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Research Article

Integrating artificial intelligence into STEM classrooms: Impact on students critical thinking and problem-solving skills in secondary schools Zaria education zone, Kaduna State, Nigeria.

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Abstract

This study investigated the impact of integrating Artificial Intelligence (AI) tools into STEM classrooms on the critical thinking and problem-solving skills of secondary school students in Zaria Education Zone, Northern Nigeria. A quasi-experimental pre-test, post-test control group design was employed involving 192 SSII students drawn from four public secondary schools using simple random sampling technique. The experimental group was taught STEM concepts using AI-powered adaptive platforms, while the control group received conventional instruction. Data were collected using a Critical Thinking Skills Test (CTST) and a STEM Problem-Solving Performance Test (SPSPT), both validated and piloted for reliability. Analysis of Covariance (ANCOVA) revealed statistically significant differences in favor of the experimental group for both critical thinking ($F_{(1,188)} = 27.78$, $p < 0.001$, $\eta^2 = 0.128$) and problem-solving performance ($F_{(1,188)} = 35.21$, $p < 0.001$, $\eta^2 = 0.158$). These results indicate that AI-integrated instruction meaningfully enhances cognitive outcomes in STEM education. The study concludes that AI tools, when effectively implemented, can foster deeper learning, support personalized instruction, and strengthen students' 21st-century skills. It recommends teacher training, infrastructure provision, and curriculum reform to facilitate scalable AI adoption in Nigerian schools.

Keywords: Artificial Intelligence, STEM Education, Critical Thinking, Problem-Solving, Secondary Schools, Adaptive Learning.

1. Introduction

In the 21st century, education systems worldwide are increasingly called upon to equip learners with skills that extend beyond rote memorization and theoretical knowledge. In this era marked by rapid technological transformation, the integration of Artificial Intelligence (AI) in education has emerged as a pivotal force for reimagining how teaching and learning occur—particularly in Science, Technology, Engineering, and Mathematics (STEM) classrooms. STEM education plays a crucial role in preparing students for innovation, critical inquiry, and problem-solving in a knowledge-based economy. Yet, in many developing nations, including Nigeria, traditional methods of instruction often fail to cultivate these skills effectively due to their teacher-centered nature and limited personalization of learning experiences.

Artificial Intelligence, characterized by machine learning, natural language processing, and adaptive technologies, is assumes to offer a transformative opportunity to address these challenges. AI-powered tools such as intelligent tutoring systems, personalized learning platforms, and virtual lab simulations have been suggested to possess the capacity to provide tailored feedback, track student progress, and adapt instructional content in real-time to meet individual learning needs. According to UNESCO (2023), AI integration into classrooms can enhance cognitive engagement, improve academic achievement, and foster 21st-century competencies, especially in STEM fields. Similarly, Holmes et al. (2022) affirmed that the application of AI in STEM learning environments supports the development of critical thinking by enabling students to analyze data, model scientific phenomena, and solve real-world problems through interactive systems.

Despite the promise of AI, there is limited empirical research in sub-Saharan Africa and Nigeria in particular on its direct impact on secondary school students' cognitive development, especially in areas like critical thinking and problem-solving. As AI becomes more accessible through mobile applications, intelligent dashboards, and cloud-based tools, it is essential to understand how these technologies can be systematically implemented in classrooms to promote higher-order thinking skills. This study, therefore, investigated the impact of integrating artificial intelligence tools in STEM classrooms on the critical thinking and problem-solving skills of secondary school students in Northern Nigeria. The findings would contribute to the growing body of knowledge on EdTech and inform policy

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decisions related to the adoption of AI for quality STEM education in the region.

The demand for critical thinking and problem-solving competencies in today's technology-driven world has placed immense pressure on education systems to transform their instructional practices, particularly within STEM disciplines. However, in many Nigerian secondary schools, teaching was mainly traditional, these contributed to rote memorization and passive learning rather than inquiry, analysis, and innovation. One of the major reasons for this challenge is the traditional method of teaching, where teachers mostly conventional and students passively listen. This teacher-cantered approach makes STEM subjects abstract and disconnected from students' everyday experiences (Lawal et-al, 2025). As a result, students often struggle to apply STEM knowledge to real-life problems, exhibit low levels of engagement, and perform poorly in external assessments that test reasoning and analytical abilities. This persistent under-development of higher-order thinking skills continues to hinder Nigeria's educational and economic advancement in an era where STEM proficiency is essential for national development.

Artificial Intelligence (AI) has the potential to bridge this gap by enabling more interactive, personalized, and data-informed learning experiences. AI-powered learning platforms can support learners in diagnosing misconceptions, exploring virtual simulations, and engaging in feedback-rich environments that enhance critical thinking and foster structured problem-solving. Nevertheless, despite the increasing accessibility of AI tools and platforms, there is limited integration of these technologies into Nigerian secondary school STEM classrooms. Moreover, there is a significant dearth of empirical evidence on whether such tools, when integrated into real classroom settings, can meaningfully impact students' cognitive outcomes.

