spent in classroom instruction rather than demonstrated mastery. This approach often emphasizes lecture-based instruction and algorithmic problem-solving, with assessment focused primarily on recalling formulas and procedures rather than conceptual understanding or application. Critics argue that this model fails to accommodate varying learning paces and styles, potentially leaving behind students who need more time to grasp fundamental concepts.

In contrast, competence-based approaches prioritize depth over breadth, allowing students to spend more time on challenging concepts until they achieve mastery. Assessment in CBC focuses on authentic demonstrations of learning through projects, experiments, and real-world problem-solving rather than standardized tests alone. This approach aligns with the Next Generation Science Standards, which emphasize cross-cutting concepts and science practices alongside content knowledge.

Research comparing traditional and competence-based approaches has yielded promising results for CBC. Studies have found that students in competence-based programs demonstrate higher engagement levels, better retention of concepts, and improved ability to apply knowledge in novel contexts. For example, a study examining competency-based learning in New Hampshire schools found that students showed increased motivation and ownership of their learning when they could progress at their own pace and demonstrate mastery through multiple modalities.

2.3 Implementation Challenges and Considerations

Despite its potential benefits, implementing CBC presents significant challenges for educational institutions and teachers. One major concern is the accreditation status of competence-based programs, as many accrediting bodies use traditional metrics that may not align with CBC approaches. This can create barriers for students seeking financial aid or transferring credits between institutions, potentially limiting the accessibility of competence-based programs.

Another implementation challenge involves teacher preparation and support. Shifting from traditional instruction to competence-based facilitation requires significant professional development, as teachers must learn to design authentic assessments, provide individualized feedback, and manage diverse pacing within their classrooms. Research suggests that successful CBC implementation depends on comprehensive training and ongoing support for educators, who often struggle with the transition from content-deliverers to learning facilitators.

Additionally, resource limitations can pose significant obstacles to effective CBC implementation, particularly in developing countries. Competence-based approaches often require smaller class sizes, specialized materials for hands-on learning, and technology infrastructure to support individualized instruction—resources that may be scarce in underfunded educational systems. These challenges are particularly acute in science education, where laboratory equipment and materials are essential for authentic competency demonstration.

2.4 Competence-Based Education in Science Contexts

The application of CBC in science education represents a particularly promising approach given the discipline's emphasis on inquiry skills and practical application of knowledge. Science education naturally aligns with competence-based approaches through its focus on the scientific method, experimental design, and evidence-based reasoning. In physics specifically, competencies might include designing investigations, analyzing data, developing models, and applying principles to explain real-world phenomena.

Research on competence-based science education has shown positive effects on student outcomes. Studies indicate that students in competence-based science programs demonstrate better conceptual understanding, improved problem-solving abilities, and more positive attitudes toward science compared to their peers in traditional programs. These findings suggest that CBC may be particularly effective for overcoming common misconceptions in physics, which often persist through traditional instruction that emphasizes calculation over conceptual understanding.

The teaching of energy concepts specifically benefits from a competence-based approach due to the abstract nature of energy and its fundamental role across physics domains. A competence-based framework allows students to develop conceptual models of energy through hands-on activities and real-world applications, helping them overcome the common tendency to view energy as merely a formula to be memorized rather than a conceptual tool for understanding physical systems.

3 Methodology

3.1 Research Design

This study employed a mixed-methods research design to comprehensively assess the effectiveness of CBC in teaching energy concepts in physics. The combination of quantitative and qualitative data collection provided a more complete understanding of the intervention's impact than either approach alone could achieve. The quantitative component involved pre-test and post-test measurements of student understanding, while the qualitative component gathered rich descriptive data through semi-structured interviews with students and teachers. This approach aligned with established research methodologies for evaluating educational interventions, allowing for both statistical measurements of outcomes and nuanced understanding of experiences.

The research was conducted as a case study of a single implementation of CBC in a specific educational context, providing depth of understanding while acknowledging limitations in generalizability. The case study approach allowed researchers to examine the complex interplay of factors influencing CBC implementation, including teacher facilitation, student characteristics, and institutional context. This methodological choice was particularly appropriate given the exploratory nature of the research and the need to understand not just whether CBC was effective but how it worked in practice.

3.2 Participants and Setting

The study involved 30 public high school students from Lusaka, Zambia, selected through random sampling from a larger population of grade 11 physics students. The sample included 16 male and 14 female students, ranging in age from 15 to 18 years. Participants represented diverse academic achievement levels based on their previous physics grades, ensuring a representative sample of the student population. The school was selected based on its willingness to implement CBC approaches and its typical representation of Zambian public schools in terms of resources, class size, and student demographics.

In addition to student participants, two physics teachers with varying levels of experience (5 years and 12 years respectively) participated in the study, implementing the CBC approach and providing feedback through interviews. Both teachers received preliminary training on CBC principles and implementation strategies but had limited prior experience with full competence-based instruction, making them representative of many teachers who would be implementing CBC in similar contexts.

Table 1: Participant Demographics

Category	**Number**	**Percentage**
Total Students	30	100%
Male	16	53.3%
Female	14	46.7%
Age Range		
15-16 years	12	40%
17-18 years	18	60%
Prior Physics Performance		
High achievers	10	33.3%
Average achievers	14	46.7%
Low achievers	6	20%
Teachers	2	-

3.3 Data Collection Methods

Quantitative data was collected through identical pre-test and post-test assessments administered before and after the CBC intervention. The assessment instrument consisted of 20 multiple-choice questions and 5 free-response problems designed to measure both conceptual understanding and application skills related to energy concepts. The assessment was validated by physics education experts and piloted with a similar student population to ensure reliability and appropriateness for the study context. The tests were scored using a standardized rubric, with possible scores ranging from 0 to 100 percent.

Qualitative data was gathered through semi-structured interviews conducted with a purposively selected subset of 12 students (representing high, average, and low achievers based on pre-test scores) and both physics teachers. Interview protocols included questions about learning experiences, engagement levels, perceived understanding of energy concepts, and challenges encountered during the intervention. Interviews were audio-recorded, transcribed, and translated when necessary to ensure accuracy of data representation.

Additionally, classroom observations were conducted during three CBC lessons to document implementation fidelity, student engagement, and instructional strategies. Observation notes provided contextual data to supplement and triangulate findings from tests and interviews, offering insights into how the CBC approach was actually enacted in the classroom setting.

3.4 The CBC Intervention

The CBC intervention focused on energy concepts in physics, including work, power, kinetic energy, potential energy, and energy conservation. The intervention consisted of eight instructional sessions over four weeks, replacing the traditional approach to teaching energy concepts. Each session incorporated key principles of competence-based education, including:

- Clear competency statements outlining what students should be able to do by the end of each session
- Multiple learning pathways allowing students to engage with concepts through different modalities (experiments, simulations, problems)
- Formative assessments providing ongoing feedback on competency development
- Authentic application tasks requiring students to apply energy concepts to real-world situations

The lesson on energy basics emphasized "learning through doing and the ability to see things from others' perspectives and consider the whole picture”. Sample activities included designing and testing solar cookers to understand heat transfer, calculating power output in various physical activities, and investigating energy transformation in household devices. These activities aligned with established best practices for teaching energy concepts, which emphasize hands-on experimentation and real-world connections.

3.5 Data Analysis

Quantitative data from pre-test and post-test assessments were analysed using paired samples t-tests to determine whether statistically significant differences existed between scores before and after the CBC intervention. Effect sizes were calculated using Cohen's d to measure the practical significance of the intervention. Additionally, gain scores were analysed across different achievement levels to determine whether the CBC approach differentially benefited students with varying prior knowledge.

Qualitative data from interviews and observations were analysed using thematic analysis following the approach outlined by Braun and Clarke. This involved familiarization with the data, generating initial codes, searching for themes, reviewing themes, and defining and naming themes. The analysis process employed both deductive codes based on the research questions and emergent codes that arose from the data itself. Triangulation between different data sources (interviews, observations) and between researchers enhanced the trustworthiness of the qualitative findings.

4 Results

4.1 Quantitative Findings

The analysis of pre-test and post-test scores revealed significant improvements in students' understanding and application of energy concepts following the CBC intervention. The average pre-test score was 45% (SD = 12.4), indicating limited prior knowledge and application ability before the intervention. The average post-test score increased to 75% (SD = 10.2), demonstrating substantial improvement in conceptual understanding and application skills after experiencing CBC.

A paired samples t-test confirmed that this improvement was statistically significant ($t(29) = 9.87$, $p < .001$). The large effect size (Cohen's d = 2.15) indicated that the CBC intervention had a substantial impact on student learning outcomes. These results suggest that the competence-based approach effectively enhanced students' mastery of energy concepts in physics.

Table 2: Pre-Test and Post-Test Score Comparison

Assessment	Mean Score	Standard Deviation	t-value	p-value	Effect Size
Pre-Test	45%	12.4	9.87	< .001	2.15
Post-Test	75%	10.2			

Further analysis examined performance gains across different achievement levels based on pre-test scores. Low-achieving students (pre-test scores below 40%) showed the greatest percentage improvement, with average gains of 38 points. Average achievers (pre-test scores between 40-60%) gained an average of 29 points, while high achievers (pre-test scores above 60%) gained an average of 22 points. This pattern suggests that CBC may be particularly beneficial for students who struggle with traditional physics instruction, potentially helping to address achievement gaps.

4.2 Qualitative Findings

Thematic analysis of interview transcripts and observation notes revealed several key themes regarding the implementation and experience of CBC in physics education:

4.2.1 Enhanced Engagement and Motivation

Students consistently reported increased engagement and motivation when learning through the competence-based approach compared to traditional physics instruction. One student noted, "I used to just memorize formulas for tests, but actually building devices and seeing energy principles in action made me understand why they matter." This sentiment was echoed by many participants, who described greater interest in physics when they could actively investigate concepts rather than passively receive information.

Teachers also observed heightened participation, particularly among students who typically struggled in physics. One teacher commented, "Even my usually quiet students were engaged in discussions about energy transformation because they had concrete experiences to draw from." Observations confirmed these reports, with students demonstrating sustained attention during activities and enthusiastic participation in group work.

4.2.2 Contextualized Learning and Application

Both students and teachers emphasized the value of contextualized learning in developing meaningful understanding of energy concepts. Students described how applying energy principles to real-world situations—such as calculating the power output of their own bodies during different activities—helped them connect abstract formulas to tangible experiences. As one student explained, "When we measured how much power we generated climbing stairs, work and energy suddenly made sense instead of just being variables in an equation."

Teachers noted that the emphasis on application helped students overcome common misconceptions about energy, particularly regarding energy transformation and conservation. By designing experiments and observing energy principles in action, students developed more accurate mental models that supported sophisticated reasoning about physical systems.

4.2.3 Challenges in Implementation

Despite overall positive experiences, participants identified several implementation challenges with the CBC approach. Teachers reported difficulties in managing different pacing among students, noting that while individualized progression was ideal in theory, it posed practical challenges in a classroom with limited resources and support. One teacher explained, "It was challenging to provide enough attention to each student when they were working at different paces and on different activities."

Students mentioned occasional confusion about expectations in the more open-ended competence-based activities, particularly those accustomed to highly structured traditional instruction. Some expressed initial discomfort with the increased autonomy but generally adapted as they became more familiar with the approach. As one student described, "At first I wasn't sure what I was supposed to be learning, but once I got used to figuring things out for myself, I felt like I understood better."

4.2.4 Assessment and Feedback Considerations

Both teachers and students highlighted the importance of ongoing feedback in the competence-based approach. Students valued the multiple opportunities to demonstrate competency through different modalities, noting that this reduced anxiety and allowed them to show understanding in ways that worked for them. As one student stated, "I'm not good at tests, but when I could design an experiment to show energy conservation, I could really show what I understood."

Teachers expressed appreciation for the rich assessment information available through CBC but noted the time-intensive nature of providing individualized feedback on multiple competency demonstrations. They emphasized the need for specialized training and support to implement competence-based assessment effectively, particularly in larger classes.

5 Discussion

5.1 Interpretation of Findings

The significant improvement in test scores observed in this study provides quantitative evidence that CBC enhances students' understanding and application of energy concepts in physics. These findings align with previous research on competence-based education, which has demonstrated positive effects on student learning across various disciplines. The particularly strong gains among low-achieving students suggest that CBC may help address equity concerns in physics education by providing alternative pathways to understanding that do not depend solely on mathematical aptitude or prior knowledge.

The qualitative findings offer insights into why CBC proved effective in this context. The themes of enhanced engagement, contextualized learning, and authentic application suggest that CBC promotes deeper cognitive processing through active knowledge construction rather than passive reception. This aligns with constructivist learning theories, which emphasize the importance of connecting new knowledge to existing mental models through authentic experience and reflection.

The challenges identified in implementation—particularly regarding pacing management and expectation clarity—echo concerns raised in the literature on competence-based education. These findings suggest that successful CBC implementation requires not only curricular changes but also significant shifts in classroom culture and teacher practices. The transition from traditional instruction to competence-based facilitation represents a substantial change that demands comprehensive support and professional development for educators.

5.2 Theoretical Implications

This study contributes to the growing theoretical understanding of how competence-based approaches support learning in science education. The findings suggest that CBC aligns particularly well with the epistemic practices of physics, where knowledge is developed through empirical investigation and model-building rather than authority-based reception. By engaging students in authentic practices of the discipline, CBC helps develop not only conceptual understanding but also scientific habits of mind that are essential for future learning and application.

The effectiveness of CBC in teaching energy concepts specifically supports conceptual change theory in science education. Energy represents a concept that often requires substantial restructuring of intuitive ideas about the physical world. The contextualized, experiential learning promoted by CBC appears to facilitate this conceptual restructuring by making abstract principles tangible through direct investigation and application.

5.3 Practical Implications

The practical implications of this study extend to multiple educational stakeholders:

For teachers, the findings suggest that competence-based approaches can enhance physics instruction but require significant adaptation of current practices. Successful implementation demands focus on designing authentic assessments, providing individualized feedback, and facilitating rather than directing learning. Teachers may need support in developing strategies for managing diverse pacing while maintaining classroom cohesion and ensuring all students achieve essential competencies.

For educational leaders and policymakers, this study provides evidence supporting the investment in CBC implementation, particularly in science education. The findings suggest that resource allocation should prioritize teacher professional development, appropriate assessment tools, and hands-on learning materials that enable authentic competency demonstration. Policymakers may need to address structural barriers to CBC implementation, including accreditation requirements and accountability measures that may not align with competence-based approaches.

For curriculum developers, this study highlights the importance of designing physics learning experiences that connect abstract concepts to tangible applications. The effectiveness of the energy unit suggests that CBC modules should incorporate multiple modalities for engagement and expression, allowing students to interact with concepts through various pathways and demonstrate understanding in different ways.

5.4 Limitations and Future Research

This study has several limitations that should be considered when interpreting the results. The relatively small sample size and specific context of a single Zambian school limit the generalizability of the findings. Further research involving larger, more diverse samples across multiple educational contexts would strengthen the evidence base for CBC in physics education.

