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Effectiveness of artificial intelligence augmented teachers' autonomy support instructional strategy on students' achievement in mathematics-related biology topics

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ABSTRACT

The study examined the effectiveness of "artificial intelligence augmented teachers' autonomy support" (AIATAS) instructional strategy on students' achievement in mathematics-related biology topics. The study adopted a pre-/post-test, non-equivalent control group quasi-experimental design. Guided by three research questions, three hypotheses were tested. A sample of 402 students, drawn by a multistage sampling procedure from a population of 3,785 SS2 biology students in the Agbani Education Zone, Enugu State, Nigeria, participated in the study. A valid and reliable mathematics-related biology achievement test (Kuder-Richardson-20 = 0.87) was used for data collection. Research questions were answered using mean and standard deviation, while hypotheses were tested using analysis of covariance. Findings revealed a significant effect of AIATAS on students' achievement; no significant influence of school type; and a significant interaction between instructional strategy and school type. The study highlighted the need for teachers to adopt the AIATAS instructional strategy, among others.

Keywords: artificial intelligence, teachers' autonomy support, mathematics-related, biology, school type, instructional strategy

INTRODUCTION

Most students, especially those inclined to the arts and those struggling with mathematics, thoughtfully avoid mathematical calculations. Perhaps, due to the tasking nature of mental reasoning and scrupulous precision required in dealing with numbers. Thence, the sight of mathematical calculations in biology becomes challenging for such students. But the role of mathematics is a crucial pillar for cognitive development, analytical and computation skills, and undeniable advancements in most disciplines (Pokhrel, 2023; Wijaya et al., 2022). Thus, the abstractness and organization of the ideas, structures and principles of mathematics can essentially support the understanding of other discipline (Thanheiser, 2023). Its importance makes it a bedrock of the sciences and almost a crucial part of all science subjects, necessary for national and social-economic growth (Federal Republic of Nigeria, 2014; Mantey et al., 2022). This means that the presence of mathematical computations in biology, as mathematics-related topics is actually in place and a fundamental tool for stimulating critical thinking in the subject.

Interestingly, biology is an integral part of the natural science that has to do with the survival and functioning of living organisms in their environment. Bashar (2018) described biology as a broad field, covering issues of chemicals and machines in cells, to the broad-scale concepts of ecosystems and climatic changes. Ewere (2023) summed up biology as the study of life processes in plants and animals. In this light, biology in this study refers to the scientific study of systems and processes that support life in plants and animals as they interact in their environment. Specifically, the focus in this study is on biology topics that require mathematical knowledge, referred to as mathematics-related biology topics. According to Aghogho (2024) some topics in the biology curriculum for senior secondary schools in Nigeria have elements of mathematics. This means that the understanding of such biology topics depends on students' proficiency in mathematics.

Mathematics-related topics in the Nigerian secondary school biology curriculum primarily involve quantitative analysis, calculations, and the application of mathematical concepts to biological data and phenomena. Such topics that are considered as mathematics-related, according to Aghogho (2024) and Nigerian Educational Research and Development Council (2025), include genetics and heredity, ecology and population studies, cell biology and physiology, and scientific skills. In genetics and heredity, the knowledge of probability and ratios is used to calculate the likelihood of an organism inheriting certain traits, predicting genotypic and phenotypic ratios in monohybrid and dihybrid crosses, as in Mendel's laws, sex determination. In ecology and population studies, the knowledge of ratios, rates, percentages and basic arithmetic is used to calculate population density, growth rate and size, quantifying energy transfer across trophic levels. In cell biology and physiology, ratios, rates, basic arithmetic, and graphs are used to understand concepts like concentration gradients, for diffusion and osmosis, and calculating water potential, and measuring and visualizing growth rates over time. In scientific skills, which is general to all topics, accurate use of units, reading scales and basic arithmetic, such as addition, subtraction, multiplication, division are used for measurements; line graphs, bar charts, pie charts, tables are used for data presentation and interpretation, and calculating averages or percentages to analyze results from experiments; the knowledge of approximation and significant figures are used in applying rules of approximation and significant figures when recording and reporting experimental data; also, the knowledge of ratios, rates, and proportion are used across various topics for comparisons, comparing feeding habits and analyzing rates of biological processes.

The knowledge of biology is of great importance to man's survival. Biology-knowledge in major advancements in the health sector, technology of ergonomic devices and other human-dependent technologies, and human capacity developments in plant and animal-based food and nutrition, to enhance productivity and solve numerous related problems (Ewere, 2023). Biology is considered a prerequisite for the study of related fields like anatomy, cell biology, genetics, genetic engineering, nursing, medicine, neuroscience, pharmacology, evolution and ecology are anchored (Chinweuba-Eze, 2021). This highlights the importance of biology for national development and emphasizing the need for a practical orientation to the teaching of the subject, developing students' skills in scientific inquiry, problem-solving and acquainting students with necessary competencies for realizing life goals.

In light of the relevance and role of biology in national development, expectations are high on students to achieve optimally in the subject, having being exposed to the scientific theories and practices of the science. However, the outcome of such exposure has not been forth yielding satisfactorily in Nigeria and is raising crucial questions. Many students still struggle with unsatisfactory academic achievement in the subject. Agboghoroma and Oyovwi (2015), Chibabi et al. (2018), Umar et al. (2018), Balarabe et al. (2019), and Abubakar (2024) have shown a continued general decline in students' academic achievement in sciences, especially in biology. More explicitly, the West African Examination Council (2017-2021) chief examiners' report shows the severity of this problem across secondary schools in Nigeria. Largely, the report attributes the unsatisfactory achievement of students in biology to their poor performance in mathematics-related biology topics (West African Examination Council, 2017-2021). This situation has led to a lack of interest and recurring underachievement in the subject (Abubakar, 2024).