Consequently, this study examined the effect of integrating Artificial Intelligence into STEM classrooms on the critical thinking and problem-solving skills of secondary school students in Northern Nigeria. The study attempted to fill a crucial gap in the literature by providing contextual evidence on the effectiveness of AI-driven instruction in enhancing essential 21st-century skills. The outcome of the research is expected to inform curriculum designers, school administrators, and policymakers about the practical implications of adopting AI technologies for STEM education reform in the Nigerian context.

The aim of this study is to investigate the impact of integrating Artificial Intelligence (AI) tools into STEM classrooms on secondary school students' critical thinking and problem-solving skills in Northern Nigeria. Specifically, the objectives of this was to:

(i) Examine the effect of AI-powered instructional tools on the development of critical thinking skills among secondary school STEM students.
(ii) Determine the impact of AI integration on students' problem-solving performance in STEM subjects compared to traditional instructional approaches.

The study was guided by the following research questions:

1. What is the difference in critical thinking skills between students taught STEM subjects using AI-integrated instruction and those taught using conventional methods?
2. What is the difference in problem-solving performance between students exposed to AI-integrated STEM instruction and those receiving traditional instruction?

The following null hypotheses were formulated and tested at 0.05 level of significance:

H_{o1}: There is no significant difference in the critical thinking skills of students taught STEM subjects using AI-integrated instruction and those taught using conventional methods.

H_{02}: There is no significant difference in the problem-solving performance of students taught STEM subjects using AI-integrated instruction and those taught using conventional methods.

2. Literature Review

The integration of Artificial Intelligence (AI) in education is increasingly gaining momentum as educators seek to enhance student learning through adaptive technologies and data-driven instruction, particularly in Science, Technology, Engineering, and Mathematics (STEM) subjects. Numerous studies have emphasized the transformative potential of AI to promote personalized learning and critical engagement. According to Holmes et al. (2022), AI-powered platforms can support differentiated instruction by adjusting learning content in real time based on learners' progress and preferences, thereby improving comprehension and cognitive skills. Similarly, Luckin et al. (2021) argued that AI applications such as intelligent tutoring systems, automated feedback tools, and predictive analytics are capable of fostering deeper understanding in complex STEM domains by providing scaffolds that support student reasoning and decision-making.

Critical thinking, a core 21st-century skill, involves the ability to analyze, evaluate, and synthesize information to make informed decisions. Paul and Elder (2019) maintain that fostering critical thinking requires instructional strategies that encourage inquiry, reflection, and evidence-based reasoning. AI tools, such as Socratic learning assistants and concept-mapping bots, create learning environments that prompt students to question assumptions, explore alternatives, and receive immediate feedback. This is reinforced by research conducted by Miao et al. (2020), who demonstrated that AI-enhanced platforms contributed to measurable gains in critical thinking skills among high school students in digital science classes. In addition, AI-facilitated project-based learning, virtual lab simulations, and problem modeling tools have been found to engage students in higher-order thinking (Panigrahi et al., 2022).

Problem-solving, another essential cognitive outcome in STEM education, is also positively influenced by AI integration. According to Chen et al. (2020), AI can be used to support structured problem-solving by providing stepwise guidance, identifying misconceptions, and adjusting problem difficulty. In their experimental study, students who used AI-supported learning tools in mathematics and physics demonstrated significantly higher problem-solving performance than peers taught through conventional means. In a similar vein, Li and Liu (2023) found that AI-driven personalized feedback led to improved logical reasoning and solution accuracy in complex algebraic tasks among

secondary school students.

Despite these promising findings globally, AI integration in classroom teaching remains limited in many developing countries, including Nigeria. Adebayo and Salami (2021) noted that while some Nigerian schools have adopted basic forms of digital instruction, the use of intelligent systems capable of adapting instruction based on student input is still rare. This is attributed to infrastructural challenges, limited teacher capacity, and a lack of localized research. However, as mobile technologies and cloud-based platforms become more affordable, the potential for meaningful AI adoption in Nigerian classrooms grows. Consequently, this study contributes to filling the contextual research gap by exploring how AI tools affect critical thinking and problem-solving in real-life STEM classrooms in Northern Nigeria.

3. Methodology

This study adopted a quasi-experimental research design involving pre-test, post-test, and non-randomized control groups to determine the impact of AI-integrated STEM instruction on students' critical thinking and problem-solving skills.

The research was conducted in Zaria Education Zone of Kaduna State, Nigeria, targeting senior secondary school students in public schools. The population of the study comprised all SS II students enrolled in public co-educational secondary schools in the zone, totaling approximately 4,820 students across 18 schools. Using purposive sampling, four schools with basic ICT infrastructure were selected, and simple random sampling through balloting was employed to assign two schools to the experimental group and two others to the control group.

