



Comparative Analysis of AI-Enhanced and Traditional Biology Instruction on Performance among Secondary School Students in Zaria, Kaduna State

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ABSTRACT

This study, titled Comparative Analysis of AI-Enhanced and Traditional Biology Instruction on Performance among Secondary School Students in Zaria, Kaduna State, was guided by two specific objectives, along with corresponding research questions and hypotheses. The study focused on Senior secondary Biology students in Zaria, Kaduna State. A quasi-experimental research design was employed, involving a total population of 699 students. A sample of 192 students was selected using purposive sampling from two intact classes. The instrument for data collection was the Biology Performance Test (BPT), which yielded a reliability coefficient of 0.76 after pilot testing. Data collection was self-administered, with research questions analyzed using mean and standard deviation, while hypotheses were tested using the t-test. Findings revealed that the AI-enhanced instructional strategy significantly improved students' academic performance in Biology compared to the traditional method ($p = 0.000$). Additionally, there was a statistically significant difference in performance between male and female students exposed to AI-enhanced instruction ($p = 0.000$). The study recommends that the Kaduna state government and education stakeholders should invest in comprehensive teacher training programs focused on the effective use and integration of AI tools in biology pedagogy.

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INTRODUCTION

The integration of Artificial Intelligence (AI) in educational settings has emerged as a transformative approach with the potential to revolutionize teaching and learning processes across various disciplines, including biology education. In recent years, AI-enhanced instruction has garnered significant attention globally for its capacity to personalize learning experiences, provide immediate feedback, and create immersive simulations that enhance conceptual understanding (Eludire, 2023; Aminu *et al.*, 2024). Biology education, with its abstract concepts, complex molecular processes, and intricate ecological relationships, presents unique challenges that traditional instructional methods sometimes struggle to address effectively. Mohammed and

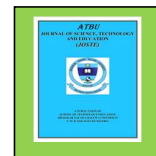
Abdulkadir (2023) opined that AI technologies offer promising solutions through interactive visualizations, adaptive learning systems, and virtual laboratories that can make abstract biological concepts more concrete and accessible. The evolution of AI applications in science education has progressed from basic computer-assisted instruction to sophisticated intelligent tutoring systems and immersive simulations. As noted by Okebukola (2023), these advancements have created opportunities for transforming biology instruction from predominantly text-based and theoretical approaches to experiential and personalized learning environments. AI-enhanced biology instruction incorporates tools such as virtual dissections, 3D molecular modelling, adaptive assessment systems, and

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intelligent tutoring applications that respond to individual student learning patterns (Dlamini & Mbatha, 2022). These technologies can potentially address persistent challenges in biology education, including concept visualization, individualized instruction, and engagement with complex biological processes.

However, the implementation of AI-enhanced biology instruction varies significantly across different educational contexts. While developed nations have made substantial progress in integrating these technologies into science curricula, developing countries like Nigeria face considerable challenges in adoption and implementation (Durodola, 2023). As highlighted by Rahman et al. (2023), factors such as infrastructure limitations, teacher preparedness, and policy frameworks significantly influence the extent to which AI technologies are effectively utilized in science classrooms. In the Nigerian context specifically, Olawale and Chen (2024) observed marked disparities in AI integration between urban and rural schools, with resource constraints particularly pronounced in non-urban settings.

Research on educational technology implementation in Nigeria has demonstrated both potential benefits and significant challenges. Studies by Adamu et al. (2018) and Yakubu et al. (2023) have documented improvement in student engagement and conceptual understanding when appropriate technologies are effectively integrated into science instruction. Similarly, Falode et al. (2023) reported enhanced visualization capabilities and increased student motivation when multimedia and simulation tools were incorporated into biology teaching. However, these benefits have not been consistently realized across different educational settings due to various implementation barriers. According to Ahmed and Hamzat (2023), Nigerian secondary schools often struggle with fundamental infrastructure challenges, including inconsistent power supply, limited internet connectivity, and insufficient technological resources that constrain effective AI integration. Teacher factors also play a crucial role in the successful implementation of AI-enhanced instruction. Nwagwu and Okonkwo (2023) discovered that teacher

preparedness, including both technical skills and pedagogical knowledge, significantly predicts the quality of technology integration in Nigerian classrooms. Studies by Adedoyin and Soykan (2023) revealed considerable gaps in teacher readiness for AI implementation, with many biology teachers lacking adequate training in both the technical aspects of AI tools and their pedagogical applications. This preparation gap represents a significant barrier to effective implementation, as teachers ultimately determine how and to what extent AI tools are utilized in instructional processes.