Previous efforts have focused on other areas concerned with learning. Efforts to curb the persistent lingering trend of students' poor academic achievement in biology has been targeted at training qualified biology teachers for exposing students to adequate learning experiences; provision of instructional materials (Adewale et al., 2016; Rijal, 2016); enhancing students' variables and psychological variables (Effiong, 2024; Fareo, 2019; Johnson, 2024; Kapur, 2018; Olaleye et al., 2017); advocating parental support (Chinweuba-Eze, 2021); as well as helping teachers improve on classroom management, enhance instructional approaches and method (An & Mindrila, 2020; Balarabe et al., 2019; Onu et al., 2020; Umar, 2023). However, these efforts have not allayed the situation, with growing concerns among education stakeholders. Yet, accusing fingers continue to point to a lacuna in the instruction. Adebanjo (2019) and Nnaji et al. (2023) suggest that an appropriate instructional strategy that exposes students to the management of difficult learning contents may enhance students' improved achievement, especially in mathematics-related biology topics. Hence, this study focusses on the instructional strategy adopted by teachers in biology.

The instructional strategies are crucial tools in the hands of teachers, especially if effectively deployed. This is because the instructional strategy used by the teacher in conveying the needed information can determine students' learning pace. Although, the conventional chalk-and-talk strategy, used for many decades now, is mostly prevalent in secondary schools in Nigeria. This strategy has an underlying philosophy that pegs knowledge as fixed and can only be accessed from the teacher (Yusuf et al., 2018). The relevance of the conventional instructional strategy may not be overruled (Sharma & Kumar, 2018), but recent philosophies have argued the inappropriateness of construing students as mere recipients of knowledge. It is worthy to notice the active roles of students in knowledge creation and their capability of initiatives that facilitate ownership of their learning and skills development in a threat-free environment (Rhalmi, 2016). More so, when students are allowed to contribute, there is a greater tendency for sustained interest and engagement in the learning endeavor, especially in the present technology driven world (Zhu et al., 2025). Hence, it becomes necessary to consider the effectiveness of innovative learner-centered instructional strategies for teaching mathematics-related biology topics. This can allow students to experience mathematics-related biology instructions differently, as active players who reason, explore and share their knowledge, rather than depending on teachers' experience. Ibemenji et al. (2019), Onu et al. (2020), Ojekwu and Ogunleye (2020), and Li et al. (2024) have shown that such innovative learner-centered instructional strategies can enhance students' academic achievements, especially in biology. In this direction, the overarching need in this study gave in to experiment on the effectiveness of artificial intelligence augmented teachers' autonomy support (AIATAS) instructional strategy on students' achievement in mathematics-related biology topics.

Artificial intelligence (AI) has consistently evolved over the current decade with a great consistency in bridging knowledge gaps. AI has a history dating to the 1950s in the philosophical ideas of thinking machines by Alan Turing, according to Stone et al. (2016) and the coining of the term "AI" by McCarthy et al. (1955) in the Dartmouth Workshop, which birthed the term as the integration of reasoning in machine technology. According to Pearl (2018), AI focusses on enabling machines to perform tasks that would normally require a thinking man. AI connotes systems designed to respond to prompts and act in ways that typically require human intelligence (Dwivedi et al., 2021). Nnaji et al. (2025) described AI as computerized systems, which can reason, perceive, learn, make decisions and complete pedagogical-related assignments as a thinking human teacher will do. These insights lend the perspective of AI in this study as intelligent systems in technological devices with algorithms that enable learning and the execution of human-kind reasoning and decision making on tasks, especially in the learning of biology.

AI has widely been adopted in many fields. With a proof of high impacts across many domains, AI continues to break new frontiers with improved efficiency in the field of education González-Calatayud et al. (2021). Wang et al. (2024) asserted the diverse perspectives of AI's growing evolution in education. Rather than the total reliance on the human-teacher's presence, in-person instruction and printed materials, AI now hold a vast body of knowledge which require prompting to adapt and produce reliable results (Chen et al., 2020; Drigas & Ioannidou, 2012). With the right prompts (demand instructions), students can access relevant information without the assistance of the human-teachers and the physical libraries, in seconds (Holstein et al., 2019). AI can aid improved academic achievement by fostering student-centered learning, by means of tailored feedback (Kose & Arslan, 2017; Ledesma & García, 2017). AI powers many learning management systems (LMS), such as Absorb LMS and Docebo, in the delivery of multiple AI capabilities including intelligent content creation, administrative task automation, and personalized learning that support teaching and learning activities in schools (Leh, 2022). AI can highlight areas where students may be experiencing learning difficulties and redefine the nature of the teacher-student interactions in a technology enhanced way (Hwang et al., 2020; Li et al., 2024; Liu et al., 2017; Xu & Ouyang, 2022). AI in the learning if biology can effectively transform the modes of instruction, underscoring the critical role of technology in expanding the limits of knowledge and giving autonomy to students for their own learning.

Autonomy in learning is a crucial way of raising students' awareness with improved desire to contribute to knowledge creation, especially when supported. According to Patall and Zambrano (2019), teachers' autonomy support (TAS) instructional strategy is an essential tool for fostering students' motivation, engagement, learning and achievement. According to Reeve and Cheon (2021), TAS involves taking the student's perspective, encouraging self-initiation and providing meaningful rationales for learning activities to foster student engagement. Siacor et al. (2023) defined autonomy support as instructional behaviors that increases students' sense of agency and ownership over their learning environment, resources and experiences. The teacher's role in this instructional strategy is that of empathy, choice provision, and encouragement of student voice. Patzak and Zhang (2025) offer a more integrative perspective, describing autonomy support as a pedagogical approach that blends the instructional content with structured guidance and maintains students' optimal motivation and learning outcomes. In this study, TAS instructional strategy connote an instructional strategy that nurtures students' sense of volition, to initiate and engage in the search for viable knowledge that addresses learning needs, especially those related to mathematics-related biology topics.