The short-term nature of the intervention (four weeks) provides information about immediate learning gains but does not address long-term retention or transfer of energy concepts. Future studies should investigate whether the benefits of CBC persist over time and whether students can apply their learning in novel contexts beyond the specific activities encountered during instruction.

Additionally, this study focused primarily on student outcomes rather than detailed analysis of implementation processes. Future research should more closely examine the specific instructional practices that maximize the effectiveness of CBC in physics education, potentially identifying essential elements and supportive conditions for successful implementation.

6 Conclusion and Recommendations

This study provides evidence that Competence-Based Curriculum implementation significantly enhances students' understanding and application of energy concepts in physics. The mixed-methods approach revealed not only substantial improvements in test scores but also positive changes in engagement, motivation, and contextualized learning. These findings suggest that CBC offers a promising alternative to traditional physics instruction, particularly for complex concepts like energy that benefit from hands-on investigation and real-world application.

Based on the findings, the following recommendations are proposed:

6.1 Policy Recommendations

Educational policymakers should prioritize the integration of CBC into physics education curricula, developing standards and frameworks that support competence-based approaches while addressing implementation challenges such as accreditation and assessment.

Funding agencies and educational ministries should allocate resources for the development of CBC instructional materials, particularly hands-on learning tools that facilitate authentic competency demonstration in science education.

Assessment systems should be adapted to align with competence-based approaches, incorporating multiple modalities for demonstrating understanding and focusing on application rather than solely recall of information.

6.2 Teacher Training and Support

Teacher education programs should incorporate training in CBC principles and practices, preparing new teachers to implement competence-based approaches in their classrooms.

Professional development for current teachers should focus on the specific skills needed for CBC implementation, including designing authentic assessments, providing individualized feedback, and managing diverse pacing.

Collaborative networks should be established to support teachers implementing CBC, providing opportunities for sharing best practices, problem-solving challenges, and developing professional communities around competence-based science education.

6.3 Future Research Directions

Longitudinal studies should examine the sustained impact of CBC on physics learning, investigating whether improvements in conceptual understanding and application ability persist over time.

Comparative research across different educational contexts should explore how CBC implementation varies based on cultural, resource, and institutional factors, identifying essential elements for success across diverse settings.

Implementation studies should investigate the specific teaching practices that maximize the effectiveness of CBC in physics education, providing detailed guidance for educators seeking to adopt competence-based approaches.

In conclusion, the implementation of Competence-Based Curriculum in physics education represents a promising approach for enhancing students' understanding and application of complex concepts like energy. By focusing on competencies rather than content coverage, CBC helps prepare students for real-world problem-solving and critical thinking—skills that are essential for success in both academic and professional contexts. While implementation challenges exist, the potential benefits justify continued investment in and research on competence-based approaches to science education.

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Article 13

Effects of Realistic Mathematics Education and Mathematical Modelling Approaches on Senior Secondary School Students Attitude and Achievement in Geometry in North Central, Nigeria

ABUBAKAR, Mohammed Ndanusa [1], HASSAN, A. A. [2];
ndanusa006@gmail.com, hassan.ahmed@futminna.edu.ng,

GIMBA, R. W. [3]; USMAN, Hussaini [4] & USMAN, Hassan [5]

Niger State Teachers Professional Development Institute[1&4], Federal University of Technology Minna[2&3], Niger State College of Education Minna[5],

Abstract

This study investigates the effects of Realistic Mathematics Education (RME) and Mathematical Modelling (MM) approaches on senior secondary school students' attitudes and achievement in geometry in North Central, Nigeria. A pretest and posttest control group factorial design were employed. Four research questions were answered, and four hypotheses were tested in this study. The population of the study was made up of Two hundred and eleven thousand, three hundred and seventy-eight (211,378) students in the Senior Secondary schools in North Central. Cluster sampling, purposive sampling and random sampling were used to select 361 students from twelve co-educational secondary schools in the North Central States of Nigeria that participated in the study. The schools were assigned to experimental groups; I, (RME), experimental group II (MM) and Control Group (Lecture Method). A Geometry Achievement Test (GAT) containing 20 – questions covering topics in Plane and Circle Geometry was used to collect data for both pre-tests and post-test while Mathematics Attitude Questionnaire (MAQ) was used for collecting data on attitude of students towards Geometry, experts validated the instruments. A Pearson product moment correlation and Crombach alpha formula were used to determine the reliability coefficient of GAT and MAQ which yielded 0.80 and 0.87 respectively, establishing the robustness of these instruments. The data were analyzed using descriptive statistics (mean and standard deviation), inferential statistics, analysis of variance (ANOVA), Analysis of Covariance (ANCOVA) and Scheff post hoc test was used. The hypotheses were tested at 0.05 level of significance. Results indicate significant differences in mean achievement scores among students taught Geometry using RME, MM approaches, and conventional lectures. In addition, both RME and MM approaches contribute to improved attitudes towards Geometry. Additionally, gender differences in achievement were noted with RME and MM. These findings have notable implications for the evolution of curricula and the enhancement of instructional strategies in mathematics education. The study provides valuable insights for educators seeking to improve geometry learning experiences and outcomes by employing effective instructional approaches.

Keywords; *Impact, Attitude, Achievement, Mathematical Modelling, Mathematics representation, Realistic Mathematics Education*

1. Introduction

1.0 Background to the Study

Science, Technology, and Mathematics Education (STME) are regarded as key indicators of a nation's socio-economic and geopolitical development. Studies have shown the significant impact of STME on countries like China, which has become a major economic power due to its emphasis on scientific and technological development. In Nigeria, the National Policy on Education and curriculum reforms have underscored the importance of Mathematics as a compulsory subject in basic education, reflecting its vital role in contemporary society.

Despite the importance of Mathematics, student performance in Senior Secondary School examinations remains discouraging. Various studies have consistently reported low achievement levels among Nigerian students in secondary school Mathematics. This trend has raised concerns about the future of Mathematics Education in the country.

To address this issue, new teaching methodologies have been introduced, including Realistic Mathematics Education (RME). RME, developed in the Netherlands, emphasizes math as a human activity connected to real-life situations. It aims to make math learning enjoyable and meaningful by using real-world contexts as a starting point for learning. RME involves problem-solving, discussions, and rational solution development, helping students understand mathematical concepts in practical contexts. This approach is believed to improve students' mathematical representation and problem-solving skills.

Mathematical modeling is another approach that makes math relevant by representing real-world problems mathematically. It helps students understand and solve real-life issues, particularly in areas like geometry. Modeling is seen as a central aspect of successful math teaching and learning, fostering a "culture of mathematizing" in schools.

These teaching approaches align with constructivist learning theory, which emphasizes the role of experiences and connections in student education. Constructivism suggests that students construct knowledge based on their experiences, and teachers should create problem-solving environments where students can construct their own knowledge.

The study aims to investigate the Impact of Realistic Mathematics Education and Mathematical Modeling on senior secondary students' achievement and attitudes toward Geometry in North Central Nigeria. It seeks to understand how these teaching approaches impact students in a specific geographical context and differs in scope, content, sample size, data collection, and analysis from previous studies in the field.

1.2 Purpose of the Study

The purpose of this study is to determine the Impact of Realistic Mathematics Education and Mathematical Modelling Approaches on Senior Secondary School Students' Achievement and Attitudes towards Geometry in North Central, Nigeria. Specifically, the study will be carried out to achieve the following objectives;

1. determine the main effects of Realistic mathematics Education, Mathematical Modelling approaches and conventional lecture method on the student's geometry Achievement;
2. determine the attitude of students towards geometry when taught using Realistic mathematics education approach;
3. determine the attitude of students towards Geometry when taught using Mathematical Modelling approach;
4. find the effects of Mathematical Modelling approach on the attitude of students towards Geometry before and after treatment.
5. determine the difference in the mean achievement scores of male and female students in Geometry when taught using Realistic Mathematics Education approach;

1.3 Research Questions

The following research questions were raised for the study.

1. What are the main effects of Realistic mathematics Education, Mathematical Modelling approach and conventional lecture method on the student's Geometry Achievement?
2. What is the difference in the mean attitude of students towards Geometry before and after when taught using Realistic mathematics education approach?
3. What is the difference in the mean attitude of students towards Geometry before and after when taught using Mathematical Modelling approach?
4. What differences exist in the mean achievement scores of male and female students in Geometry when instructed using the Realistic Mathematics Education approach?
5. What differences exist in the mean achievement scores of male and female students in Geometry when instructed using the Mathematical Modelling approach?

1.4. Research Hypotheses

The following null hypotheses were formulated and will be tested at 0.05 alpha level of significance.

HO1: There is no significant difference of Realistic Mathematics Education, Mathematical Modelling approach and conventional lecture method on the students' Geometry Achievement.

HO2: There is no significant difference in the mean attitude scores of students towards Geometry before and after being taught using Realistic Mathematics Education approach.

HO3: There is no significant difference in the mean attitude scores of students towards Geometry before and after being taught using Mathematical Modelling approach

HO4: There is no significant difference between the mean attitude scores of students towards Geometry before and after exposure to Mathematical Modelling approach.

HO5: There is no significant difference between the mean achievement scores of male and female students in Geometry when taught using Realistic Mathematics Education approach.

2. Methodology

The study employed a pretest and posttest control group factorial design, utilizing a three by two (3 × 2) factorial design. This design involved three treatment levels (Realistic Mathematics Education (RME) and Mathematical Modelling (MM) and two levels of gender (Male and Female) to test the study's hypotheses. The target population consisted of Senior Secondary school students in North Central Nigeria for the 2021/2022 academic session, with a total population of 211,378 senior secondary school Mathematics students in SSII. The selection of SSII was based on the focus of the study on challenging Mathematics concepts within the SSII syllabus. The sample for the study included 361 Mathematics students from 12 co-educational public senior secondary schools in the North-Central Geopolitical Zone of Nigeria. These schools were selected using purposive sampling based on similar environmental conditions, including manpower, gender composition, and school type (public schools). Within each sampled school, an intact class of SS 2 was randomly selected from each arm, resulting in three groups: experimental group I (107 students), experimental group II (126 students), and a control group (128 students). Data collection instruments included the Geometry Achievement Test (GAT) and the Mathematics Attitude Questionnaire (MAQ). GAT comprised 20 subjective items with a total score of 100 marks, covering plane and circle geometry content. MAQ was used to assess students' attitudes toward geometry and consisted of two parts: part one collected student bio-data, while part two included 50 items assessed on a 5-point Likert scale. The items covered four subscales: personal confidence in the subject matter, the usefulness of the subject's content, perception of the subject as a male domain, and perception of teachers' attitude. Scoring for positive and negative items differed, with positive items scored SA = 5, A = 4, U = 3, D = 2, and SD = 1, while negative items were scored SA = 1, A = 2, U = 3, D = 4, and SD = 5. The instruments underwent face, construct, and content validation by specialists in the field of Pure Mathematics and Science Education. Reliability analysis yielded a coefficient of 0.80 for GAT and 0.87 for MAQ. Data collection occurred in two stages: the first stage involved training mathematics teachers and administering pretests, while the second stage involved four weeks of exposing the experimental group to RME and MM activities using treatment instruments (worksheets), while the control group received traditional lectures. Posttests were administered to both groups to assess their achievement in mathematical RME and MM. Data analysis was conducted using mean and standard deviation for research questions and dependent t-tests and ANCOVA statistics for hypothesis testing, with a significance level of 0.05.

3. Results

3.1 Research Question One

What is the Impact of Realistic mathematics Education, Mathematical Modelling approach and conventional lecture method on the student's Geometry Achievement?

Table 1: Mean and Standard Deviation of Pre-test and Post-test achievement Scores of Experimental Group I, II and the Control Group

Group	N	Pretest	SD	Post-test	SD	Mean difference
Experimental Group I	128	32.69	12.93	83.39	8.97	50.70
Experimental Group II	107	38.23	10.77	79.60	8.21	41.37
Control Group	126	38.11	12.35	66.51	15.23	28.40

Table 1 shows the mean and standard deviation achievement scores of experimental groups I, experimental group II and control groups at pre-test and post-test. From the result, it can be deduced that the mean and standard deviation scores at pre-test and post-test for Experimental Group I (RME) as = 32 .69, SD= 12.93 and = 83.39, SD= 8.97 respectively. This gives the mean difference of 50.93 in favour of post-test. Similarly, the mean and standard deviation scores at pre-test and post-test for Experimental Group II were administered to both groups to assess their achievement in mathematical RME and MM. Data analysis was conducted using mean and standard deviation for research questions and dependent t-tests and ANCOVA statistics for hypothesis testing, with a significance level of 0.05.

3.2 Research Question Two

What is the difference in the mean attitude of students towards Geometry when taught using Realistic mathematics education approach?

Table 2: Mean and Standard Deviation of Experimental Group 1 students' attitude towards Geometry.

Groups	N	Mean	S. D	Mean difference
Before	128	67.09	12.72	
After	128	83.08	14.01	15.99

Table 2 reveals that experimental group 1 has (Mean = 67.09 and S. D= 12.72.); at pre-test while at post - test experimental group 1 has (Mean = 83.08 and S. D= 14.01). This indicates that students had better attitude towards Geometry when exposed to Realistic Mathematics Education approach than before they were exposed to Realistic Mathematics Education with a mean difference of 15.99. To determine if the difference in the attitude is significant, ANOVA was used as presented in Table 4

3.3 Research Question Three

What is the difference in the mean attitude of students towards Geometry before and after when taught Geometry using Mathematical Modelling approach?

Table 3: Mean and Standard Deviation of Experimental Group 2 students' attitude towards Geometry.

Groups	N	Mean	S. D	Mean Difference
Before	107	61.35	7.73	15.16
After	107	76.51	6.64	

Table 3 reveals that experimental group 2 has (Mean = 61.35 and S. D= 7.73.); at pre-test while at post- test it has (Mean = 76.51 and S. D= 6.64). This indicates that students had better attitude towards Geometry when exposed to Mathematical Modelling approach than before they were exposed to Mathematical modelling with a mean difference of 15.16. As a result of this identified difference in the mean attitude towards Geometry, hypothesis 3 was tested at 0.05 level to determine if the observed difference was significant.

3.4 Research Question four

What differences exist in the mean achievement scores of male and female students in Geometry when instructed using the Realistic Mathematics Education approach?

Table 4 Mean and Standard Deviation of Male and Female students' taught Geometry using Realistic Mathematics Education (RME) Approach.

Groups	N	Mean $\overline{(X)}$	S. D	Mean difference
Male	76	85.84	7.26	6.42
Female	52	79.42	7.91	

Table 4 reveals that male students have (Mean = 85.84 and S. D= 7.26.); while Female has

(Mean = 79.42 and S. D= 7.91). This indicates that male students had higher mean score in Geometry when exposed to Realistic Mathematics Education (RME) approach than their Female counterpart with a mean difference of 6.42. To determine if the difference in the mean score is significant, independent t-test was used to test hypothesis 4.

3.5 Research Question five

What differences exist in the mean achievement scores of male and female students in Geometry when instructed using the Mathematical Modelling approach?