The educational landscape in Kaduna State, Nigeria, presents characteristics that influence AI implementation in biology education. As one of Nigeria's more populous and educationally diverse states, Kaduna encompasses both well-resourced urban schools and significantly constrained rural institutions (Ibrahim *et al.*, 2023). Zaria, as an educational hub within the state, houses a mix of established institutions and developing schools with varying levels of technological readiness. According to assessments by Adamu et al. (2018) and Muhammed and Olatunji (2024), secondary schools in Zaria demonstrate considerable variation in both infrastructure capacity and teacher preparedness for educational technology integration, creating an environment where implementation quality differs substantially across institutions. Despite the growing body of research on educational technology in Nigerian contexts, comparative analysis, specifically examining AI-enhanced biology instruction versus traditional approaches, remains limited. While studies have documented general patterns of technology adoption and implementation challenges, there is insufficient empirical evidence regarding the comparative effectiveness of AI-enhanced and traditional instructional approaches for biology education in the specific context of northern Nigerian secondary schools (Okoli & Ahmed, 2023). This knowledge gap limits evidence-based decision-making regarding educational investments and instructional approaches in biology education.

Statement of the Problem

Despite the rapid advancement of educational technologies, many secondary

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schools in Zaria, Kaduna State, continue to rely predominantly on traditional instructional methods for teaching Biology. These conventional approaches, often teacher-centered and textbook-driven, may not effectively address the diverse learning needs of students or foster deeper conceptual understanding of complex biological processes. At the same time, Artificial Intelligence (AI)-enhanced instruction is gaining global attention for its ability to personalize learning, promote interactive engagement, and support data-driven teaching strategies. However, in many Nigerian classrooms, including those in Zaria, the integration of AI tools into Biology education remains limited due to infrastructural, pedagogical, and awareness-related challenges. There is a growing concern that the continued reliance on traditional teaching methods may hinder students' academic performance and their preparedness for modern scientific and technological advancements. Yet, little empirical evidence exists comparing the effectiveness of AI-enhanced instruction to traditional teaching methods in the local context. This gap in knowledge raises important questions about which instructional approach yields better learning outcomes in Biology. Therefore, this study seeks to conduct a comparative analysis of AI-enhanced and traditional Biology instruction on the academic performance of secondary school students in Zaria, Kaduna State, to provide insights into teaching practices and the broader adoption of innovative educational technologies.

Research Objectives

The objectives of the study are to:

1. Determine the academic performance of secondary school students taught biology using AI-enhanced instruction and those taught using the traditional lecture method in Zaria, Kaduna State.
2. Ascertain gender differences in students' performance when exposed to AI-enhanced biology instruction.

Research Questions

The questions raised to guide the study are:

1. What is the difference in the academic performance of secondary school students

taught biology using AI-enhanced instruction and those taught using the traditional lecture method in Zaria, Kaduna State?

2. Is there any gender difference in Biology students' performance when exposed to AI-enhanced Biology Instruction?

Null Hypotheses

H0₁: There is no significant difference in the academic performance of secondary school students taught biology using AI-enhanced instruction and those taught using traditional methods.

H0₂: There is no significant gender difference in Biology students' performance when exposed to AI-enhanced biology instruction.

METHODOLOGY

The study adopted a quasi-experimental design, incorporating a post-test approach as recommended by Sambo (2008). The target population consisted of all Senior Secondary II (SS II) Biology students in Zaria Local Government Area, Kaduna State, totalling six hundred and ninety-nine (699) students across selected secondary schools. A sample of one hundred and ninety-two (192) students was purposively selected from this population via intact classes. The research instrument utilized was a self-developed test titled Biology Performance Test (BPT), comprising 25 multiple-choice items designed to assess students' understanding of the digestive system in Biology. Each item offered four alternatives (A–D), and the test was administered within a 40-minute duration.