The TAS instructional strategy enables the teacher to release the learning control to the students. This strategy enhances students' freedom and structures instructional endeavors to balance directed queries with discovery learning. This way, teacher assigns learning tasks that demand students to make decisions, then students follow directed questions to address the learning needs (Kusurkar & Croiset, 2015). Hornstra et al. (2020) argued that TAS flips the traditional instructional strategy to allow student seek useful information that addresses the learning needs. TAS hands students the right to consider relevant options, make choices, show respect and using information for enhancing learning (Stroet et al., 2015). In this direction, the integration of AI to augment the TAS can provide students with an information store, coupled with an assistant that assists them dig deep and compare information with the view of coming up with the best line of information that most suitably addresses the problem, effectively. The focus is to provide students with a veritable support that allows them obtain quick and reliable information that can help improve their learning in school, unlike the orthodox TAS where students may find a huge discomfort and frustration with sourcing required information. This AIATAS instructional strategy may hold benefits for students' academic achievements in any school type.

In experimenting with the effectiveness of AIATAS instructional strategy on students' academic achievement, a subtle buildup of curiosity bothers on if school type may suggest any differential effect. More so, the subject of school type has been scantily researched in literature as most studies focus on students' gender, which is rather related. In Nigeria, senior secondary schools are either single-sex school type or mixed-sex school type. Wong and Siu (2018) described mixed-sex schools as coeducational schools, where male and female students are educated together in the same environment to reduce gender stereotypes, foster mutual respect, and prepare students for real-world social and professional interactions, which is opposed to single-sex schools. According to Özdere (2023), educational institutions may enroll students of only one gender and aim to tailor instruction to the specific learning styles or developmental needs of the gender, while others may enroll both gender groups and provide uniformly blended instruction to them. In this study, school type connotes the gender characteristics of the student populations in the school, classified as either mixed-sex when male and female students study in the same school environment or single-sex when only a single gender of student study in the school. The argument, by drawing from the views of Busari (2016), suggest that single-sex schools may have the advantage of improved academic achievement and reduced gender-based distractions, but they could as well empower gender-based stereotypes, and inhibit collaborative learning in both directions.

Although both school types run on the same curriculum contents, students' academic achievement may experience differences as a result of social and environmental factors that differentiate the instructional modes and patterns in both school settings. More so, the integration of AI technology for augmenting TAS instructional strategy may perform differently in both school types. One can only imagine the blended benefits of AI in learning environments and the benefits of TAS on students' academic achievement in mathematics-related biology topics in both school type settings. Hence, the overarching need in this study was to experiment on the effectiveness of AIATAS instructional strategy on students' achievement in mathematics-related biology topics. The main goal of this study was to determine the effect of AIATAS instructional strategy on students' academic achievement in biology.

THEORETICAL FOUNDATION

Theoretically, this study on AIATAS was founded on the self-determination theory (SDT), which was developed by Ryan and Deci (2000). Ryan and Deci (2000) argued that it is not just enough to understand how people process information; it is more important to understand the basic needs that drive or give power to such goals. The SDT, a macro theory of human motivation, emphasizes that people have three basic psychological needs, which, when satisfied in a social context (classroom), make a deeper engagement level and enhanced learning outcomes possible. The SDT posits that individuals thrive when three basic psychological needs are met: autonomy, competence and relatedness. The SDT emphasizes a learning climate where students feel empowered and intrinsically motivated. When teachers foster the autonomy psychological need, students are more likely to develop intrinsic motivation, which is strongly associated with deeper engagement and improved academic performance. As students determine to address the desired learning needs, they develop a sense of positive responsibility and ownership of what they learn, thus solidifying their achievement from the content of instruction. The SDT framework argues that TAS can positively influence student achievement, particularly in cognitively demanding subjects like biology, especially mathematics-related topics.

LITERATURE REVIEW

Previous studies have shown the benefits of both TAS and AI, independently for pedagogical success. Evidence in the literature shows that TAS may effectively improve students' academic achievement in mathematics-related biology topics. Studies show that the TAS strategy has a positive effect on students' achievement in languages (Hofferber et al., 2014; Wang et al., 2017). According to Cheon et al. (2020), TAS helps teachers improve students' classroom behavior and their academic achievement. Across multiple countries, Hagger et al. (2020) found that TAS was linked to higher academic achievement and well-being. Tilga et al. (2021) found TAS to be the main factor that led to better academic outcomes and increased motivation in physical education classes. Sun et al. (2021) showed that TAS positively influenced students' academic achievement in the sciences through increased self-efficacy and engagement. Similarly, Yang et al. (2022) in a longitudinal found that TAS significantly enhances student engagement for improved academic achievement. Brandisauskiene et al. (2022) found that TAS improved students' learning strategies and academic achievement in schools for children from low socio-economic status homes. González-Cutre et al. (2023) found that TAS led to improved academic outcomes and reduced dropout intentions in secondary schools. More so, Zhou et al. (2023) found that TAS gave feedback which improved students' mathematics achievement and reduced test anxiety. Li et al. (2024) found that the adoption of TAS in online learning environments significantly fostered students' achievement and persistence on tasks. Patzak and Zhang (2025), in a meta-analysis revealed that blending TAS with structured guidance led to optimal motivation and better academic outcomes. However, some studies still showed no significant effect of TAS on students' academic achievement (Admiraal et al., 2022; Gurganious, 2017). This shows an inconclusive investigation on the effectiveness of TAS, especially with respect to students' academic achievement in mathematics-related biology topics, which has sparked argument on what the role of AI will be in this direction.