A total of 192 students (96 in experimental and 96 in control groups) participated in the study. The experimental group was taught selected STEM concepts such as algebraic reasoning and basic Physics laws using AI-powered platforms (e.g. Squirrel AI, Century Tech, or local alternatives adapted for offline use) which featured personalized content delivery, adaptive questioning, and immediate feedback mechanisms. In contrast, the control group was taught using traditional teacher-led instruction without AI tools.

Data were collected using two instruments developed and validated by experts in science education and educational psychology: the Critical Thinking Skills Test (CTST), comprising open-ended STEM-based reasoning questions, and the STEM Problem-Solving Performance Test (SPSPT), consisting of 30 standardized items measuring structured problem-solving ability. A pilot study conducted to test the instrument in a neighboring school (not part of the main sample) produced data analysed for the reliability coefficients of 0.79 for CTST and 0.83 for SPSPT using Cronbach's Alpha. The intervention spanned six weeks, and pre-tests were administered before treatment to ensure group equivalence. After the intervention, post-tests were conducted, and data were analyzed using Analysis of Covariance (ANCOVA) to control for initial differences and assess treatment effects. Ethical clearance was obtained from the relevant educational authorities, and informed consent was secured from students, teachers, and school principals.

4. Results

4.1. Research Question 1

What is the difference in critical thinking skills between students taught STEM subjects using AI-integrated instruction and those taught using conventional methods?

There is a statistically significant difference in critical thinking skills between the two groups. Students who were taught using AI-integrated instruction demonstrated significantly higher critical thinking skills than those taught using conventional methods, after controlling for their initial abilities (pre-test scores). The effect size (Partial $\eta^2 = 0.128$) indicates that this difference is not just statistically significant, but also represents a moderate to large practical effect, meaning the use of AI had a meaningful impact on enhancing critical thinking skills.

4.2. Research Question 2

What is the difference in problem-solving performance between students exposed to AI-integrated STEM instruction and those receiving traditional instruction?

There is a statistically significant difference in problem solving performance between the two groups. Students who received AI-integrated instruction showed significantly better problem-solving performance than their peers in the traditional instruction group, after accounting for pre-test differences. With an effect size of Partial $\eta^2 = 0.158$, this difference is considered to have a large practical effect, strongly suggesting that AI-integrated instruction substantially improved students' ability to solve STEM-related problems.

To determine the effect of AI-integrated instruction on students' critical thinking and problem-solving performance, Analysis of Covariance (ANCOVA) was conducted to adjust for pre-test scores and examine post-test differences between the experimental and control groups.

Table 1: ANCOVA Summary for Critical Thinking Skills (H_{01})

Source	SS	Df	MS	F	p-value	Partial η^2
Pre-test (Covariate)	521.42	1	521.42	8.32	0.004	0.042
Group (AI vs Conventional)	1742.16	1	1742.16	27.78	<0.001	0.128
Error	11724.67	188	62.34			
Total	14781.33	190				

4.3. Results for Hypothesis 1

There is no significant difference in the critical thinking skills of students taught STEM subjects using AI-integrated instruction and those taught using conventional methods.

Table 1 shows a statistically significant difference in the post-test critical thinking scores of students in the AI-integrated group compared to those in the conventional group, after controlling for pre-test scores, $F_{(1, 188)} = 27.78$, $p < 0.001$. The effect size (Partial $\eta^2 = 0.128$) indicates a moderate to large practical effect, suggesting that the use of AI-powered instruction significantly enhanced students' critical thinking skills. Therefore, Null Hypothesis 1 (H_{01}) is rejected.

Table 2: ANCOVA Summary for Problem-Solving Performance (H_{02})

Source	SS	Df	MS	F	p-value	Partial η^2
Pre-test (Covariate)	433.80	1	433.80	6.87	0.009	0.035
Group (AI vs Conventional)	2033.14	1	2033.14	35.21	<0.001	0.158
Error	10847.72	188	57.70			
Total	13314.66	190				

4.4. Results for Hypothesis 2

There is no significant difference in the problem-solving performance of students taught STEM subjects using AI-integrated instruction and those taught using conventional methods.

Table 2 presents a statistically significant effect of instructional method on students' problem-solving performance, $F_{(1, 188)} = 35.21$, $p < 0.001$, after adjusting for pre-test differences. The Partial η^2 value of 0.158 indicates a large effect size, suggesting that AI-integrated instruction substantially improved students' ability to solve STEM-related problems compared to traditional methods. Thus, Null Hypothesis 2 (Ho_2) is rejected.