The instrument was validated for face, content, construct, and predictive validity by experts in Biology, test and measurement, and English language from the Federal University of Education, Zaria. For reliability testing, a pilot study involving 50 students from GGSS Zaria was conducted. The test-retest method using Pearson Product-Moment Correlation (PPMC) yielded a reliability coefficient of 0.76, indicating a strong and consistent reliability of the instrument.

During the intervention phase, two instructional strategies were employed. The

experimental group received instruction on the digestive system using an AI-enhanced method, while the control group was taught the same content through the traditional lecture method. After six weeks of instruction, a post-test was administered to both groups to assess the impact of the teaching strategies on students' performance. Data collected were analyzed using Mean and Standard Deviation for the

research questions, while hypotheses were tested using the independent sample t-test via the Statistical Package for the Social Sciences (SPSS), version 23.

RESULTS

Data collected were analysed and presented as follows:

Table 1: Mean and standard deviation post-test Scores of Biology students taught using AI-enhanced instruction and those taught using the traditional lecture method

Variable	N	Mean	SD	Mean Diff.
Experimental group	83	24.82	3.46	6.45
Control group	109	18.37	4.11	

The data presented in Table 1 revealed a difference in academic performance between the two groups. The experimental group, comprising 83 students who received AI-enhanced instruction, had a higher mean score of 24.82 with a standard deviation of 3.46, while the control group,

consisting of 109 students taught using the traditional lecture method, had a mean score of 18.37 with a standard deviation of 4.11. The mean difference of 6.45 favours the experimental group, suggesting that the use of AI-enhanced Biology instruction positively influenced students' academic performance.

Table 2: The Mean Performance Scores of Male and Female Students in the Experimental Group

Variable	N	Mean	Std. Dev	Mean Difference
Male	55	24.21	3.52	1.43
Female	28	25.64	3.18	

Table 2 shows the comparative mean performance scores of male and female students within the experimental group that was exposed to AI-enhanced Biology instruction. The results indicate that female students (N = 28) outperformed their male counterparts (N = 55), with a higher mean score of 25.64 compared to 24.21. The standard deviation

suggests slightly more consistency in the female students' performance. The mean difference of 1.43 points in favour of female students suggests that the AI-enhanced instructional strategy may have been more effective or engaging for female learners in this context.

Table 3: t-test analysis on post-test Scores of Biology students, taught using AI-enhanced instruction and those taught using the traditional lecture method.

Variable	N	Mean	S. D	Df	t.cal	P.
Experimental group	83	24.82	3.46	190	11.85	*0.000
Control group	109	18.37	4.11			

*Significant at $p \leq 0.05$

The result in Table 3 presents a t-test analysis comparing the academic performance

of students taught Biology using AI-enhanced instruction and those taught using traditional

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lecture methods. The experimental group had a mean score of 24.82 and SD = 3.46, while the control group had a mean score of 18.37 and SD = 4.11. The p-value is 0.000, which is less

than the 0.05 level of significance. This indicates a statistically significant difference in performance between the two groups.

Table 4: Summary of t-test statistics on gender difference in students' performance when exposed to AI-enhanced biology instruction

Variables	N	Mean	SD	df	t-cal	P.
Male	55	24.21	3.52	81	5.97	0.000
Female	28	25.64	2.58			

*Significant at $p \leq 0.05$

Table 4 presents a t-test analysis of gender differences in students' performance scores when exposed to AI-enhanced versus traditional biology instruction. The male students recorded a mean score of 24.21 and SD = 3.52, while the female students had a mean score of 25.64 and SD = 2.58. The p-value is 0.000, which is less than the 0.05 significance level. This indicates a statistically significant difference in performance between male and female students.