The adoption of AI in formative assessments have continued to garner empirical support. Wang et al. (2024) found that AI is majorly improves students' achievement. Also, Meylani (2024) revealed that AI enhances learning by providing personalized learning pathways, fostering critical thinking, which is essential in solving mathematical problems. Mishra et al. (2025) believes that the integration of AI in teaching and learning mathematics can trigger innovative strategies that address the limitations of the conventional teaching through technological advancements in modern science. Lara et al. (2025) argued that AI integration in the classroom can reshape instructional methodologies, transforming what we used to know about teaching and learning of mathematics to a more modern, flexible and productive experience. Chen (2025) revealed that AI-assisted personalized learning systems yielded transformative effects on student academic achievements in mathematics and has the potential to address mathematics-related academic challenges. Holman et al. (2025) found that AI interventions in mathematics significantly improved students' learning outcomes, particularly when integrated over long periods. Vieriu and Petrea (2025) and Ugwoke et al. (2025) found that the integration of AI in educational assessments yielded improvements in learning outcomes. Although, ample evidence supports the integration of AI in educational pedagogical efforts, one can only wonder if school type can play a role in the augmentation of TAS instructional strategy using AI.

Furthermore, the literature suggest that school types may influence students' academic achievement. This may be considered importantly since the composition of student populations which defines the instructional orientation of the school could influence student' psycho-social characteristics that interfere or support academic achievements. Movchan (2018) asserted that students' learning capabilities are greatly affected by the social, physical, psychological or cultural factors within a learning environment. The debate on the influence of school type bothers on if academic differences exist between students in mixed and single-sex schools exposed to AIATAS (Yalcinkaya & Ulu, 2012). Consequently, studies have shown that achievement in science subjects may be influenced by school type (Ogundiwin & Olusa, 2017). While Okonkwo and Samuel (2024) found that school type has no effect on students' performance in science, Busari (2016) and Eleje et al. (2021) opine that studies on the role of school type on students' achievement is inconclusive with conflicting findings. Hence, the investigation in this study sought to determine if differences exist in students' academic achievement in mathematics-related biology topics after exposure to AIATAS in mixed and single sex school types.

Studies suggest that AIATAS can be effective in improving students' academic achievement in mathematics-related biology topics, irrespective school type, due to the huge benefits accounted to the integration of AI in learner-centered instructional strategy. Although, research evidences on the effectiveness of AI and TAS instructional strategy abound in other countries, education stakeholders are mostly unaware of its effectiveness on secondary school students' academic achievement in mathematics-related biology topics in Nigeria. Also, the situation is novel to the extent that studies have not flooded the integration of AI in augmenting TAS instructional strategy for pedagogical purposes. This prompted the researchers' curiosity to investigate the effectiveness of AIATAS instructional strategy on students' academic achievement in mathematics-related biology topics in mixed and single-sex school environments in Nigeria. Hence, the present study sought to determine the effect of AIATAS instructional strategy on students' academic achievement in mathematics-related biology topics. Specifically, the study addressed the following research concerns:

1. What are the mean academic achievement scores of students in mathematics-related biology topics taught using the AIATAS instructional strategy and those taught using the conventional instructional strategy?
2. What are the mean academic achievement scores of students in mathematics-related biology topics in mixed and single-sex schools taught using AIATAS instructional strategy?
3. What is the interaction effect of strategy and school type on students' academic achievement in mathematics-related biology topics?

Table 1. Pre-/post-test quasi-experimental research design

Group	Pre-test	Treatment	Post-test
Experimental	Pre-test	Experimental group (AIATAS)	Post-test
Control	Pre-test	Control group (conventional)	Post-test

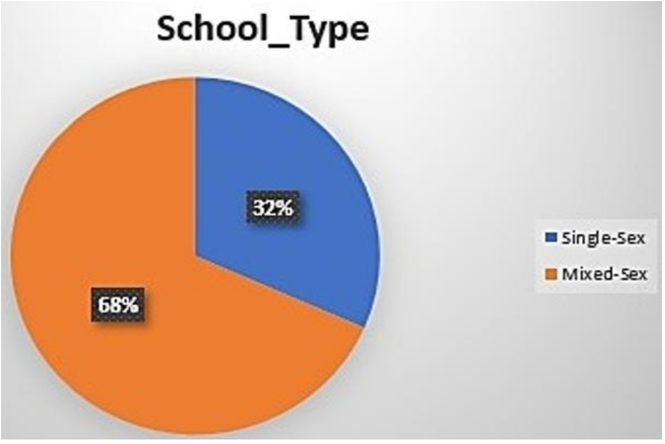

Figure 1. Sample distribution by school type (the authors' own elaboration)

Hypotheses

The null hypotheses tested at 0.05 level of significance in the study were:

1. **H_{01}.** There is no statistically significant difference in the mean academic achievement scores of students in mathematics-related biology topics taught using AIATAS instructional strategy and those taught using the conventional instructional strategy.
2. **H_{02}.** There is no statistically significant difference due to school type in the mean academic achievement scores of students in mathematics-related biology topics taught using AIATAS in mixed and single-sex schools.
3. **H_{03}.** There is no statistically significant interaction effect of instructional strategy and school-type on the mean academic achievement scores of students in mathematics-related biology topics.

MATERIALS AND METHODS

The study employed the pre-test post-test non-equivalent group, quasi-experimental research design (**Table 1**). According to Nworgu (2015), a quasi-experimental research design is one in which randomization of subjects is impossible, but intact classes or pre-existing groups of subjects are assigned to experimental and control groups. Quasi experiment was used because the participants were not randomly assigned to the groups, experimental (AIATAS) and control (conventional); intact classes were used and considered appropriate for this study.