Table 5 Mean and Standard Deviation of male and female students' taught Geometry using Mathematical Modelling (MM) Approach.

Groups	N	Mean $\overline{(X)}$	S. D	Mean difference
Male	59	76.02	9.10	7.98
Female	48	84.00	6.67	

Table 5 reveals that male students has (Mean = 76.02 and S. D= 9.10.); while Female students has (Mean = 84.00 and S. D= 6.67). This indicates that Female students had higher mean score in Geometry when exposed to Mathematical Modelling (MM) approach than their male counterpart with a mean difference of 7.98. To determine if the difference in the mean score is significant, independent t-test was used to test hypothesis 5.

Hypotheses Testing

Hypothesis One (HO_1)

There are no significant differences between the mean achievement scores of students taught geometry using Realistic Mathematics Education, Mathematical Modelling approach, and Conventional Lecture Method

Table 6 Summary of Analysis of Covariance (ANCOVA) Scores of Experimental groups and control group

Source	Type III Sum of Squares	Df	Mean Square	F	P
Corrected Model	18753.327[a]	3	6251.109	48.416	.000
Intercept	207708.592	1	207708.592	1608.750	.000
Covariate	9.727	1	9.727	.075	.784
Treatment	18459.443	2	9229.721	71.486	.000
Error	46092.906	357	129.112		

Total	2177891.000	361
Corrected Total	64846.233	360

*: Significant at $P < 0.05$

Table 6 showed the ANCOVA result of the comparison of posttest scores of students in Experimental groups and the control group. An examination of the table shows (F (2, 360) = 71.49, $P < 0.05$). On this basis, hypothesis one was rejected. Therefore, there was significant difference between students' Geometry Achievement when taught using Realistic Mathematics Education, Mathematical Modelling approach than those taught using conventional lecture. Scheffe's post- hoc test was carried out to find out where the differences lie as shown in table 7.

Table 7: Scheffe's Post-hoc Analysis of Mean score of students in Experimental groups and control group

Treatment	Experimental I (RME)	Experimental II (MM)	Control (LM)
Experimental I (RME)	-	3.79*	16.50*
Experimental II (MM)	-3.79*	-	12.71*
Control (LM)	-16.50*	-12.71*	-

*: Significant at $P < 0.05$

Table 7 showed the Scheffe's post- hoc analysis of mean score of students in Experimental groups and control group. The table indicated that significant difference exists between RME vs MM, RME vs LM, MM vs LM and LM vs MM with mean difference of 3.79, 16.50 and 12.71 respectively indicating those taught using RME and MM had a higher mean score when taught Geometry than those taught using LM.

Hypothesis Two (HO_2)

There is no significant difference between the mean attitude scores of students towards Geometry before and after exposure to Realistic Mathematics Education approach.

Table 8: Summary of Dependent t-test Analysis of students' attitude towards Geometry when taught using RME approach

Groups	N	Mean (x)	SD	Df	T	P	Remark
Before	128	67.09	12.72	127	8.821	0.000	Significant
After	128	83.08	14.01				

*: Significant at $P < 0.05$

Table 8 shows the analysis of dependent sample t-test of mean attitude scores of students towards Geometry before and after exposure to Realistic Mathematics Education Approach. It reveals that the calculated t–value = 8.821, df = 127, p = 0.000 indicating $P < 0.05$. Hence, Null Hypothesis four (HO_2) was rejected. This mean, there was significant difference in the mean attitude scores of students taught Geometry before and after exposure to Realistic Mathematics Education.

Hypothesis Three (HO_3)

There is no significant difference between the mean attitude scores of students towards Geometry before and after exposure to Mathematical Modelling approach.

Table 9: Summary of Dependent sample t-test Analysis of students' attitude towards Geometry when taught using MM approach

Groups	N	Mean $(\overline{X})$	SD	df	T	P	Remark
Before	107	61.35	7.73	106	14.641	0.000	Significant
After	107	76.51	6.64				

*: Significant at $P < 0.05$

Table 9 shows the analysis of dependent sample t-test of mean attitude scores of students towards Geometry before and after exposure to Mathematical Modelling Approach. It reveals that the calculated t–value = 14.641, df = 106, p = 0.000 indicating $P < 0.05$. Hence, Hypothesis three was rejected. This mean, there was significant difference in the mean attitude scores of students taught Geometry before and after exposure to Mathematical Modelling.

Hypothesis Six (HO_4)

There is no significant difference between the mean achievement scores of male and female students in Geometry when taught using Realistic Mathematics Education approach.

Table 10: Summary of Independent t-test Analysis of Male and Female students in Experimental group 1 taught using RME approach

Groups	N	Mean $(\overline{X})$	SD	df	T	P	Remark
Male	76	85.84	7.26	126	4.74	0.000	Significant
Female	52	79.42	7.91				

*: Significant at $P < 0.05$

Table 10 shows the means, standard deviations and t-test for Students achievement in geometry by gender which was significant at $p < 0.05$ with t =4.74 thus, Null hypothesis 4 (HO_4) was rejected. Therefore, there was significant gender difference between the mean scores of Students taught with Realistic Mathematics Education approach. Male students perform better than their Female counterparts.

Hypothesis Five (HO_5)

There is no significant difference in the mean achievement scores of male and female students' when taught Geometry using Mathematical Modelling approach.

Table 4.24: Summary of independent t-test Analysis of Male and Female students in Experimental group II taught using MM approach

Groups	N	Mean $(\overline{X})$	SD	Df	T	P	Remark
Male	59	76.02	9.10	105	5.03	0.000	Significant
Female	47	84.00	6.67				

*: Significant at $P < 0.05$

Table 5 shows the means, standard deviation, and t-test for Students achievement in geometry by gender which was significant at $p < 0.05$ with $t = 5.03$ thus, hypothesis 5 was rejected. Therefore, there was significant gender difference between the mean scores of students taught with Mathematical Modelling approach. Female students perform better than their male counterparts.

4. Discussion o f the Findings

The study reveals that using Realistic Mathematics Education (RME) and Mathematical Modelling (MM) approaches to teach Geometry offers significant advantages over traditional lecture-based methods. The hands-on, interactive nature of RME provides students with practical learning experiences, which leads to improved academic performance. By connecting mathematical concepts with real-world applications, RME helps students better understand Geometry. MM enhances this by promoting a constructivist approach, encouraging problem-solving and critical thinking, which deepens understanding and equips students with skills relevant to real-world challenges.

A key finding is the significant difference in Geometry achievement between male and female students when taught using RME and MM. This aligns with research by Hassan et al. (2019), which demonstrated improved Geometry outcomes for both genders after exposure to MM. Similarly, studies by Leder and Forgasz (2017) highlight the positive impact of RME on both genders, suggesting it reduces performance gaps by offering a more engaging and contextualized learning environment.

These findings are consistent with earlier studies by Effandi et al. (2017), Zakaria and Syamaun (2017), Nicola (2011), Baskan and Alev (2013), and Sokolowski (2015), all of which underscore the positive effects of RME and MM on students' mathematics achievement. Collectively, the evidence points to the potential of these approaches to transform mathematics education.

The study also found a significant improvement in students' attitudes toward Geometry after being taught with the RME approach. This corresponds with research by Verschaffel et al.

(2019), which shows that RME enhances students' attitudes by linking mathematics to real-world contexts. Leung and Wong (2017) observed similar positive changes in attitudes among primary school students. However, Henningsen and Stein (2017) noted that while RME improves problem-solving skills, it does not always lead to significant changes in attitude.

In terms of the MM approach, the study found a significant improvement in students' attitudes towards Geometry. This supports findings by Blum and Leiss (2020), who reported positive attitude shifts with MM, and Gravemeijer et al. (2017), who emphasized its role in fostering active learning and inquiry. However, Chen et al. (2017) provided a differing perspective, suggesting that MM does not consistently lead to positive attitude changes.

5. Conclusion

The study concludes that the Realistic Mathematics Education (RME) approach is more effective than Mathematical Modeling (MM) and traditional lecture methods in teaching Geometry. While both RME and MM positively impact students' academic achievement and attitudes, RME is especially effective in making lessons engaging, understandable, and enjoyable. If adopted widely, RME could complement regular classroom instruction in Mathematics, offering a powerful tool for improving students' performance and attitudes towards challenging topics like Geometry. MM also holds promise as an effective method for enhancing achievement and attitudes toward Geometry in secondary schools, particularly in North Central Nigeria.

6. Recommendations

Based on the major findings of this study, the following recommendations are proffered as follows:

1. There should be development and incorporation of targeted activities within RME and MM approaches, such as using GeoGebra software to create interactive geometry models, to enhance students' geometry representation skills.
2. There should be crafted structured problem-solving exercises aligned with RME and MM principles, such as creating a "Geometry Scavenger Hunt" where students find real-world examples of geometry concepts, to improve problem-solving abilities.
3. Teachers should regularly evaluate students' attitudes towards Geometry using surveys or questionnaires, such as administering a pre- and post-test survey to track attitude improvements, to identify areas for further development.
4. Teachers should customize RME and MM approaches to meet the distinct needs of male and female students, such as creating gender-specific activities that cater to different learning preferences, to optimize their Geometry achievement levels.

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Article 14

Integration of STEM Curriculum at Secondary School Level of Education in Nigeria

[1]Yakubu, A. A. & [2]Nuhu, I. L.

Department of Science Education, Federal University Gusau, Zamfara State

Abstract

The integration of STEM Curriculum into the Nigerian secondary school Science curriculum offers a pathway to increase students' acquisition of essential 21st-century skills. This paper explored the rationale, challenges, and opportunities associated with incorporating STEM education into the curriculum to prepare students for the complexities of a globalized world. STEM education, held promise across diverse sectors such as healthcare, agriculture, Engineering, Mathematics and environmental conservation. The paper discussed the nature of Nigerian secondary school science curriculum with special interest in Biology, emphasizing its thematic and spiral organization, and identified gaps where STEM Education with particular interest in biotechnological topics were underrepresented. Challenges in implementation, including lack of qualified teachers, resource constraints, and ethical considerations, were explored. Opportunities, such as promoting practical, inquiry-based learning and promotion of interdisciplinary connections, were highlighted. The paper concluded that successful integration of STEM education requires fundamental efforts to review secondary school Science curriculum. Thus, it suggested curriculum review, partnerships for access to STEM Education resources to facilitate instruction, and teachers’ professional development.

Keywords: *STEM education, 21st-century skills, Secondary school, curriculum*

1. Introduction

In the 21st century, education systems worldwide face the challenge of preparing students for a rapidly evolving and increasingly complex global competitiveness. As societies transition towards knowledge-based economies, the acquisition of 21st-century skills such as critical thinking, problem-solving, collaboration, creativity, adaptability, and ethical awareness, has become imperative for students to thrive in a competitive and interconnected world (Isma’il & Cyril, 2022; Trilling & Fadel, 2008). In Nigeria, the education sector faces the challenge of adapting curriculum frameworks to meet the demands of the modern era and the country's socio-economic development goals. Aham et al. (2022) argue that teaching and learning have shifted towards equipping students with the skills to solve real-life problems they encounter daily, rather than solely focusing on classroom-based knowledge.

According to Bahri et al. (2014), STEM Education promotes the acquisition of 21st century skills, which are key for the contemporary economy. For the nation to flourish in this century, there is a need for strategic priority to emphasize technologically infused topics in Sciences (Aham et al., 2022). STEM Education, a field at the intersection of Science Technology, Engineering and Mathematics, encompasses a wide range of applications that leverage in Sciences, Engineering, Technology and Mathematics to develop products and processes beneficial to society. For instance, in recent years, biotechnology has emerged as a powerful tool with diverse applications in sectors such as healthcare, agriculture, environmental conservation, and industrial manufacturing (Schmidt, 2023). Understanding the basics of STEM Education is essential for appreciating its significance and potential impact on various aspects of human life. As STEM Education continues to evolve, it is essential to stay informed about the latest developments and ethical considerations shaping the field's future.

As part of ongoing efforts to reform the educational system, there is a growing recognition of the need to integrate emerging fields such as STEM Education into the curriculum to equip students with the knowledge, skills, and competencies required for success in the 21st century (Okeke, 2019). Hiong and Osman (2013) have proven the possibility of integration of 21st century skills in science education. Since the beginning of the 21st century, STEM education through modern biotechnology has been integrated into senior secondary science curricula in numerous countries, including the United States, England, Canada, and New Zealand (Kooffreh et al., 2021; Nordqvist & Johansson, 2020). Biotechnology education incorporates aspects of ethics and morals, which are less frequently encountered in subjects like chemistry, physics, or other areas of biology (Nordqvist & Johansson, 2020). Biotechnology education often includes ethical, emotional, political, and social dimensions, setting it apart from many other science natural science subjects. For example, while scientists generally agree that genetically modified food is safe, many people still have concerns or oppose their use (Nordqvist & Johansson, 2020).

Biotechnology is formed by combining biology and technology. It involves using microorganisms or biological substances to carry out particular manufacturing processes or industrial functions (Unoma & Menkiti, 2017). It is the application of biological knowledge and techniques to develop products and processes that improve human health, agriculture, industry, and the environment, holds immense promise as a catalyst for advancing education and driving innovation (UNESCO, 2015). By integrating biotechnology into the secondary school biology curriculum, teachers can engage students in hands-on learning experiences that not only deepen their understanding of biological concepts but also nurture the development of critical thinking skills and scientific inquiry (Adeyanju & Adeyemo, 2023). Survey conducted in Nigeria by Unoma and Menkiti (2017) revealed that secondary school students exhibit a high level of unawareness regarding biotechnology products and services. Another study by Kooffreh et al. (2021) revealed that secondary school students generally demonstrated limited knowledge, perception, and interest in biotechnology.

These studies stand in contrast to the findings of Bahri et al. (2014) in Malaysia, where secondary school students were reported to possess a moderate level of knowledge, perception, and attitude towards biotechnology. Consequently, Unoma and Menkiti (2017) and Kooffreh et al. (2021) emphasized the need for integrating biotechnology into the current Nigerian senior secondary school biology curriculum, a step that has not yet been taken. The integration is essential for increasing students' understanding and appreciation of the benefits of biotechnology.

In the area of Chemistry and physics at secondary School levels of education, application in phorensic technology, electrolysis, nuclear reactions, organic synthesis, many to mention but a few, if these concepts are adequately integrated into the Nigerian Secondary science curriculum through STEM, will result to sustainable growth and development in the area of human capacity building, power, Engineering, transporting, biodiversity, food production, Health sector and Agriculture. Based on this background, this paper explores the rationale, challenges, and opportunities associated with integrating STEM education into the Nigerian secondary school science curriculum to advance 21st-century skills among students.