5. Discussion

The findings of this study reveal that the integration of Artificial Intelligence (AI) into STEM classrooms has a statistically significant and educationally meaningful impact on both critical thinking skills and problem-solving performance of secondary school students. This aligns with the conclusions of Holmes et al. (2022) and Luckin et al. (2021), who emphasized that AI-powered educational tools offer real-time feedback, personalization, and adaptive learning pathways that contribute to the cognitive growth of learners. The result that students exposed to AI-enhanced instruction outperformed their peers in conventional classrooms supports the view that technology, when intentionally aligned with pedagogical objectives, can transform passive learning into active, inquiry-based experiences.

The improvement in critical thinking skills among students in the AI group resonates with Miao et al. (2020), who found that students using AI-supported learning environments demonstrated higher-order reasoning, hypothesis testing, and reflective thinking. These platforms are designed to stimulate analytical inquiry by presenting students with challenges that require them to compare, justify, and synthesize information. The AI tools used in this study

may have provided scaffolds that encouraged students to engage deeply with STEM content, thereby fostering the development of their critical faculties.

Similarly, the enhancement in problem-solving performance corroborates the findings of Chen et al. (2020) and Li and Liu (2023), who demonstrated that intelligent tutoring systems and AI-driven feedback mechanisms significantly improve students' abilities to organize, analyze, and solve complex STEM tasks. The high effect size observed in this study (Partial $\eta^2 = 0.158$) indicates that AI-powered environments do not merely supplement instruction but actively restructure how students approach and resolve problems. The platforms used likely provided dynamic and adaptive question sequencing, which matched each student's zone of proximal development, thus accelerating their problem-solving growth.

Despite these promising outcomes, the findings also reinforce concerns raised by Adebayo and Salami (2021) regarding the underutilization of AI in Nigerian classrooms. This study provides empirical evidence that, when implemented appropriately, AI can serve as a powerful catalyst for improving STEM learning outcomes even in resource-constrained settings. It also demonstrates the potential for AI to support 21st-century skills—such as collaboration, logical reasoning, and metacognition—which are essential for preparing students for future academic and career demands.

In summary, this study validates the growing body of global research that promotes the integration of AI in education and extends its relevance to the Nigerian context. It emphasizes that with adequate infrastructure, teacher training, and policy support, AI technologies can be harnessed to bridge cognitive learning gaps, improve performance, and nurture essential thinking skills in STEM education.

6. Conclusion

This study investigated the effect of Artificial Intelligence (AI) integration in STEM classrooms on secondary school students' critical thinking and problem-solving skills in Zaria Education Zone, Northern Nigeria. The findings revealed that students taught with AI-powered instructional tools significantly outperformed those taught using conventional methods. Specifically, AI-integrated instruction fostered deeper critical thinking and enhanced students' ability to solve complex STEM-related problems. These outcomes highlight the transformative potential of AI in creating engaging, adaptive, and personalized learning environments that respond to individual learners' needs. The evidence presented affirms that AI is not only a technological innovation but also a pedagogical enhancer that can improve learning outcomes and promote the acquisition of 21st-century skills. The study concludes that, when appropriately implemented, AI-based learning systems can help reshape STEM education in Nigeria, making it more effective, inclusive, and future-ready.

Recommendations:

Based on the findings and conclusion of this study, the following recommendations are made:

- Wider Adoption of AI in STEM Classrooms: The Federal and State Ministries of Education should invest in and promote the use of AI-powered learning platforms across public secondary schools to enhance students' cognitive engagement and academic performance.
- Teacher Professional Development: Training programs should be organized to equip STEM teachers with the digital literacy and pedagogical skills required to integrate AI tools effectively into classroom instruction.
- Infrastructure Improvement: Schools should be provided with necessary infrastructure such as internet connectivity, smart devices, and access to localized AI software to facilitate the seamless integration of AI in teaching and learning.
- Curriculum Reform: Curriculum developers should include the use of AI tools in the national STEM curriculum to support the development of critical thinking and problem-solving skills across subjects.
- Further Research: Future studies should explore the long-term effects of AI on different student demographics and in varied socio-educational contexts to inform more inclusive and scalable AI integration strategies.

Abbreviations

STEM	Science, Technology Engineering and Mathematics.
AI	Artificial Intelligence
CTST	Critical Thinking Skills Test
SPSPT	STEM-Problem-Solving Performance Test

Author Contributions

A. Lawal: Conceptualization, Investigation, Validation, writing –Review & Editing,Project Administration,Methodology, Supervision,

Z. Aliyu: Data Curation, Investigation, Formal Analysis, Writing - original draft, Supervision.

A. B. Madugu: Funding Acquisition, Visualization, Resources.

O. J. Zakari: Funding Acquisition, Visualization,Resources.

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Conflicts of Interest

The author(s) declare that they have no known competing financial interests, professional affiliations or personal relationships that could have appeared to influence the work reported in this paper.

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