The population of the study was made up of all the 3,785 senior secondary II (SS 2) biology students in government-owned (public) secondary schools in Agbani Education Zone of Enugu State, Nigeria (**Figure 1**). The Agbani Education Zone comprises three local government areas (LGAs), viz Nkanu-

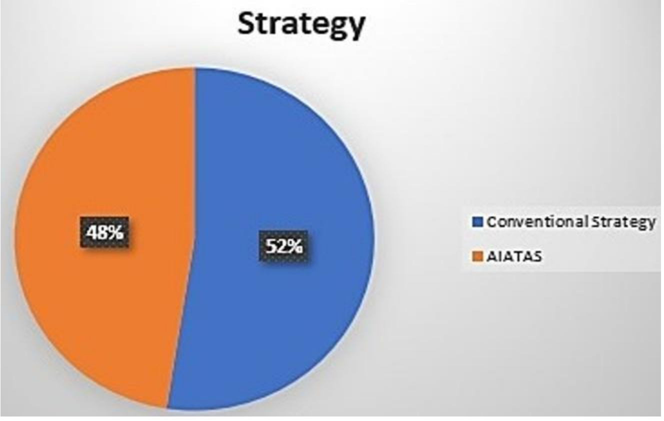

Figure 2. Sample distribution by strategy (the authors' own elaboration)

East LGA, Nkanu-West LGA and Enugu South LGA. The population of the study comprised 2,576 male and 1,209 female students in the 45 secondary schools (34 mixed-sex and 11 single-sex) in the area. From the population, a sample size of 402 SS 2 students was drawn from intact classes of six public secondary schools by a multistage sampling procedure. In the first stage, a simple random sampling technique (by balloting with replacement, to provide equal opportunity) was used to select two LGAs from the Agbani Education Zone. In the second stage, cluster sampling technique was used to draw three mixed-sex and three single-sex senior secondary schools from each of the sampled LGAs (six mixed-sex and six single-sex schools, 12 senior secondary schools in all). In the third stage, simple random sampling technique, by a flip of coin method, was used to randomly assign each of the sampled schools to the groups (experimental and control). The assignment of the sample considered the six schools from each LGA, such that four mixed-sex and two single-sex schools emerged in the experimental and control groups, without gender specifications. Finally, by a simple random technique, by dip of luck method, a single intact class of SS 2 biology students from each of the sampled schools was drawn for the study (12 intact classes in all, eight mixed-sex schools and four single-sex schools). The total of 402 SS 2 biology students from the 12 sampled schools (mixed-sex= 275 [68% of sample], single-sex = 127 [32% of sample]; experimental group = 191 [48% of sample], control group = 211 [52% of sample]) participated in the study.

The instrument for data collection was a 50-item multiple-choice mathematics-related biology achievement test (MR-BAT), with each question stem accompanied by four response options A-D (**Figure 2**). The MR-BAT was developed by the researcher from the SS 2 Nigeria biology curriculum, using a table of specification, based on the mathematics-related topics covered in the experiment, including genetics and heredity – probability and ratio; ecology and population studies – basic arithmetic, ratio, rates and percentages; cell biology and physiology – basic arithmetic, ratios, rates, and graphs; scientific skills- basic arithmetic, averages, percentages, conversions involving metric units, reading scales, tables, line graphs, bar charts and pie charts. The minimum score on the MR-BAT was zero, while the maximum score was 50. The instrument was face validated by three experts from the department of science education, University of Nigeria, Nsukka. Specialist biology teachers were involved for content validation using the item objective congruence (IOC) method; the IOC index of 0.82 was obtained. The instrument was trial tested on a group of 30 SS 2 biology students in the Enugu East LGA, Enugu Education Zone, which is outside the study area, but shares similar educational, cultural and demographic characteristics with the study area. To assess the internal consistency of the instrument, a reliability coefficient of 0.87 was determined for the MR-BAT using the Kuder-Richardson-20 method. The MR-BAT was adjusted as highly reliable for data collection in the study, in line with Cohen et al. (2018).

In the pre-treatment stage, the researchers obtained permission from the principals of the sampled schools and familiarized with the SS 2 biology teachers in the sampled schools who served as research assistants in the study participants for the study. The 12 research assistants possessed a minimum qualification of a bachelor's degree or its equivalent in biology education and other related courses. They are also regular biology teachers in the sampled schools with at least three years post qualification teaching experience. The researchers briefed the research assistants on the objectives and modalities of the study and scheduled harmonized virtual training sessions for the teachers over the weekends (Friday and Saturday). The training session was held online through the Google Team platform. The researcher provided the internet connection used by the teachers for engaging in the study. During the training, the researchers introduced the research assistants to the details of the AIATAS instructional strategy and clarified and harmonized the instructional procedures in the instructional guide developed and provided by the researcher. The research assistants were allowed to practice and get used to the instructional guide. The research assistants were also introduced to the method of data collection, administration of the instrument (MR-BAT) for the pretest and its reshuffled version for the posttest. Questions were entertained, extensively discussed and clarified in the separate training groups for both the control group and experimental group sessions. This was to clarify grey areas and foster uniformity in the experimental procedure. The pre-treatment phase lasted for two weeks, weekends only.

The treatment phase was the actual instructional phase when the experiment was conducted. One week before the actual treatment commenced, the MR-BAT was administered as a pretest on-the-spot to the students in both the experimental and control groups. During the actual treatment, the experiment group was taught using the AIATAS instructional strategy while the control group was taught using the conventional instructional strategy, based on the researchers' provided instructional plans for both groups. The control group had no access to AI enabled smartphones, while the AIATAS group accessed the free versions of the Gemini and ChatGPT AI chatbot tools installed on their smartphones to augment the TAS instructional strategy, based on the researchers' provided instructional plans for both groups. The AIATAS involved teachers presenting students with the learning need prompts and requesting them to seek out solutions to the challenges in the learning needs, independently or collaboratively, as they consider appropriate for each task, with the help of AI tools (Gemini and ChatGPT AI chatbots) on internet-enabled smartphones. Students in both groups were provided with texts with concise cues to the learning tasks, with which they verified AI generated information. The researcher rented and provided the internet enabled smart phones that were used for the experiment. Each activity was timed to ensure that students focused on the learning objectives. In the control group, the conventional teacher-talk-chalk instructional strategy was used for instruction. At the end of the instructional period, the researchers provided the reshuffled version of the MR-BAT items, which the research assistants administered to the participants as a posttest. The treatment phase lasted for eight weeks, weekdays only. In all, the study lasted for 10 weeks (from January 20, 2025, to March 28, 2025).