2. The Nature of Nigerian Senior Secondary School Science Curriculum

Curriculum is prearranged experiences that serve as a teacher's guide and often the sole resource used by teachers. It links educational goals and subject content with the act of teaching in the classroom, containing the syllabus and required subject content learned in the school system (Westbrook et al., 2013). A coherent curriculum has the greatest impact on student success and is the means through which the philosophy of education can be actualized. This implies that the curriculum encompasses all experiences to which learners are exposed under the guidance of the school. Essentially, the function of a curriculum includes everything that affects and influences a learner to be relevant and useful to their society. Parish (2013) contends that learning must be focused on the curriculum. Therefore, the science curriculum is a key reference point for science teachers and a vehicle for effective instruction. It encompasses required content learned in the school system.

Nigeria operates a federal system, and as a result, the Federal Ministry of Education, through National Education Research and Development Council (NERDC) and with the inclusion of stakeholders, prepared the biology curriculum under which all senior secondary schools in Nigeria operate (Abe & Owoey, 2016). According to Yakubu (2024), Biology, Chemistry and Physics subjects are essential part of the secondary school science curriculum, offering students an in-depth understanding of the world. The current Nigerian Secondary School Science Curriculum was adapted and revised from the 1985 edition developed by Comparative Education Study and Adaptation Centre (CESAC) under National Education Research and Development Council (NERDC, 2008). The objectives of the curriculum, derived from the National Policy on Education (FRN, 2013), The aims of the Nigerian senior secondary school biology curriculum are to prepare students to acquire:

1. Adequate laboratory and field skills in sciences;
2. Meaningful and relevant knowledge in biology, Chemistry, Mathematics and Physics;
3. Ability to apply scientific knowledge to every day's life in matters of personal and community health and agriculture;
4. Reasonable and functional scientific attitude.

The syllabus, as contained in the Nigerian Educational Research and Development Council (NERDC, 2008) curriculum, is arranged spirally using a thematic approach (Oyovwi, 2021). The content and topics cover four major themes:

1. Organization of Life: This includes topics describing the basic structure and classification of living things, such as cell structure and functions.
2. Organisms at Work: This theme covers anatomy and physiological activities, including the digestive, respiratory, and nervous systems.
3. The Organism and its Environment: This theme explains the relationship between organisms and their environment, covering ecology and conservation.
4. Continuity of Life: This describes reproduction, genetics, and evolution.

These themes are directly relevant to secondary school students and society at large. The spiral and thematic arrangements ensure a gradual progression of learning concepts from concrete to abstract (Ogunkola & Samuel, 2011). The curriculum's spiral approach means that students study the same topics throughout their academic careers, with each encounter becoming more complex and reinforcing previous knowledge. The NERDC (2008) curriculum organizes its content into six sectors: Topic, Performance Objectives, Content, Activity (Teacher and Students), Teaching and Learning Materials, and Evaluation Guide. This organization guides teachers in preparing the scheme of work and daily lesson plans.

The curriculum emphasizes field studies, guided discovery, laboratory techniques, and skills, along with conceptual thinking. The curriculum promotes student-centered instruction with a focus on experimentation, questioning, inquiry, discussion, and problem-solving, which are essential for students' comprehension (Aham et al., 2022; NERDC, 2008). However, explicit references to biotechnology topics are not prevalent within the curriculum.

2.1 Rationale for Integration of STEM Curriculum with Special interest in Biotechnology content knowledge at Secondary School Level of Education

The integration of biotechnology into the Nigerian secondary school biology curriculum holds significant importance in preparing students for the challenges and opportunities of the 21st century. By incorporating biotechnology into the curriculum, Nigerian secondary schools can equip students with the knowledge, skills, and mindset necessary to thrive in a rapidly evolving scientific world. One of the primary reasons for integrating biotechnology into the biology curriculum is to align education with real-world applications and industry demands.

Biotechnology plays a central role in various sectors, including healthcare, agriculture, environmental conservation, and industrial manufacturing. By exposing students to basic biotechnological concepts and techniques, it will help in preparing students for future careers in biotechnology-related fields (Oyinloye, 2018). Moreover, integrating biotechnology into the curriculum nurtures critical thinking, problem-solving, and innovation skills among students. Biotechnological research and development require creativity, analytical thinking, and the ability to work collaboratively across disciplines. By engaging students in hands-on biotechnological experiments and projects, teachers can cultivate these essential skills and nurture a culture of scientific inquiry and discovery (Ajayi & Akinpelu, 2023).

Furthermore, incorporating biotechnology education enhances the attractiveness of biology as a subject and promotes student engagement and motivation. Traditional biology education often focuses on memorization of facts and concepts, which may not resonate with all students. By introducing cutting-edge topics such as gene editing, synthetic biology, and personalized medicine, teachers can capture students' interest and curiosity, inspiring them to explore the fascinating world of biotechnology (Adeyanju & Adeyemo, 2023). Also, biotechnology education promotes ethical awareness and responsible citizenship among students. The ethical implications of biotechnological advancements, such as genetic engineering and cloning, raise complex moral and societal questions. By discussing these ethical dilemmas in the classroom, teachers can cultivate students' moral reasoning and encourage thoughtful reflection on the societal implications of biotechnology (Bello & Maude, 2019; Isma'il et al. 2021).

Furthermore, integrating biotechnology into the curriculum contributes to national development goals by building human capital and innovation-driven growth. In an increasingly globalized economy, countries that invest in science, technology, engineering, and mathematics (STEM) education gain a competitive edge in innovation and economic competitiveness. By equipping Nigerian students with biotechnological knowledge and skills, the country can harness its scientific talent to address local challenges and participate actively in the global biotechnology

2.2 Challenges in Integrating and Implementing STEM Curriculum at Secondary School Level of Education

Integrating STEM education into the secondary school science curriculum presents various challenges that teachers and policymakers must address to ensure effective implementation and optimal learning outcomes. STEM Education offers immense potential for preparing students with essential 21st-century skills, but several barriers hinder its seamless integration into the curriculum, some of which are discuss below:

2.2.1 Lack of qualified teachers with proficiency in STEM Education: STEM Education is a complex and rapidly evolving field that requires specialized knowledge and skills to teach effectively. Many secondary school science teachers may not have received adequate training or professional development in STEM concepts and techniques. Regarding this matter, Sodangi et al. (2022) argued that continuous professional development is essential for effective implementation of the science curriculum by teachers. In similar vein, Ajayi and Adeyemi (2022) noted that, without competent teachers, schools may struggle to deliver high-quality STEM education, limiting students' exposure to the field. Teachers who are not well-versed in STEM education may not be able to effectively integrate new developments and technologies into their curriculum, thereby failing to prepare students for the demands of the 21st-century workforce.

2.2.2 Resource constraints: Resource constraint pose a significant barrier to implementing STEM education in secondary schools. Many schools in Nigeria lack the necessary laboratory facilities, equipment, and reagents needed to conduct STEM experiments and demonstrations (Oyinloye, 2018). The cost of acquiring and maintaining STEM equipment can be prohibitive for schools with limited budgets, especially in rural or underserved areas. As a result, students may miss out on hands-on learning experiences essential for understanding STEM concepts.

2.2.3 Outdated curriculum and teaching materials: The Science curriculum in Nigerian secondary schools often prioritizes traditional topics while neglecting emerging areas such as Artificial Intelligence, gene editing, synthetic biology among others. This gap can hinder students from gaining up-to-date knowledge in STEM Education. More so, Adeyanju and Adeyemo (2023) highlighted that, textbooks and instructional materials may not always reflect the latest advancements, which can limit students' understanding of current STEM education concepts (Adeyanju & Adeyemo, 2023). The curriculum, although comprehensive in its traditional scope, does not adequately reflect the rapid advancements in STEM education, making it imperative to update both the curriculum and teaching resources to ensure that students receive a modern and relevant STEM education.

2.2.4 Ethical considerations: Ethical considerations surrounding STEM education present challenges for teachers and policymakers. For instance, Biotechnological advancements, such as genetic engineering and cloning, raise complex moral and societal questions that must be addressed responsibly in the classroom. However, according to Bello and Maude (2019; Isma'il et al. 2021), undertaking these ethical dilemmas can be challenging, particularly when cultural and religious beliefs influence perceptions of STEM education. Hence, teachers must ensure that biotechnology education promotes ethical awareness and promotes critical thinking about the societal implications of biotechnological innovations.

2.2.5 Lack of awareness and appreciation for biotechnology: Lack of awareness and appreciation for biotechnology among stakeholders, including parents, students, and policymakers, poses a challenge to its implementation in the curriculum (Unoma & Menkiti, 2017; Kooffreh et al., 2021). STEM education is a relatively new and interdisciplinary field that may not receive sufficient recognition or support compared to traditional academic disciplines. Teachers must advocate for the importance of STEM education in preparing students for future careers and addressing societal challenges (Oladipo, 2023).

2.3 Opportunities in Implementing STEM Education in Science Curriculum at Secondary School Level of Education in Nigeria

Secondary school students represent the optimal demographic for cultivating fundamental knowledge in STEM education, as they constitute the future potential to elevate a country to a high-income and developed status (Bahri et al., 2014). Therefore, the integration of STEM education into the secondary school science curriculum presents numerous opportunities for enriching students' learning experiences, development of scientific literacy, and preparing them for future careers in science and technology. STEM education offers a wide range of opportunities for hands-on experimentation, interdisciplinary learning, and real-world applications in various fields. Bahri et al. (2014) argue that early exposure to proper STEM education is essential to enhance students' awareness of ethical issues related to STEM.

One significant opportunity of implementing STEM education is the promotion of practical, inquiry-based learning experiences for students. STEM education involves hands-on experimentation, data analysis, and problem-solving, providing students with opportunities to engage in authentic scientific inquiry and discovery. By conducting STEM experiments and projects, students develop critical thinking skills, scientific reasoning, and laboratory techniques essential for success in STEM (science, technology, engineering, and mathematics) disciplines (Oyinloye, 2018). In addition, integrating STEM education into the curriculum facilitates interdisciplinary learning by connecting biology with other scientific disciplines such as chemistry, physics, mathematics, and computer science. By exploring the interdisciplinary nature of STEM education, students develop a broader perspective on science and its role in addressing complex societal challenges (Adeyanju & Adeyemo, 2023).

Furthermore, implementing STEM education in secondary schools creates pathways for career readiness and workforce development in emerging fields of studies. STEM education is a rapidly growing industry with diverse career opportunities in research, healthcare, agriculture, environmental conservation, and biomanufacturing. By exposing students to biotechnological concepts and techniques early in their education, schools can inspire interest and cultivate talent in STEM-related fields of study, addressing the growing demand for skilled professionals in the sector (Ajayi & Adeyemi, 2022).

Integrating STEM education into the curriculum enhances students' awareness and understanding of ethical, social, and environmental issues associated with biotechnological advancements (Kooffreh et al., 2021). STEM education through Biotechnology raises complex ethical dilemmas related to genetic engineering, cloning, bioprospecting, and biosecurity, which require thoughtful consideration and informed decision-making. By engaging students in discussions and debates about these ethical considerations, teachers can promote ethical awareness, empathy, and responsible citizenship among future leaders and innovators (Bello & Maude, 2019; Isma'il et al. 2021).

Moreover, implementing STEM education creates opportunities for collaboration and partnerships between educational institutions, industry stakeholders, and research organizations. companies, research institutions, and government agencies can serve as valuable resources for schools, providing expertise, mentorship, and access to cutting-edge technologies and facilities. Through collaborations with external partners, schools can enrich students' learning experiences, expose them to real-world applications of STEM, and inspire future career pathways in the industry (Oladipo, 2023).

2.4 Advancing 21st Century Skills through STEM Education in Science Curriculum at Secondary School Level of Education

Developed countries have been incorporating 21st-century skills into their classrooms for some time, resulting in significant impacts on education (Ahmad & Ismail, 2023). In the 21st century, the integration of STEM education into the science curriculum presents a unique opportunity to advance students' acquisition of essential skills and competencies needed for success in a rapidly evolving world. The 21st century requires a workforce capable of respectful communication, critical reasoning, creative problem-solving, and collaboration from diverse perspectives to enhance industry quality (Ahmad & Ismail, 2023; Isma'il & Cyril, 2022;

Oghenevwede, 2022). Alismail and McGuire (2015) note that the integration of these skills has become a fundamental component of education curricula globally. Therefore, it is important for students in Nigeria to be well acquainted with 21st-century skills right from secondary school to ensure they thrive in a rapidly evolving global economy and future career aspirations.

Integration of STEM education into the Nigerian senior secondary school science curriculum will helps teachers prepare students for future professional endeavors while addressing 21st century challenges and opportunities. The integration facilitates the development of 21st century skills (see Table 1). These skills include critical thinking, problem-solving, collaboration, communication, creativity, innovation, adaptability, lifelong learning, ethical awareness, information literacy, technological literacy, and social responsibility, which are essential for preparing students for scientific challenges and opportunities in today's society. Ahmad and Ismail (2023) reported that engaging students in these skills improves their motivation toward learning.

Table 1: Integrable Biotechnology Concepts and 21st Century Skills

Biotechnology Concept	Curriculum Integration	Activities	Assessment	21st Century Skills
Basic Genetic Engineering	Include genetic engineering in topics like pest-resistant crops.	Problem-solving activities exploring genetic solutions to agricultural problems.	Case studies and problem-based learning assessments.	Critical Thinking, Problem-Solving, Technological Literacy
Genetically Modified Organisms (GMOs)	Teach the creation, benefits, and ethical concerns of GMOs.	Group projects on GMO research.	Group assignments assessing teamwork and presentation skills.	Collaboration, Communication, Ethical Awareness
Cloning	Discuss basics of cloning with examples like plant cloning.	Hands-on experiments and ethical debates on cloning.	Role-playing and simulations for critical thinking and ethical reasoning.	Critical Thinking, Ethical Awareness, Social Responsibility
Bioremediation	Explain bioremediation using local environmental issues.	Collaborative projects on bioremediation strategies.	Group presentations and reports.	Collaboration, Problem-Solving, Social Responsibility
Fermentation	Teach the basics of fermentation	Simple fermentation experiments	Lab reports and practical demonstrations.	Practical Skills, Critical

	and its uses in food and industry.	(e.g., making yogurt or bread).		Thinking, Innovation
Ethical Discussions	Incorporate ethical discussions into each biotechnology topic.	Classroom debates on genetic modification and biotechnology ethics.	Essays and debates for ethical reasoning.	Ethical Awareness, Responsibility
Introduction to Biotechnology	Focus on the evolving nature of biotechnology.	Update students with recent advancements through articles and research.	Assess integration of new information into learning.	Adaptability, Lifelong Learning, Information Literacy

Source: *Author, 2024*

2.4.1 Critical Thinking and Problem-Solving: STEM education encourages students to think critically, analyze data, and solve complex problems through inquiry-based learning approaches. By engaging in hands-on laboratory experiments, research projects, and case studies, students develop the ability to formulate hypotheses, design experiments, and evaluate evidence systematically (Adeyanju & Adeyemo, 2023; Isma'il & Cyril, 2022). STEM education through Biotechnological techniques such as DNA sequencing, genetic engineering, and bioinformatics provide real-world contexts for students to apply their critical thinking skills and address scientific challenges related to healthcare, agriculture, environmental conservation, and bio-manufacturing.