DISCUSSION OF FINDINGS

The findings of this study revealed that the AI-enhanced instructional strategy had a significant positive effect on students' academic performance in Biology compared to the traditional lecture method among secondary school students in Zaria, Kaduna State. This aligns with growing global evidence that Artificial Intelligence (AI) can revolutionize science education by personalizing learning, offering instant feedback, and simulating real-life biological processes (Eludire, 2023; Aminu et al., 2024). Biology, a subject that encompasses abstract and complex concepts such as the digestive system, often poses challenges when taught using conventional methods. However, AI technologies such as intelligent tutoring systems, virtual laboratories, and adaptive assessments make these concepts clearer and more accessible to learners (Mohammed & Abdulkadir, 2023). The significant performance gains recorded among the experimental group in this study support earlier findings by Adamu et al. (2018) and Falode et al. (2023), who noted that when integrated effectively, digital tools can improve students' motivation, comprehension, and

academic outcomes in science-related subjects. Furthermore, the improved outcomes observed in this study are consistent with Okebukola (2023), who emphasized that AI's integration transforms traditional science instruction from passive, text-based learning into interactive and student-centered environments. The experimental group's enhanced performance may also reflect the personalized support and immediate feedback offered by AI tools, which are known to increase student engagement and mastery of complex material (Dlamini & Mbatha, 2022). While these benefits were evident in the present study, it is important to recognize that the broader success of AI-enhanced instruction depends heavily on contextual factors, including teacher preparedness, infrastructure availability, and institutional support (Durodola, 2023; Rahman et al., 2023).

Another notable finding is the statistically significant difference in performance between male and female students exposed to AI-enhanced biology instruction, with female students performing slightly better in this study. This gender gap echoes concerns raised by Olawale and Chen (2024), who observed disparities in digital tool adoption and usage based on gender, often influenced by prior exposure and confidence in using technology. Despite the potential of AI to offer inclusive and equitable learning experiences, gender-specific dynamics, such as access to devices, cultural attitudes towards science and technology, and digital literacy levels, can impact outcomes (Nwagwu & Okonkwo, 2023). The finding calls for intentional efforts to design gender-sensitive interventions that ensure both male and female students benefit equally from AI-enhanced

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learning. Moreover, the performance difference may also be linked to teacher-related factors. According to Adedoyin and Soykan (2023), many biology teachers in Nigeria lack sufficient training in AI tools, which affects their ability to guide and support diverse learners effectively. In a context like Zaria, where schools differ significantly in terms of technological readiness and infrastructure, as evidenced by studies (Ibrahim et al., 2023; Muhammed & Olatunji 2024), the uneven application of AI-enhanced strategies may unintentionally widen performance gaps between subgroups.

While this study contributes to the emerging body of knowledge on the impact of AI-enhanced instruction in Nigerian secondary schools, it also highlights a gap in comparative analyses within northern Nigerian contexts. As noted by Okoli and Ahmed (2023), there is a lack of localized evidence comparing AI and traditional methods in biology instruction. This study, therefore, offers important empirical data to guide educational planning, teacher training, and policy development aimed at integrating AI more effectively in science education across diverse educational settings in Nigeria.

CONCLUSION

This study has demonstrated that AI-enhanced instructional strategies significantly improve the academic performance of secondary school students in Biology compared to traditional teaching methods in Zaria, Kaduna State. The integration of AI technologies in the classroom provided learners with interactive, personalized, and visually engaging content, enabling a better understanding of complex biological concepts. These findings affirm the transformative potential of AI in science education, particularly in subjects like Biology that benefit from experiential and visual learning approaches. Furthermore, the study revealed a gender difference in performance, with female students outperforming males, highlighting the need for more inclusive and equitable AI-based learning environments. While the advantages of AI-enhanced instruction are evident, challenges such as unequal access to technology, inadequate infrastructure, and insufficient teacher preparedness continue to limit its full implementation in many Nigerian schools.

Addressing these barriers is critical to maximizing the benefits of AI in education and ensuring all students, regardless of gender or background, can thrive in a technology-supported learning environment.

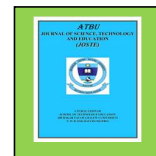
RECOMMENDATIONS

In light of the findings, the following recommendations are made:

1. Kaduna state government and Education stakeholders should invest in comprehensive training programs for biology teachers, focusing on the effective use of AI tools and their pedagogical integration.
2. Secondary Schools in Zaria should adopt strategies that encourage equal participation of male and female students in AI-enhanced instruction.

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