The post-treatment phase was the period of sorting, marking, scoring, data screening and coding in preparation for the analysis of the data collected in the study. The data collected were also analyzed in this phase. The analysis of the data in the study was done using statistical package for the social sciences. Mean and standard deviation were used to answer the research questions, while analysis of covariance (ANCOVA) was used to test the hypotheses at 0.05% level of significance. The data collected met the basic assumptions of ANCOVA, including homogeneity of slopes, linearity between covariates (pre-test) and the dependent variable (students' achievement in mathematics-related biology topics), the covariates conceptually and empirically showed independence with the treatment group by a mean value range of 19.24 and 19.94; the Levene's test ($F(3) = 34.002$, sig. = 0.064) indicated a homogeneity of variance across groups; and the Shapiro-Wilk statistic ($W(402) = 0.923$, sig. = 0.101) indicated that the data showed no difference from a normal distribution. The decision rule for testing the hypotheses was to reject the null hypotheses (**H_0**) if the associated exact probability value was less than 0.05 ($p < 0.05$), otherwise do not reject **H_0**.

In the study, the following control measures were adopted to address the interference of extraneous variables on the outcome of the study. The researchers were not directly involved in the experiment to address the issue of *experimental bias*. Twelve regular teachers each from the selected schools were recruited as research assistants to interact directly with the students. They were trained on the objectives and modalities of the experiment and to administer the treatment. However, the conduct of the experiment was supervised regularly by the researchers to ensure they conform with the guidelines. To address the issue of *diffusion*, 12 different schools were used for the study, six each for the experimental group and the control groups to prevent contamination of the participants by way of communicating or sharing information about the treatment. To address the concern for *Hawthorne's effect*, the use of regular biology teachers in the schools prevented the participants from being aware that they were used for an experiment. So, any chance in their behavior was attributed to the effect of the groups, and none recorded as a change to suit the desirable due to knowledge of the experiment. Intact classes of the participants were randomly assigned to the two groups (experimental and control) without randomization of the participants themselves, in order not to disrupt the normal school arrangement. To address the issue of *instrumentation*, The same instrument was used for both pretest and posttest (although items were reshuffled in the posttest). This was done to ensure that any change in the students' test achievement scores were due to the treatment but not due to instrument variance. To address the concerns for *testing effect*, the eight weeks period between the testing sessions ensured that testing effect and test-wiseness do not confound the outcome of the experiment. The period between the pretest and posttest was considered long enough to ensure that the students forgot most of their responses to the pretest items. Also, reshuffling of the test items before the posttest contributed to ensure the testing effect was addressed, as well.

The study involved 12 intact classes of students exposed to different instructional strategies. The experimental group which received AIATAS consisted of 35 students from single-sex schools and 156 students from mixed sex schools; the conventional instructional group consisted of 92 students from single-sex schools and 119 students from mixed-sex schools. This unequal group sizes resulted from the use of intact classes in Nigerian schools where the availability of eligible participants within the sampled schools rather than from differential selection of participants into the treatment conditions. Thus, random assignment of participants to the treatment conditions was not feasible, consistent with the quasi-experimental nature of the study. The imbalance in group sizes was acknowledged as a potential limitation in comparing the group differences by influencing the precision of group estimates and robustness of statistical procedures where group variances differ substantially. Consequently, the interpretation of differences between the two conditions was made with caution, and the baseline equivalence of the groups was examined using the pretest scores before evaluating the treatment effect. Finally, to address the issue of *intergroup variation,* the participants were drawn from intact classes of SS 2 biology students who already had to the same baseline experience in biology. To control for potential pre-existing differences, pretest scores were considered in the analysis of the posttest scores using ANCOVA, appropriately. More so, the analysis of the pretest scores indicated no significant difference in the biology baseline knowledge of the participants. The assumptions underlying the analysis, including homogeneity of regression slopes and the suitability of the covariance adjustment, were examined before interpreting the results. The unequal group sizes were therefore treated as an important methodological consideration rather than ignored, and the findings concerning the superiority or otherwise of ALATAS over conventional instruction were interpreted within the limitations imposed by the non-equivalent group sizes and the quasi-experimental design.

Declaration Ethical Approval

The research ethics committee at the University of Nigeria granted ethical approval for the study. The achievement test used in collecting data and methodology for this study was approved by the Human Research Ethics Committee of the University of Nigeria, Nsukka. Also, before the commencement of the study, approval was obtained from the principals of the sampled secondary schools and the respondents were presented with informed consent forms to complete and sign, to indicate their willingness to participate in the study. The ethics committee certify that the study was performed in

Table 2. Mean (M) and standard deviation (SD) of students' achievement in mathematics-related biology topics due to instructional strategy

Instructional strategy	N	Pre-test		Post-test		Mean gain	Difference in mean gain
		M	SD	M	SD		
AIATAS	191	19.74 & CI (19.54-19.93)	1.36	41.04 & CI (40.55-41.53)	3.42	21.30	8.54
Conventional	211	19.36 & CI(19.16-19.56)	1.49	32.12 & CI(31.27-32.97)	6.24	12.76	

Table 3. ANCOVA of the difference in students' achievement in mathematics-related biology topics

Source	Type III sum of squares	df	Mean square	F	Significance	Partial eta squared
Corrected model	8,764.72[a]	4	2,191.18	90.54	0.00	0.48
Intercept	1,687.08	1	1,687.08	69.71	0.00	0.15
Pre-test	149.74	1	149.74	6.19	0.01	0.02
Strategy	5,543.54	1	5,543.54	229.07	0.00	0.37
School_type	294.32	1	294.32	12.16	0.00	0.03
Strategy * School_Type	134.78	1	134.78	5.57	0.02	0.01
Error	9,607.41	397	24.20			
Total	549,711.00	402				
Corrected total	18,372.13	401				