2.4.2 Collaboration and Communication: According to Yusof et al. (2022), effective class activities rely heavily on communication and collaboration, signifying the critical importance of 21st century skills. Chiruguru (2020) describes collaboration as the ability of a group of students to effectively complete tasks, share responsibilities, and achieve a common goal. STEM education promotes collaboration and communication skills by encouraging teamwork, interdisciplinary learning, and knowledge-sharing among students. Through group projects, laboratory exercises, and classroom discussions, students collaborate with peers, share ideas, and work towards common goals (Ajayi & Adeyemi, 2022). Collaborative learning experiences in STEM education require students to communicate effectively, listen to diverse perspectives, and negotiate consensus, mirroring the collaborative nature of scientific research and innovation. By working collaboratively, students develop interpersonal skills, empathy, and cultural competence essential for success in diverse professional settings.

2,4,3 Creativity and Innovation: STEM education nurtures students' creativity and innovation by encouraging them to explore novel solutions to scientific problems and societal challenges. By engaging in project-based learning, design thinking activities, and open-ended inquiries, students have the freedom to generate new ideas, experiment with different approaches, and take risks in their learning (Bello & Maude, 2019; Isma'il & Cyril, 2022). STEM education through Biotechnological innovations such as gene editing technologies, synthetic biology, and personalized medicine inspire students to think creatively and envision the possibilities of biotechnology to address global issues such as disease prevention, food security, environmental sustainability, and renewable energy.

2.4.4 Adaptability and Resilience: Adaptability and Resilience involve adjusting behaviours, thinking, or attitudes, to fit in the current or future environments while respecting time, resources, and systems constraints (Hiong & Osman, 2013). STEM education cultivates adaptability and resilience skills by exposing students to the dynamic and evolving nature of scientific knowledge and technology. The rapid pace of STEM education advancements requires students to embrace change, learn continuously, and adapt to new information and methodologies (Oyinloye., 2018). By experiencing uncertainties, setbacks, and failures in laboratory experiments and research projects, students develop resilience, perseverance, and a growth mindset that prepares them to thrive in a complex and unpredictable world.

2.4.5 Ethical and Social Responsibility: Social responsibility involves effectively managing technology and utilizing it in a manner that promotes the common good (Hiong & Osman, 2013). STEM education instills ethical awareness and social responsibility in students by exploring the ethical, legal, and societal implications of biotechnological innovations. Students critically examine ethical dilemmas related to genetic engineering, cloning, gene editing, and bioprospecting, considering diverse perspectives and values (Bello & Maude, 2019). Through engagement with ethical issues in STEM education, students cultivate empathy, integrity, and a sense of responsibility towards the ethical use of biotechnological advancements and their effects on individuals, communities, and the environment.

3. Conclusion

In the 21st century, the global education setting faces the challenge of equipping students with essential 21st century skills to thrive in a competitive and interconnected world. STEM education, with its diverse applications in healthcare, agriculture, and industry, represents a key area for integrating into the Nigerian secondary school science curriculum. This integration not only increases students' understanding of STEM concepts but also cultivates 21st century skills such as critical thinking, problem-solving, collaboration, and ethical awareness. Overcoming the challenges and taking advantage of the opportunities of STEM education, Nigeria can prepare students for future scientific challenges and opportunities in socio-economic development and sustainable growth in the country. Successful integration of STEM education requires fundamental efforts to review secondary school science curriculum and teacher training.

4. Recommendations

The following recommendations were made based on the conclusion

1. A review of the Nigerian secondary school science curriculum should be initiated to integrate STEM education topics. This reform should prioritize updating content, introducing new STEM concepts, and ensuring alignment with 21st-century skills.

2. Partnerships between educational institutions, industry, research organizations, and government agencies should be encouraged. These partnerships can provide schools with access to resources, expertise, and career talk on STEM related issues.
3. There should be provision of training or professional development opportunities for Science teachers to improve their content knowledge and pedagogical skills in STEM instruction. This is necessary for effective teaching and learning of STEM concepts in relation to their real world applications.

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Article 15

Effectiveness of Personalized-Learning Strategy on Performance in STEM Concepts among Senior Secondary School Biology Students in Kaduna North Education Zone, Kaduna State, Nigeria

Ahmed Muideen, Misbahu Adamu Sani

muhydeenahmed9@gmail.com, misbahumas@gmail.com

&

Zainab Muhammad Shuaibu
zeelamee@gmail.com

SMASE National INSET Centre, National Teachers' Institute, Kaduna-Nigeria

Abstract

This study investigated the Effectiveness of Personalized-Learning Strategy on Secondary School Biology Students' Performance in Nutrition Concepts in Kaduna North Education Zone, Kaduna State, Nigeria. The study employed quasi-experimental design involving 150 students as sample for the study from a population of 6,721 SS 2 students. The experimental group was treated using Personalized-Learning Strategy while the control group was taught using the conventional method. The instrument; Biology Performance Test (BPT) was used for data collection with a reliability coefficient (r) of 0.82. Descriptive statistics was used to answer the research questions while the null hypotheses were tested using independent samples t-test at $P \leq 0.05$ levels of significance. Results revealed a statistically significant difference between the performance of students in the treatment and control groups while no statistical difference of significance was observed between the male and female students. The findings of this study suggest the effectiveness of Personalized-Learning Strategy as a teaching strategy for STEM concepts and thus recommends among others, its adoption by STEM teachers because of its positive effect on students and gender suitability.

Keywords: *Biology, Secondary Education, Personalized-learning, STEM, Students' Achievement*

1. Introduction

In an era where Science, Technology, Engineering, and Mathematics (STEM) education is critical for national development, innovative approaches to teaching and learning are essential.

This is because STEM education is vital for preparing learners for future careers, driving innovation, and addressing real-world challenges, making it an essential part of modern education. Science is a systematic enterprise that builds and organizes knowledge in the form of testable explanations and predictions about the universe (Harper, 2020). Science as a body encompasses the study of physic, chemistry and biology among others.

Biology as a STEM subject is the scientific study of life and living organisms, including their structure, function, growth, evolution, distribution, and taxonomy (Mouhamad, 2018). It explores the intricate relationships between living things and their environment, examining the underlying mechanisms and processes that sustain life on earth (Ali, 2021). Several teaching strategies are available for teaching biology at the senior secondary school (FME, 2013). However, the suitability of a given strategy depends on the concept in consideration. According to Abudullai (2020), instructional strategies such as personalized-learning that involve active participation and engagement of students could be more effective in teaching STEM subjects such as biology for better understanding and improved performance.

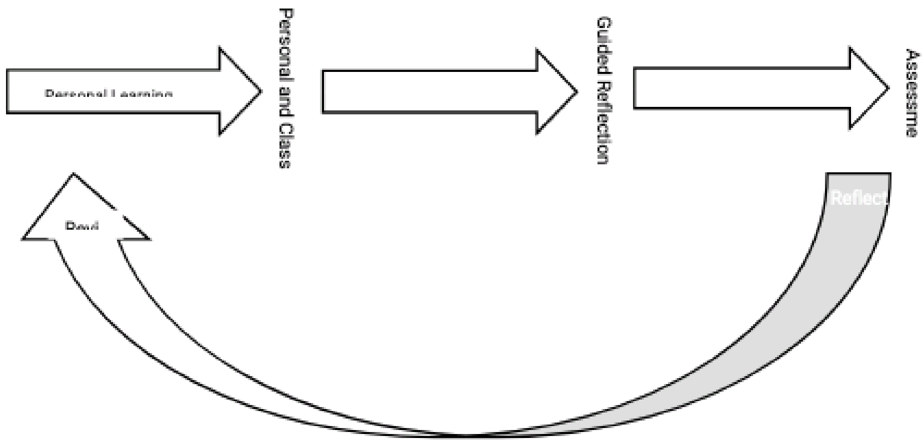
1.1 Personalized Learning Strategy

Personalized learning is an educational approach that tailors instruction to meet the individual needs, strengths, and interests of each student. It is grounded in the idea that students learn best when teaching methods and materials are adapted to their unique learning styles, pacing, and preferences (Pane, Steiner, Baird, & Hamilton, 2015). According to Patrick, Kathryn and Allison (2013), Personalized-Learning Strategy refers to a diverse variety of educational programmes, learning experiences, instructional approaches, and academic support strategies that are, designed to enable the academic success of each student. Personalized-Learning Strategy is a system which aims to teach the learner through activities performed personally, based on his/her abilities and needs, in order to acquire knowledge, attitudes, and skills, with supervision and guidance from the teacher (Al-Zboun and Mawadiah, 2016).

Studies have shown that personalized learning can lead to significant improvements in student outcomes, particularly in STEM subjects where conceptual understanding is crucial (Means, Toyama, Murphy, Bakia, & Jones, 2010). Personalized-Learning Strategy enables students to take their personal learning needs into considerations, which when used with the traditional instruction methods, tends to reduce students' learning time (Hotomaroglu, 2012) and could improve academic performance. Personalized-Learning aimed at creating an educational system that responds directly to the diverse needs of individuals rather than imposing a 'one size fits all' model on students (Williams, 2013 and Bates, 2014). Personalized-Learning Strategy actively engages students in the process of learning which ultimately leads to improved learning outcomes and learning experiences (Bentley and Miller (2004). The role of the teacher in the Personalized-Learning Strategy is restricted to the provision of assistance to students in developing Personalized-Learning plans, as well as diagnosing the points of strength and weaknesses in their knowledge, and modifying the learning setting and the teaching process according to the needs of students (Bautista, 2012).

A number of researchers have developed models of Personalized-Learning Strategy among which is the **Clark's Personalized-Learning instruction (2003)**. Clarke (2003) described the

Personalized-Learning Instruction model as learning procedure that takes into account the students' active participation in their learning from planning to execution of activities. The Clarke (2003) model is presented as follows:



Personalized-Learning Strategy Model
Source: Adopted from Clarke (2003).

1. **Personal Learning Plans:** Students and their teacher regularly assess student strengths, interests, and recent achievements so they can plan for further learning activities that challenge students to achieve more.
2. **Portfolios:** Students collect evidence of their learning from classes that show they are moving toward achieving their goals and meeting their expectations.
3. **Student Presentations (or Exhibitions):** Students explain the meaning of their work to a gathering of their friends, teachers, and guidance receiving feedback on their progress and ideas for new investigations.
4. **Assessment:** From the presentation of the students, the teacher makes necessary correction and assess the students based on the content of the lesson.

1.2 Theoretical Framework

Cognitive development theory (Piaget, 1964) and social interaction theory (Vygotsky, 1978) provide theoretical basis for this study. The two theories focus on active participation and engagement of students in the teaching and learning process for better understanding and achievement. Cognitive development theory states that, developmental stages deal with the nature of knowledge itself and how humans gradually come to acquire, construct, and use it. Piaget explains cognitive developmental stage as the change in reasoning level of a child acquiring new ways of understanding their environment. This theory assumes that all children go through the same sequence of development, but they do so at different rates. Teachers must make special efforts to provide classroom activities for individuals and small groups, rather than for the total class group.

The social interaction theory holds that a child's cognitive development is as a result of social interaction which plays a fundamental role in the development of cognition. Social interaction emphasized that effective learning happens through participation in social activities, making the social context of learning crucial. The theory emphasized that students must take some responsibility for their learning while the teacher acts as a facilitator who encourages students to discover principles for themselves and to construct knowledge by working to solve realistic problems.

1.3 Literature Review

Several studies have explored use of pernalized-learning strategy and its effect on students' academic performance. For instance, Akinsola and Awofala (2009) investigated the effect of Personalized Print-based Instruction on Achievement and Self-efficacy in Mathematics word problems among senior secondary students in Lagos State, Nigeria. The study employed Quasi-experimental design. With a sample size of 320 students. Mathematics Word Problem Achievement Test (MAWPAT) and Self-Efficacy Questionnaire (SEQ) were used for data collection. The results showed that significant differences existed in the Mathematics Word Problem Achievement Test and Self-Efficacy beliefs of personalized and non-personalized groups. Significant differences were also reported for male and female students of personalized groups and male and female students of non-personalized groups. Bautista (2012) examined the effect of Personalized Instruction on academic achievement of students in Physics in General Education Department of Cagayan Valley Computer and Information Technology College, Inc., Santiago City, Isabela, Philippines. The study employed quasi-experimental involving pretest posttest control group design. The sample was 78 Physics students divided into two groups (experimental group and control group). Teacher-made Achievement Test instrument was used for data collection. Findings from the study revealed significant differences in the achievement between the experimental and control groups in favour of the experimental group.

Savio-Ramos (2015) investigated the Efficacy of Personalized-Learning in Algebra as a remediation tool among students of Arizona University, United State. The study employed quasi experimental research design with a sample size of 117 students. Attitudinal Test (AT) instrument was used for data collection. Results reveal no significant difference in both groups. However, findings revealed that, students exposed to the Personalized-Learning environment had more positive perceptions towards Personalized-Learning than those exposed to non-Personalized-Learning. Ferhat and Mehmet (2016) examined the effect of Personalized Instruction System on the academic achievement of students of Software Engineering Department of Technology Faculty in Turkey. The pretest-posttest control group experimental design was used in the study with sample of 60 students. The instrument, Academic Achievement Test (AAT) was used for data collection. Results, reveals significant differences between the experimental and control group in favour of the experimental group. Further evidence from the study shows that Personalized-Learning strategy had positive effect on students' learning when used in combination with traditional learning environment.

Swan (2017) examined the effect of Personalized-Learning and its' effectiveness on Understanding and practice in College of Education, Health and Human Development, University of Canterbury, New Zealand. The study employed quasi-experimental design with a sample of 50 Physics students. The experimental group were taught using the personalized system of instruction, while the control group were taught using the traditional teaching method. The findings revealed significant differences in the achievement between the experimental and control group. The significant difference in the achievement was in favour of the experimental group. Alalwneh and Alomari (2018), examined the Impact of Personalized Teaching Strategy on the Achievement of the students of Vocation in Irbid University college, Irbid. The study employed quasi-experimental research design with a sample size of 62 female students The students were divided into experimental group which was taught using the personalized system of instruction, and the control group which was taught using the traditional teaching method. Results of the study showed significant differences in favour of the experimental group.

1.4 Statement of the Problem

Despite the numerous applications of biology in provision of basic need of man, poor performance of biology students in Senior Secondary School Certificate Examinations has persisted over the years (West African Examination Council Chief Examiners' Reports, 2019-2022). Instructional materials and other learning facilities which constitutes the school environment blended with appropriate teaching method facilitate teaching and learning process. The use of inappropriate method in teaching biology renders adequate facilities unproductive and promote concept difficult, which constitutes a problem. Several attempts geared toward the discovery of appropriate strategies for optimum learning of biology have indicated the potential benefits of personalized learning in improving academic outcomes (Pane et al., 2017; Walkington, 2013). However, there is a paucity of research specifically addressing how these strategies impact students' performance in Biology. This study therefore, aimed to fill this gap by investigating the effectiveness of personalized-learning strategy on the performance of senior secondary school Biology students in STEM concepts in Kaduna North Education Zone, Nigeria.

1.5 Objectives of the Study

This study was carried out to investigate the effectiveness of personalized-learning strategy on students’ academic performance in biology in Senior Secondary Schools in Kaduna North, Nigeria. The specific objectives of the study are to:

1. Determine the effect of personalized-learning strategy on Senior Secondary Schools Biology students’ academic performance in Kaduna North;
2. Find out the effect of personalized-learning strategy on male and female Senior Secondary Schools Biology students’ academic performance in Kaduna North.

1.6 Research questions

The following research questions were formulated to guide the study.

1. What is the difference between the academic performance mean score of students taught biology concepts using personalized-learning strategy and those taught using conventional lecture method in Senior Secondary Schools in Kaduna North?

2. What is the difference between the academic performance mean score of male and female students taught biology concepts using personalized-learning strategy in Senior Secondary Schools in Kaduna North?

1.7 Hypotheses

The following hypotheses were developed to answer the research questions.

Ho1: There is no significant difference between the academic performance mean score of students taught biology concepts using personalized-learning strategy and those taught using conventional lecture method in senior secondary schools in Kaduna North.

Ho2: There is no significant difference between the academic performance mean score of male and female students taught biology concept using personalized-learning strategy in senior secondary schools in Kaduna North.

2.0 Methodology

This study adopted quasi-experimental design. The population consist of 6,721 Senior Secondary 2 biology students in the 18 Senior Secondary Schools of Kaduna North Education Zone, Kaduna State, Nigeria. 150 Senior Secondary 2 biology students comprising of 66 male and 84 female students of intact classes in the selected schools formed the sample. 78 students were in the experimental group and 72 students in the control group. The selected classes were randomly assigned experimental and control group in each school. The instrument was Biology Performance Test (BPT) developed by the researcher which contains 25 multiple choice questions based on the contents of the Senior Secondary School Biology Curriculum. The items were selected from the West African Examinations Council (WAEC) past question papers. The instrument was given to two lecturers in science Education Department and one lecture in Measurement and Evaluation for face and content validation while the reliability coefficient was determined by test-retest method and calculated to be of 0.82 using Spearmen's Rank Order Correlation Coefficient. Mean, Standard Deviation and t-test of independent were statistical tools used for data analysis and hypotheses tested at .05 level of significance. Students in the experimental group were taught using personalized-learning strategy and those in control group were taught using conventional lecture method. The lesson lasted for 4 weeks. Before treatment, the instrument was administered to the experimental and control group as pre-test and after treatment as post-test.

3.0 Results

3.1 Research Question 1

What is the difference between the academic performance mean score of students taught biology concepts using personalized-learning strategy and those taught using conventional lecture method in Senior Secondary Schools in Kaduna North?

Data generated from Biology Performance Test (BPT) were subjected to descriptive statistics of mean and standard deviation and the result is presented in Table 1

Table 1: Mean and Standard Deviation of the Performance Scores between the Experimental Group and the Control group

Group	N	Mean	Std. D	M.D
Experimental	78	36.82	2.98	
Control	72	29.84	2.75	6.98

From Table 1, the mean score for students in the Experimental group was 36.82 and a standard deviation of 2.98, while the mean score for the control group was 29.84 and a standard deviation of 2.75 with mean difference of 6.98 in favour of the experimental group. This indicates that there is difference in the mean performance scores of the experimental group and the control group when taught using Personalized-Learning strategies and those taught using lecture method.

3.2 Research Question 2

What is the difference between the academic performance mean score of male and female students taught biology concepts using personalized-learning strategy in Senior Secondary Schools in Kaduna North?

Data generated from Biology Performance Test (BPT) were subjected to descriptive statistics of mean and standard deviation and the result is presented in Table 2.

Table 2 Performance Mean Scores of Male and Female Students Taught Biology using personalized-learning strategy

Gender (Experimental Group	N	Mean	Std. Deviation	Mean Difference
Male	34	28.59	3.88	1.61
Female	44	30.20	4.29	

Table 2 showed performance mean scores of male and female students taught Biology concepts using Personalized-Learning Strategy. The Table revealed mean scores of 28.59 and 30.20 for male and female students respectively with a slight mean difference of 1.61. In order to find out whether or not the difference is significant, the performance mean scores were subjected to t-test at $p \leq 0.05$ level of significance.

3.3 Null Hypothesis 1

There is no significant difference between the academic performance mean score of students taught biology concepts using personalized-learning strategy and those taught using conventional lecture method in senior secondary schools in Kaduna North.

To test the null hypothesis 1, the data generated via Biology Performance Test (BPT) were subjected to independent sample t-test statistics. The results obtained were computed and used to draw Table 3

Table 3: Summary of t-test Statistic on the difference between the Mean Performance Scores for Experimental and Control Groups.

Groups	N	Mean	Std. D	M.df	D.f	t	P	Remark	Decision
Experimental	78	47.48	7.51	13.61	141	8.60	0.00	Sig.	Rejected
Control	72	33.87	10.03						

Significant at P ≤ 0.05 level of significance.

Table 3 shows that there is significant difference between the mean academic performance scores of experimental and control group in favour of the experimental group. Reasons being that the calculated p-value of 0.00 is less than the adopted 0.05 alpha level of significance at degree of freedom (df) 141, in the same dimension, the t-calculated 8.60 is greater than the standard t-critical 1.98 (p value 0.00<0.05, t-cal 8.60 > t-cri 1.98 at df 141). This confirmed that the significance difference is in favour of the experimental group. Therefore, the null hypothesis which stated that There is no significant difference between the academic performance mean score of students taught biology concepts using personalized-learning strategy and those taught using conventional lecture method, is hereby rejected. This mean that there is a significant difference in performance between students taught biology using personalized-learning strategy and those taught using conventional lecture method.

3.4 Null Hypothesis 2

There is no significant difference between the academic performance mean score of male and female students taught biology concept using personalized-learning strategy in senior secondary schools in Kaduna North.

To test the null hypothesis 2, the data generated via Biology Performance Test (BPT) were subjected to independent sample t-test statistics. The results obtained were computed and used to draw Table 4.

Table 4: Summary of t-test Statistics on the difference between the Performance Scores for Male and Female Students in the Experimental Group.

Gender	N	Mean	Std. D	M.df	D.f	t	P	Remark	Decision
Male	34	47.45	8.53	0.05	52	0.02	0.98	N.S	Retain
Female	44	47.50	6.97						

Significant at P ≤ 0.05 level of significance.

Table 4 shows that there is no significant difference between the performance scores of male and female students in the experimental group. Reasons being that the calculated p-value of 0.98 is greater than the adopted 0.05 alpha level of significance at degree of freedom (df) 52 (p value 0.98 > 0.05 at df 52). This confirmed that there is no significance difference in the academic performance of male and female students in the experimental group. This is as a result of exposing both male and female students to personalized-learning strategy in the experimental group. Therefore, the null hypothesis which stated that there is no significant difference in academic performance mean score of male and female students using personalized-learning strategy, is hereby retained.

4.0 Discussion of Results

The results of hypothesis 1 (Table 3) reveals that there is a significant difference between the students exposed to Personalized-Learning Strategy and those taught using the conventional method. It was observed that performances of students who were taught using Personalized-Learning Strategy out performed others taught using the conventional method. This implies that the use of Personalized-Learning Strategy improved students' academic performance in Biology Concepts. The higher academic performance recorded by students taught using Personalized-Learning Strategy may be due to higher level of understanding acquired through active participation in the learning process. This finding is in line with that of Akinsola (2009), Bautista (2012), Savio-Ramos (2015) who found out that the Personalized-Learning Strategy was effective in enhancing students' performance. They found a significance difference in performance in favour of the experimental group. This is evidenced in the higher mean scores obtained by students in the experimental groups of their respective studies when compared to other conventional method of learning. Also, Ferhat and Mehmet (2016) and Swan (2017) in a separate study found that Personalized-Learning Strategy is effective in the teaching and learning process. They recommended the use of Personalized-Learning Strategy in the teaching and learning among secondary school students. The relatively poor performance of the subjects in the control group is an indication that the conventional method adopted in teaching science by science teachers is not effective in promoting cognitive processes in students in senior secondary school as observed by Usman (2010).

The result of hypothesis 2 (Table 4) showed that there is no significant difference between the mean academic performance of male and female student when exposed to Personalized-Learning Strategy. This implies that Personalized-Learning Strategy is gender friendly. This finding is in agreement with that of Bautista (2012), Savio-Ramos (2015), Ferhat and Mehmet (2016), Swan (2017) and Alalwneh (2018) who reported that there was no significant gender difference in performance when students were exposed to Personalized-Learning Strategy. Therefore, with these evidences Personalized-Learning Strategy is gender friendly.

5.0 Conclusion

Evidence from the results of this study showed that personalized-learning strategy is effective in teaching biology as a STEM subject. The use of this strategy enhanced students' understanding of concepts and caused a significant improvement in their performance in biology in senior secondary schools. There was significant difference in performance between students taught biology using personalized-learning strategy and those taught using conventional lecture method. Students taught using personalized-learning strategy obtained higher test scores than those taught with conventional lecture method. There was no significant difference in performance based on gender (male and female) and school type (public or private).

6.0 Contributions to Knowledge

The following contributions to knowledge were made from the results and findings of this study:

1. The research was able to establish that Personalized-Learning Strategy enhanced academic performance of secondary school biology students in STEM Concepts.
2. The findings in this study revealed that the use of Personalized-Learning Strategy is efficient in eliminating gender related differences in teaching of biology and other STEM subjects, indicating that the strategy is gender friendly.
3. The findings of this study have provided new information to the existing literature on the use of Personalized-Learning Strategy in teaching STEM Concepts.
4. The instruments adapted by the researcher (BPT) can be used by other researchers carrying out their studies in similar area and also classroom teachers.

7.0 Recommendations

Based on the findings of this study, the following recommendations are made:

1. Teachers of biology and other STEM-based subjects should adopt and use Personalized-Learning Strategy for improving students academic performance.
2. Teachers should endeavor to motivate students towards the learning of biology as a STEM subject.
3. Personalized-Learning Strategy should be use in teaching male and female biology students and other STEM subjects for improved academic performance due to its gender friendly nature.
4. Government agencies and stakeholders should organize training and retraining on regular courses, workshops, seminars and in-house training for biology and other STEM teachers on the use of Personalized-Learning Strategy for maximum and improved students' academic performance.

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Article 17

Revolutionising Physics Education: A Case Study on Implementing Concept-Based Learning in a STEM Secondary School in Zambia

Moses Kayola Phiri

kayolamoses@yahoo.com

Ministry of Education, Chiwala Boys STEM Secondary School

Chipo Namakau Sakala and Benson Banda

chiponamakau@gmail.com, Bensonbanda2003@yahoo.co.uk

Ministry of Education, Directorate of National Science Centre

Abstract

This study explores the impact of implementing a concept-based learning (CBL) approach in the physics curriculum at a selected STEM secondary school in Zambia. The research aims to assess the effectiveness of CBL in enhancing students' understanding of fundamental physics concepts and their ability to develop targeted competencies such as designing, construction and critical thinking. A quasi-experimental design was employed, with one class of 40 physics learners exposed to the CBL approach, while another class followed the traditional teaching methods. Data was collected through pre-and post-tests, classroom observations, and student interviews over three months. Data analysis incorporated thematic analysis for qualitative data using NVivo 14 and descriptive statistics for quantitative data using SPSS version 28, revealing a significant improvement in learners' conceptual understanding of energy in physics. The mean difference of 40.67 and the percentage improvement of 74.28% in the pre-CBL and post-CBL scores was more substantial compared to the mean difference of 19.0 and the percentage improvement of 34.8% in the traditional class. Additionally, qualitative data from class observations, interviews and videos revealed that students in the CBL group demonstrated higher engagement in designing and construction, greater confidence in applying physics principles, and a deeper appreciation for the subject. The findings suggest that the concept-based learning approach not only enhances students' academic performance but also fosters a more profound and enduring understanding of physics as well as competencies. This study highlights the potential of CBL as a transformative tool in physics education, particularly in STEM-focused institutions in African countries. Further research is recommended to explore the long-term effects of CBL and its applicability across different STEM disciplines.

Keywords: *Concept-based learning, STEM Secondary School, Physics education.*

1. Introduction

STEM (Science, Technology, Engineering, and Mathematics) education is critical to Africa's socio-economic development. STEM education is increasingly recognized as essential for Africa's future, particularly in fostering innovation, economic growth, and social development. However, traditional teaching methods, which focus heavily on memorization and rote learning, have proven inadequate in preparing learners for the challenges of the 21st century. Concept-Based Learning (CBL) offers an alternative pedagogical approach that emphasizes understanding underlying principles and applying knowledge in diverse contexts.

Concept-based learning has its roots in the early 1960's. The ideas presented by Birbili (2015) led to a shift in thinking about subject content and the methods employed to teach it. In order for teachers to teach effectively, there is need to understand the levels of knowledge from facts to underpinning concepts and principles (Taba: 1962). Since then, research has supported the importance of teaching conceptual rather than factual knowledge (Birbili: 2015). Unfortunately, STEM education in African secondary schools is still mainly hinged on the teaching of facts. Memorisation still appears to be a key element in classroom teaching, suggesting that facts and information are often seen as more important than the way the human brain conceptualises. However, facts are less useful today, in a 21st-century world where we can always use search engines and AI tools to get facts about any subject content. Of course, factual knowledge is important in STEM education but is not sufficient for learners to develop deep understanding, make real-world connections and develop competencies. According to Erickson (2007), "Conceptual thinking requires the ability to critically examine factual information; relate to prior knowledge; see patterns and connections; draw out significant understandings at the conceptual level; evaluate the truth of the understandings across time or situations; and, often, use the conceptual understanding to creatively solve a problem or create a new product, process, or idea." Medwell, J. & Wray, D. (2020) confirm that concept-based learning aims to promote the learning of concepts, which supports the generation and understanding of ideas, the transfer of knowledge and skills, and a critical or reflective perspective towards knowledge itself. Concept-based learning encourages educators to move beyond rote memorization and engage learners in meaningful exploration of concepts. By doing so, we can equip learners with the skills needed to navigate a world where information is readily available but understanding remains essential.

The study explored the effectiveness of the concept-based learning approach in improving learners' understanding of physics concepts. It even investigated the impact of CBL on the enhancement of learners' competencies in physics education. It further identified the challenges associated with the implementation of CBL in a Zambian secondary school setting and provided recommendations for scaling CBL in other STEM subjects and schools across Zambia and Africa at large.

1.1. Background

Like in many other African countries, physics education in Zambia faces numerous challenges. Traditional teaching methods often emphasise rote memorization and formulaic problem-solving and have been identified as barriers to learners' deep understanding of physics concepts. The growing need for a more effective educational approach has led to the exploration of concept-based learning (CBL) as a potential solution. CBL shifts the focus from memorization to the understanding of underlying principles, enabling learners to apply concepts in various contexts.