Note. [a]R squared = 0.48 (adjusted R squared = 0.47)

Table 4. Mean (M) and standard deviation (SD) of students' achievement in mathematics-related biology topics due to AIATAS based on school type

School type	N	Pre-test		Post-test		Mean gain	Difference in mean gain
		M	SD	M	SD		
Single-sex	35	19.94 & CI (19.59-20.30)	1.03	41.66 & CI (40.85-42.46)	2.35	21.72	0.51
Mixed-sex	156	19.69 & CI (19.47-19.92)	1.42	40.90 & CI (40.33-41.47)	3.61	21.21	

accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards for study procedures for human participants.

RESULTS

Table 2 shows the mean and standard deviation scores of students taught mathematics-related biology topics using the AIATAS instructional strategy and those taught using the conventional instructional strategy. **Table 2** shows that students who were taught mathematics-related biology topics using the AIATAS instructional strategy have a mean score of 19.74, 95% confidence interval (CI) [19.54, 19.93] and standard deviation of 1.36 in the pre-test, while the posttest mean achievement score of 41.04, 95% CI [40.55, 41.53] and the standard deviation of 3.42 for the same group. For the students who were taught mathematics-related biology topics using the conventional instructional strategy, a pretest mean achievement score of 19.36, 95% CI [19.16, 19.56] and standard deviation of 1.49, while their posttest mean achievement score is 32.12, 95% CI [31.27, 32.97] and standard deviation is 6.24. The mean gain for the AIATAS group is 21.30, while that of the conventional group is 12.76. The difference in the mean gains for the two groups is 8.54 in favor of the students taught mathematics-related biology topics using the AIATAS, who have a higher achievement mean gain than the students taught using the conventional instructional strategy. More so, the relative standard deviations in the pretest for both groups show that the responses of the students do not differ. However, the scores deviate more in the posttest with a higher deviation record for the conventional strategy group, indicating a wider spread of scores.

Table 3 reveals the significance of the difference in students' achievement in mathematics-related biology topics due to the instructional strategies. With an F-ratio of 229.07 and an associated probability of 0.00 due to the instructional strategy, **Table 3** shows that there is a significant difference in the mean achievement scores of students taught mathematics-related biology topics using the AIATAS instructional strategy and those taught using the conventional instructional strategy. Since the probability value of 0.00 is less than the 0.05 level of significance, the null hypothesis, which states that there is no statistically significant difference in the mean academic achievement scores of students in mathematics-related biology topics taught using AIATAS instructional strategy and those taught using the conventional instructional strategy, is rejected. Hence, the inference drawn is that the AIATAS instructional strategy has a significant effect on students' academic achievement in mathematics-related biology topics. In addition, the effect size (partial eta squared) shows a 37% variation in the academic achievement of students taught mathematics-related biology topics accounted for the instructional strategy employed in the groups.

Table 4 shows the mean and standard deviation scores of students' academic achievement in mathematics-related biology topics taught using the AIATAS instructional strategy in mixed-sex and single-sex schools. **Table 4** shows that students in single-sex schools who were taught mathematics-related biology topics using the AIATAS instructional strategy have a mean gain of 21.72, following a posttest mean achievement score of 41.66, 95% CI [40.85, 42.46], standard deviation of 2.35, and a pretest mean achievement score of 19.94, 95% CI [19.59, 20.30], standard deviation of 1.03. The students in mixed-sex schools who were taught mathematics-related biology topics using the AIATAS instructional strategy have a mean gain of 21.21, following a posttest mean

Table 5. ANCOVA of the difference in students' achievement in mathematics-related biology topics based on school type

Source	Type III sum of squares	df	Mean square	F	Significance	Partial eta squared
Corrected model	162.85[a]	2	81.43	7.42	0.00	0.07
Intercept	707.86	1	707.86	64.48	0.00	0.26
Pre-test	146.35	1	146.35	13.33	0.00	0.07
Strategy	10.14	1	10.14	0.92	0.34	0.01
School_type	2,063.89	188	10.98			
Strategy * School_Type	323,872.00	191				
Error	2,226.74	190				
Total	162.85a	2	81.43	7.42	0.00	0.07
Corrected total	707.86	1	707.86	64.48	0.00	0.26

Note. [a]R squared = 0.07 (adjusted R squared = 0.06)

achievement score of 40.90, 95% CI [40.33, 41.47], standard deviation of 3.61, and a pretest mean achievement score of 19.69, 95% CI [19.47, 19.92], standard deviation of 1.42. The difference in the mean gain for the two groups taught using the AIATAS instructional strategy is 0.51 in favor of the single-sex group, who have a higher mean achievement gain than the students in mixed-sex schools. More so, the posttest standard deviation of the mixed-sex school students is higher compared to that of the students from single schools, and higher than the pretest of both groups. This points to a greater variation in the academic achievement scores of the students in mathematics-related Biology topics in mixed-sex schools after the AIATAS strategy.

Table 5 revealed the significance of the difference in students' academic achievement in mathematics-related biology topics due to their school type. With an F-ratio of 0.92 and an associated probability of 0.34 due to the school type, **Table 5** shows that there is no significant difference in the mean achievement scores of students in mixed-sex and single-sex schools when taught mathematics-related biology topics using the AIATAS instructional strategy. Since the probability value of 0.34 is greater than the 0.05 level of significance, the null hypothesis two, which states that there is no statistically significant difference due to school type in the mean academic achievement scores of students in mathematics-related biology topics taught using AIATAS in mixed and single-sex schools, is not rejected. Although **Table 3** indicated a significant school type main effect, $F(1) = 12.16$, $p < 0.01$ for both the AIATAS and conventional instructional strategies, the **Table 5** has revealed an insignificant school type main effect, $F(1) = 0.92$, $p = 0.34$, exclusively for the AIATAS group. Hence, the inference drawn is that school type has no significant effect on students' academic achievement in mathematics-related biology topics when the AIATAS instructional strategy is considered. In addition, the partial eta squared shows a 1% variation in the academic achievement of students taught mathematics-related biology topics using AIATAS accounted for the school type.