Despite the increasing emphasis on STEM education in Zambia, physics remains a challenging subject for many learners. The traditional approach to teaching physics has not sufficiently addressed the need for conceptual understanding, leading to poor performance and disengagement. This study seeks to evaluate whether the implementation of CBL can enhance learners' comprehension and competencies in physics, thereby improving their overall academic performance. Physics education in Zambia has traditionally relied on teacher-centered methods, where learners are passive recipients of information. This approach often results in a superficial understanding of scientific concepts, with learners struggling to apply their knowledge in real-world situations. Studies have shown that the lack of interactive and student-centered learning environments contributes to low student performance in physics.

CBL is grounded in constructivist theories of learning, which advocate for the active engagement of learners in the learning process. According to Bruner (1960) and Piaget (1952), learners learn best when they are allowed to explore concepts and construct their own understanding. CBL encourages this by focusing on the 'big ideas' that transcend specific examples, helping learners to see the connections between different topics and apply their knowledge in novel situations.

Several studies have highlighted the benefits of CBL in STEM education. For instance, a study conducted in the United States demonstrated that learners who were taught using a concept-based curriculum out-performed their peers in both understanding and application of scientific concepts (Donovan & Bransford, 2005). Similarly, in South Africa, the implementation of CBL in a secondary school physics program led to significant improvements in student engagement and academic performance (Mahlangu, 2017).

1.2. Purpose of the Study

The purpose of this study was to evaluate the effectiveness of the concept-based learning approach in enhancing learners' understanding of physics concepts and their competencies in a selected STEM secondary school in Zambia.

1.3. Problem Statement

Physics education in Zambia, like in many other African countries, faces significant challenges due to the predominance of traditional teaching methods that emphasize rote memorization and formulaic problem-solving. These methods often fail to foster a deep understanding of fundamental physics concepts and do not adequately prepare learners for real-world applications or the demands of the 21st century. As a result, many students exhibit low levels of engagement, poor academic performance, and a lack of critical competencies such as problem-solving, critical thinking, designing, and construction.

Despite the increasing emphasis on STEM (Science, Technology, Engineering, and Mathematics) education in Zambia, the current pedagogical approaches have not effectively addressed the gaps in learners' comprehension and competencies, particularly in physics. Concept-Based Learning (CBL), which emphasizes understanding core principles and applying knowledge in diverse contexts, offers a potential solution to these challenges. However, there is limited empirical evidence on the effectiveness of CBL in enhancing learners' understanding of physics concepts and competencies in the Zambian context.

This study seeks to address this gap by investigating the impact of implementing a concept-based learning approach in the physics curriculum at a selected STEM secondary school in Zambia. The research aims to determine whether CBL can improve students' understanding of fundamental physics concepts, foster critical thinking and problem-solving skills, and enhance targeted competencies such as designing and construction, compared to traditional teaching methods. The study also aims to identify the challenges associated with the implementation of CBL and provide recommendations for scaling this approach across other STEM subjects and schools in Zambia and Africa at large.

1.4. **Research Objectives**

a. To explore the effectiveness of the concept-based learning approach in improving learners' understanding of physics concepts.
b. To investigate the impact of CBL on enhancing learners' competencies in physics education.
c. To identify the challenges associated with implementing CBL in a Zambian secondary school setting.

1.5. **Research Questions**

a. How effective is the concept-based learning approach in improving learners' understanding of physics concepts?
b. What is the impact of CBL on enhancing learners' competencies in physics education?
c. What challenges are associated with implementing CBL in a Zambian secondary school setting?

1.6. Significance of the Study

This study contributes to the growing body of literature on innovative pedagogical approaches in STEM education. It highlights the potential of CBL as a transformative tool for enhancing conceptual understanding, critical thinking, and engagement in physics education in Zambia and other African countries. The findings may inform policymakers, educators, and curriculum developers on integrating CBL in STEM curricula, ultimately improving educational outcomes.

1.7. Scope and Limitations of the Study

This study focused on the impact of the CBL approach in a single STEM secondary school in Zambia, limiting its generalizability to other contexts. The study was conducted over three months, which may not capture the long-term effects of CBL. Further research is needed to examine the approach's impact over a more extended period and in different settings.

1.8. Conceptual Framework

The conceptual framework for implementing concept-based learning (CBL) in this study involves a series of pedagogical strategies designed to deepen learners' understanding of physics concepts through active engagement and application. Developed by African educationists during the 2023 KCCP training sponsored by JICA, the framework begins with identifying essential concepts, such as energy and its harnessing, which are transferable across topics and applicable in real-world contexts. The next step involves designing engaging learning experiences that allow students to explore these "big ideas" through activities like experiments, simulations, and projects, fostering connections between STEM disciplines and everyday situations.

Assessment and evaluation strategies focus on understanding, application, and connections rather than rote memorization. Rubrics are used to evaluate critical thinking, problem-solving, creativity, and specific competencies such as designing and construction. Scaffolding learning is another key strategy, starting with practical, concrete examples and gradually moving toward abstract understanding. Inquiry and exploration are encouraged through open-ended questions that prompt curiosity and critical thinking, while collaboration and discussion foster a supportive learning environment through peer teaching and group projects. Reflection and revision based on feedback ensure continuous improvement in teaching and learning.

The CBL lesson was structured around the 5E Learning Model Engage, Explore, Explain, Elaborate, and Evaluate facilitating active learning and deeper understanding of energy harnessing. Activities were centred on designing and constructing energy-harnessing devices using locally available resources, allowing students to apply physics principles in meaningful, practical contexts. This approach was aimed at enhancing learners' conceptual understanding, problem-solving abilities, critical thinking, and practical competencies in designing and constructing physics-related projects.

Figure 3: 5E Model

2. Methodology

2.1. Research Design

Quasi-experimental research design was employed for this study. Quasi-experimental research is a type of research design that attempts to establish cause-and-effect relationships among variables but lacks the key element of random assignment. Unlike true experimental designs, where participants are randomly assigned to experimental and control groups, quasi-experimental designs often involve groups that are naturally occurring or pre-existing. In this study, the sample randomly selected was a class of 40 physics learners exposed to the CBL approach, while another class followed the traditional teaching methods. All the learners were from a selected Stem Secondary School in the Copper Belt province of Zambia.

2.2. Target and Sampling Procedure

The study's target population comprised physics learners at a selected STEM secondary school in the Copper Belt province of Zambia. A class of 40 learners was selected for the CBL intervention, while another class of 40 learners followed the traditional teaching methods.

2.3. Data Sources and Collection

Data was collected through multiple methods: pre- and post-tests, classroom observations, videos, interviews, and assessment rubrics. These methods provided a comprehensive understanding of learners' experiences and conceptual understanding, capturing both quantitative and qualitative data**.** These methods of data collection were selected to elicit rich descriptions. The intention was to allow for detailed, context-specific observations. By using these methods, observers captured nuances, interactions, and unexpected events. The methods also allowed flexibility as there were no predefined codes, so observers adapted to unique situations. This flexibility is valuable when exploring novel teaching methods or assessing complex behaviours. Holistic understanding is another merit of these data collection methods for the entire teaching-learning context, including nonverbal cues, learner’s reactions, and classroom dynamics considered.

2.4. Data Analysis

Data analysis involved thematic analysis for qualitative data using NVivo 14 and descriptive statistics for quantitative data using SPSS version 28. Thematic analysis allowed for identifying key themes in the qualitative data, while descriptive statistics provided insights into performance improvements between the CBL and traditional teaching groups.

2.5. Validity and Reliability

The study ensured validity by using multiple data collection methods to triangulate findings. Reliability was addressed through standardized procedures for data collection and analysis, ensuring consistency in measurement.

2.6. Ethical Considerations

Ethical approval was obtained from the relevant educational authorities, and informed consent was obtained from all participants. The confidentiality and anonymity of participants were maintained throughout the study.

This comprehensive approach ensures that the findings are robust, reliable, and applicable to the context of STEM education in Zambia. The results will be used to inform educational practice and policy, contributing to the broader discourse on pedagogical innovation in Africa.

3. Results

3.1. Results Related to Objective 1: Effectiveness of the Concept-Based Learning Approach in Improving Learners' Understanding of Physics Concepts

Table 1 shows results on the effectiveness of the concept-based learning approach in improving learners’ understanding of physics concepts.

Table 1:Learners' Understanding of Physics Concepts

Confidence in Understanding Physics	**Theme**	**Description**	**Evidence**
Deeper Conceptual Understanding	Enhanced Grasp of Fundamental Physics Concepts	Learners demonstrated a more profound understanding of core physics concepts, moving beyond rote memorization to grasp the underlying principles. CBL allowed learners to engage with the material more deeply, facilitating long-term retention and comprehension.	Learners were able to explain complex physics concepts in their own words and apply them in various contexts, such as solving non-routine problems and conducting experiments that required a deep understanding of the material.
Improved Problem-Solving Skills	Ability to Apply Concepts to Solve Complex Problems	The CBL approach encouraged learners to think critically and apply their knowledge to solve challenging physics problems. This led to an improvement in their problem-solving skills, as they were required to connect different concepts and use them creatively in new situations.	During assessments and classroom activities, learners showed an increased ability to tackle complex physics problems that required the integration of multiple concepts, a skill that was less developed before the implementation of CBL.
Increased Student Engagement	Higher Levels of Participation and Interest in Physics	CBL made physics lessons more engaging and interactive, leading to increased student participation. Learners were more motivated to learn and explore physics concepts, as the CBL approach emphasized understanding and application rather than memorization.	Teachers reported a noticeable increase in student engagement, with more learners actively participating in discussions, asking questions, and showing enthusiasm for learning physics.

Confidence in Understanding Physics	Theme	Description	Evidence
Enhanced Critical Thinking and Analytical Skills	Development of Higher-Order Thinking Skills	CBL encouraged learners to engage in higher-order thinking processes, such as analysis, evaluation, and synthesis. This approach pushed learners to think critically about physics concepts, analyse relationships between different ideas, and evaluate the validity of different approaches to problem-solving.	In classroom discussions and written assessments, learners exhibited improved analytical skills, often exploring alternative methods to solve problems and critically evaluating different solutions.
Confidence in Understanding Physics	Boost in Learners' Confidence and Self-Efficacy in Physics	As learners' understanding of physics concepts improved, so did their confidence in their ability to succeed in the subject. This was particularly evident in learners who previously struggled with physics, as they became more confident in their ability to grasp and apply difficult concepts.	Student feedback and teacher observations indicated that learners felt more confident in their understanding of physics, which was reflected in their willingness to participate in class and their improved performance in assessments.

Further, descriptive data is shown in Figures 2 based on the objective of examining the effectiveness of the concept-based learning (CBL) approach in improving learners' understanding of physics concepts, the learners' performance data before and after the implementation of CBL was analysed. The key statistics included measures of central tendency (mean, median), measures of variability (standard deviation, variance), and a comparison of pre-CBL and post-CBL scores.

Figure 2 highlights the descriptive statistics for pre and post-scores in a class with CBL intervention.

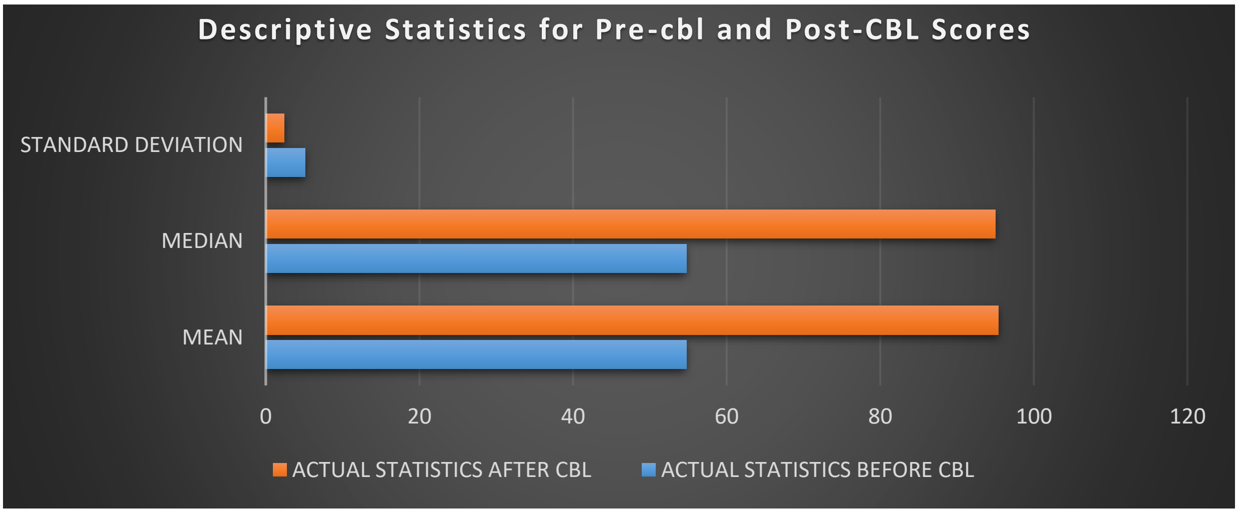

Figure 4:Descriptive Statistics for Pre- and Post-Scores in A Class with CBL Intervention

The mean score of learners significantly increased from 54.75 (pre-CBL) to 95.42 (post-CBL), indicating a substantial improvement in their understanding of physics concepts after the implementation of the concept-based learning approach.

The reduction in standard deviation from 5.15 (pre-CBL) to 2.41 (post-CBL) suggests that the scores became more consistent among learners after adopting the CBL approach, indicating a more uniform understanding of the subject matter.

Figure 3 highlights the descriptive statistics for pre- and post-scores in a class without CBL intervention (traditional class).

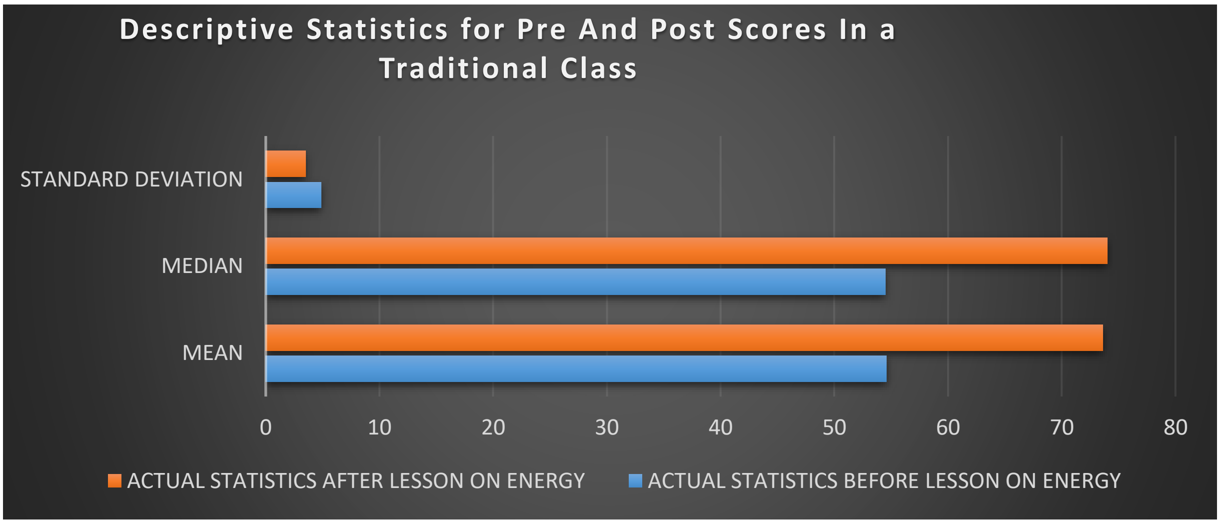

Figure 5: ***Descriptive Statistics for Pre and Post-Scores in a Traditional Class***

There was also an increase in the mean score of learners from 54.6 (pre) to 73.6 (post), indicating an improvement in their understanding of physics concepts after learning about energy. Also notable was the reduction in standard deviation from 4.86 (pre) to 3.50 (post) suggesting that the scores became more consistent among learners, indicating a more uniform understanding of the subject matter. However, this improvement was not as substantial as the one shown by the CBL intervention.

Figures 4 and 5 highlight the comparative analysis of the mean differences and percentage improvements for the CBL intervention class and traditional class.

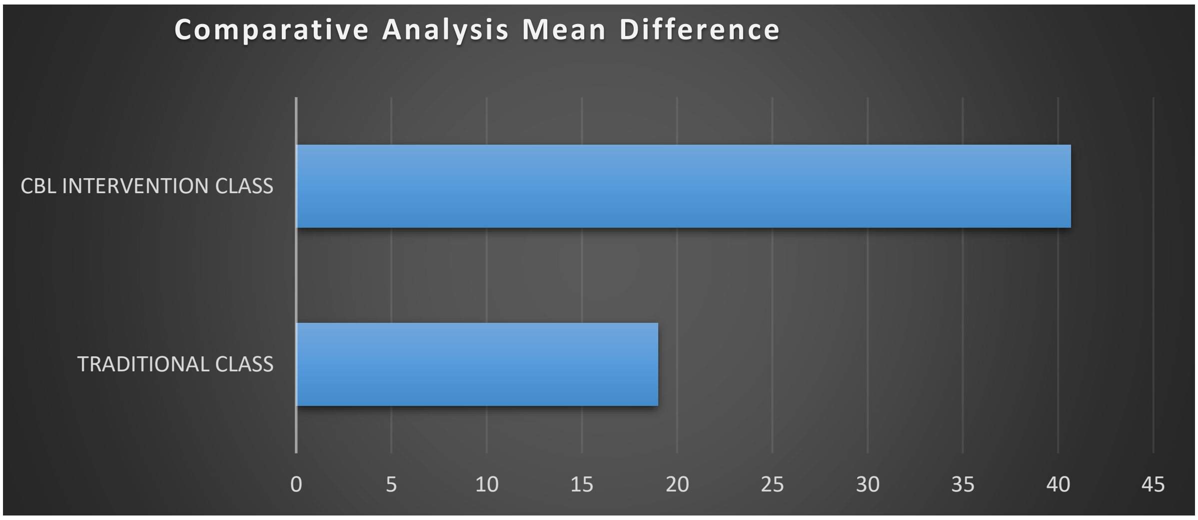

Figure 6:Comparative Analysis- Mean Differences

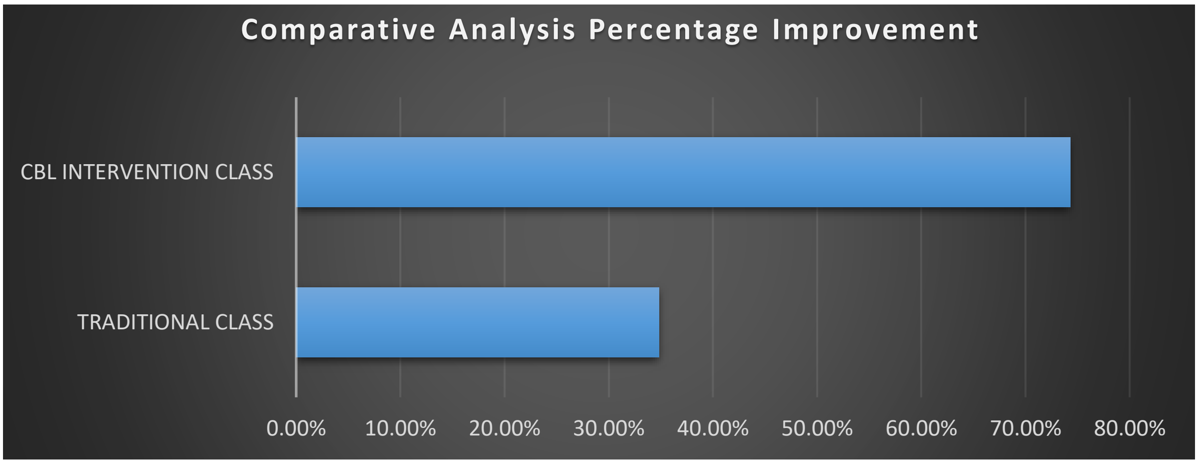

Figure 7:Comparative Analysis- Percentage Improvements

The mean difference of 40.67 and the percentage improvement of 74.28% in the pre-CBL and post-CBL scores was more substantial compared to the mean difference of 19.0 and the percentage improvement of 34.8% in the traditional class. This further highlights the effectiveness of CBL in enhancing learners' comprehension of physics.

3.2. Results Related to Objective 2: Impact of CBL on Enhancing Learners' Competencies in Physics Education

For the research objective "To investigate the impact of CBL on the enhancement of learners' competencies in physics education," the thematic analysis involved exploring how concept-based learning (CBL) influences various aspects of learners' competencies in physics, such as understanding, application, critical thinking, and engagement. Table 2 shows results on the impact of CBL on the enhancement of learners' competencies in physics education.

Table 2:Enhancement of learners' competences

Competences	Theme	Description	Evidence
Development of Designing Competence	Ability to design a device or system based on physics concepts	CBL fostered the learner’s ability to conceptualize, plan, and execute physics-related projects effectively, leading to improved proficiency in designing devices or systems by drawing, modelling, or computer-aided design.	Student Reflections: “Before learning through CBL, I often struggled to understand how to start a design project in physics. Now, I can connect concepts like energy conservation directly to my design, making my projects more accurate and functional."
			"Concept-based learning has made me think more deeply about the principles behind the design tasks. For instance, when designing a device to harness energy, I focused on understanding the conversion of energy, which made the design process more logical and straightforward."
			Analysis of class observations revealed that learners were able to produce designs that showed a clear understanding of the physics concepts involved.
Enhanced Construction Competence	Ability to construct a device or system based on physics concepts	Construction competence refers to learners' ability to physically build or assemble systems or devices that demonstrate physics principles. CBL encourages learners to apply their theoretical understanding in hands-on activities, allowing them to translate abstract concepts into tangible, functional constructs. This theme captures how	Student Reflections: "After engaging in CBL, I feel more confident in building physics devices. Understanding the underlying principles helps me ensure that my constructions work and align with the expected outcomes." "CBL has made it easier for me to connect theory with practice. When constructing a system of harnessing energy, I could predict the efficiency and adjust my

Competences	Theme	Description	Evidence
		CBL fosters a deeper comprehension of physics concepts, enabling learners to construct devices or systems with greater precision, accuracy, and innovation. As a result, learners develop practical skills that are critical for effectively demonstrating and applying physics knowledge in real-world scenarios.	design accordingly, which made the construction process smoother and more successful." Analysis of projects revealed that learners were able to produce constructs that were not only functional but also aligned with the theoretical principles they were meant to demonstrate.
			"After engaging in CBL, I feel more confident in building physics devices. Understanding the underlying principles helps me ensure that my constructions work and align with the expected outcomes."
			"CBL has made it easier for me to connect theory with practice. When constructing a system of harnessing energy, I could predict the efficiency and adjust my design accordingly, which made the construction process smoother and more successful."
			Analysis of projects revealed that learners were able to produce constructs that were not only functional but also aligned with the theoretical principles they were meant to demonstrate.
Enhanced Critical Thinking Skills	Development of Analytical and Problem-Solving Abilities	CBL fostered critical thinking by requiring learners to engage in higher-order cognitive processes, such as analysis, synthesis, and evaluation. This	During class discussions and assessments, learners were better able to articulate their reasoning, challenge assumptions, and explore alternative solutions to complex physics problems.

Competences	Theme	Description	Evidence
		shift from passive learning to active engagement led to the development of stronger problem-solving skills.	
Confidence in Physics	Boost in Learners' Self-Efficacy and Confidence in Physics	As learners gained a better understanding and ability to apply physics concepts, their confidence in their own abilities increased. This was particularly evident in learners who previously struggled with physics, as they began to see themselves as capable of mastering the subject.	Student feedback indicated a rise in self-confidence, with many expressing that they felt more capable of tackling challenging physics problems.

3.3. Results Related to Objective 3: Challenges Associated with the Implementation of CBL in Physics Education

Table 4 shows results for challenges associated with the implementation of CBL

Table 3:challenges associated with the implementation of CBL

Challenges in Transitioning to CBL	Theme	Description	Evidence
Challenges in Transitioning to CBL	Initial Adjustment Difficulties for Learners and Teachers	The shift from traditional teaching methods to the CBL approach presented challenges for both learners and teachers. Learners had to adjust to a learning style that required active engagement and critical thinking, while teachers had to adapt their instructional strategies to facilitate this new approach.	Both learners and teachers reported initial difficulties in adapting to the CBL approach, including the need for more preparation time and the challenge of shifting away from familiar teaching and learning methods. However, these challenges diminished over time as both groups became more accustomed to the new approach.

4. Discussion of Findings

4.1. Impact of CBL on Learner's Understanding of Physics Concepts

The thematic analysis of qualitative data revealed that the concept-based learning approach effectively improves learners' understanding of physics concepts by fostering deeper conceptual understanding, enhancing problem-solving skills, increasing student engagement, and developing critical thinking abilities. Although there were initial challenges in transitioning to CBL, the overall impact on learners' understanding of physics was positive, leading to increased confidence and improved academic performance. This was evidenced by their ability to apply these concepts to solve complex, real-world problems while designing and constructing devices and systems that can be used to harness energy.

The descriptive statistics also suggested that the concept-based learning approach positively impacts learners' understanding of physics concepts, improving both the average performance and consistency among learners.

These results are in line with Wieman, C. E., & Perkins, K. K. (2005), whose work study emphasised the need for transforming traditional physics education to focus more on conceptual understanding and less on rote learning. They advocated for the use of research-based instructional strategies that promote deep learning. A similar approach was proposed by Redish, E. F. (2003)**,** whose book is a comprehensive guide for physics educators, offering strategies and tools for implementing concept-based learning. It emphasises active learning, where students interact with the material, their peers, and the instructor to build a deep understanding of physics concepts.

4.2. Impact of CBL On Learner's Competences

The thematic analysis of qualitative data revealed that the concept-based learning approach significantly enhances learners' competencies in physics education by improving their conceptual understanding, ability to apply knowledge, critical thinking skills, engagement, and confidence. Learners were highly engaged in the targeted competencies of designing and construction as they were working on their projects. While there were challenges in the initial stages of implementation, the overall impact of CBL on learners' physics competencies was overwhelmingly positive, leading to a more effective and meaningful learning experience.

These findings are similar to Erickson, H. L. (2007) work, which is a foundational text in the field of concept-based learning. Erickson's book outlines how CBL can foster deep learning and develop higher-order thinking skills. It provides strategies for designing a curriculum that moves beyond rote memorization to focus on concepts, thus enhancing learners' competencies in critical thinking, creativity, and problem-solving. This seminal work by Bransford, J. D., Brown, A. L., & Cocking, R. R. (Eds.). (2000) also discusses the science of learning and the importance of understanding core concepts. It emphasizes how learning that is concept-driven, rather than fact-driven, can lead to better problem-solving abilities and adaptability, which are crucial competencies in education and beyond.

4.3. Challenges in Implementing CBL

Despite its benefits, the implementation of CBL faced some challenges. The most notable one is the resistance of both teachers and learners to the new approach. Some learners found the shift from rote learning to conceptual exploration challenging at first. Teachers noted that the first few weeks of CBL saw some resistance from learners accustomed to traditional methods, but this diminished as they became more familiar with the approach. Even some teachers complained about the requirement for more preparation time to effectively plan for initial engaging learning experiences as well as provide continuous individualised support to learners' projects.

5. Conclusions

The findings of this study indicate that the concept-based learning (CBL) approach significantly enhances learners' understanding of physics concepts and competencies in a Zambian secondary school setting. The CBL approach proved effective in improving learners' grasp of fundamental physics concepts, as evidenced by both qualitative and quantitative data. Learners exposed to CBL exhibited a deeper conceptual understanding, enhanced problem-solving skills, increased engagement, stronger critical thinking abilities, and greater confidence in their understanding of physics. The substantial mean score improvement and reduced score variability in the CBL group compared to the traditional teaching group further confirm the effectiveness of this approach in promoting a more profound and lasting understanding of physics. Moreover, the study demonstrated that CBL positively impacts the development of critical competencies among learners, such as designing, construction, and critical thinking. Learners in the CBL group showed marked improvements in their ability to design and construct devices based on physics principles, apply theoretical knowledge in practical contexts, and engage in higher-order thinking processes. These competencies are essential for success in STEM fields and reflect the transformative potential of CBL in fostering skills that go beyond rote memorization. However, the implementation of CBL was not without challenges. Both learners and teachers initially faced resistance to the new approach, requiring adjustments to a more interactive and student-centered learning environment. Additionally, teachers reported increased preparation time and the need to shift from familiar teaching methods to ones that facilitated deeper conceptual understanding. Despite these challenges, the study found that with adequate time, training, and support, both teachers and learners adapted well to the new pedagogical approach, underscoring the importance of adequate resources and continuous professional development for successful implementation.

6. Recommendations

Based on the study's findings, several recommendations are proposed to enhance the effectiveness and scalability of the concept-based learning (CBL) approach in physics education and other STEM subjects across Zambia and Africa. Firstly, there is a need for continuous professional development programs to train teachers in CBL methodologies. Such training will help educators understand and effectively implement CBL strategies, fostering a more interactive and concept-driven learning environment. Secondly, resource allocation should be prioritized to provide schools with the necessary materials, including laboratory equipment and teaching aids, to support CBL activities. Ensuring that teachers and learners have access to the tools needed for hands-on exploration will enhance the practical application of physics concepts and competencies.

Additionally, policy support from educational authorities is crucial for the broader adoption of CBL. The Ministry of Education should consider integrating CBL into the national curriculum, particularly in STEM subjects, to improve educational outcomes. Policymakers should also develop guidelines and frameworks that encourage innovative pedagogical practices and provide the necessary support to schools during the transition period. Lastly, further research is recommended to evaluate the long-term impact of CBL on student performance across different regions and subjects in Zambia. Such studies would help identify best practices, assess scalability, and refine the approach for different educational contexts, ensuring that the benefits of CBL are maximized across the broader educational landscape.

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