Table 5 shows the mean and standard deviation scores for the interaction of instructional strategy and school type on students' academic achievement in mathematics-related biology topics. For students who were taught mathematics-related biology topics using the AIATAS instructional strategy, **Table 5** shows that students in single-sex schools has a mean achievement score of 19.94, 95% CI [19.59, 20.30], and standard deviation of 1.03 in the pretest, while the posttest mean achievement score of 41.66, 95% CI [40.85, 42.46], and standard deviation record of 2.35, and students in mixed-sex

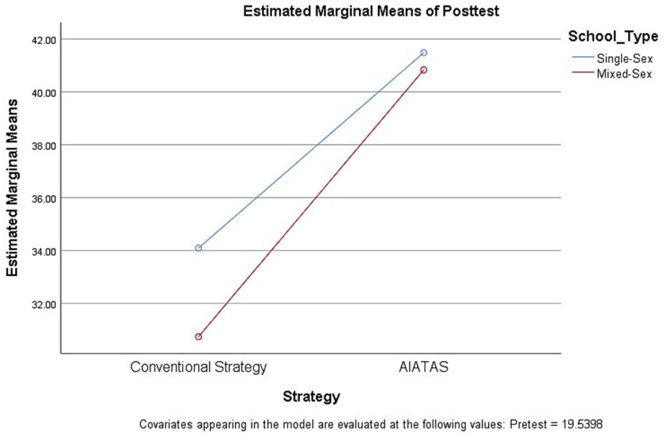

Figure 3. Interaction effect of strategy and school type on students' academic achievement (the authors' own elaboration)

schools has a mean achievement score of 19.69, 95% CI [19.47, 19.92], and standard deviation of 1.42 in the pretest, while the posttest mean achievement score of 40.90, 95% CI [40.33, 41.47], and standard deviation record of 3.61. For the students who were taught mathematics-related biology topics using the conventional instructional strategy, **Table 5** shows that students in single-sex schools has a mean achievement score of 19.51, 95% CI [19.22, 19.80], and standard deviation of 1.40 in the pretest, while the posttest mean achievement score of 34.08, 95% CI [32.98, 35.17], and standard deviation record of 5.27, and students in mixed-sex schools has a mean achievement score of 19.24, 95% CI [18.96, 19.53], and standard deviation of 1.55 in the pretest, while the posttest mean achievement score of 30.61, 95% CI [29.42, 31.79], and standard deviation record of 6.52. The difference in mean gain for the AIATAS group is 0.51, while that of the conventional group is 3.20 in favor of the single-sex school students in both groups. This indicates that students in single sex schools achieved more in mathematics-related biology topics. More so, the standard deviations in the posttests of all groups are higher than those in the pretests. However, the highest deviation in students' scores is shown in the posttest record for the conventional strategy group, indicating a wider spread of the scores. **Figure 3** indicates an interaction between instructional strategy and school type on students' academic achievement in mathematics-related biology topics.

Table 6 further reveals the significance of the interaction between instructional strategy and school type observed on students' academic achievement in mathematics-related biology topics. With an F-ratio of 5.57 and an associated

Table 6. Mean (M) and standard deviation (SD) of the interaction between strategy and school type on students' achievement in mathematics-related biology topics

Instructional strategy	School type	N	Pre-test		Post-test		Mean gain	Difference in mean gain
			M	SD	M	SD		
AIATAS	Single-sex	35	19.94 & CI (19.59-20.30)	1.03	41.66 & CI (40.85-42.46)	2.35	21.72	0.51
	Mixed-sex	156	19.69 & CI (19.47-19.92)	1.42	40.90 & CI (40.33-41.47)	3.61	21.21	
Conventional strategy	Single-sex	92	19.51 & CI (19.22-19.80)	1.40	34.08 & CI (32.98-35.17)	5.27	14.57	3.20
	Mixed-sex	119	19.24 & CI (18.96-19.53)	1.55	30.61 & CI (29.42-31.79)	6.52	11.37	

probability of 0.02 due to the interaction between instructional strategy and school type, **Table 6** shows that there is a significant interaction between instructional strategy and school type on students' achievement in mathematics-related biology topics. Since the probability value of 0.02 is less than the 0.05 level of significance, the null hypothesis three, which states that there is no statistically significant interaction effect of instructional strategy and school-type on the mean academic achievement scores of students in mathematics-related biology topics, is rejected. Hence, the inference drawn is that there is a significant interaction effect of instructional strategy and school-type on the academic achievement scores of students in mathematics-related biology topics. In addition, the partial eta squared shows a 1% variation in the biology achievement of students accounted for the interaction between instructional strategy and school type.

DISCUSSION

The findings of the study showed that students' academic achievement in mathematics-related biology topics improved significantly when using the AIATAS instructional strategy. Students exposed to the AIATAS instructional strategy achieved better than their counterparts taught using the conventional instructional strategy. The difference in the achievement of students in mathematics-related biology topics, in favor of the students taught using AIATAS, may be due to the learner-centered approach involved in AIATAS. This, coupled with the introduction of AI technology, could have been the game-changer, allowing students to source and verify reliable information that facilitates learning with ease. Perhaps, the AIATAS instructional strategy led to a higher academic achievement in mathematics-related biology topics because it may have stimulated students' determination to succeed in biology. The significant difference observed in students' academic achievement in mathematics-related biology topics could be a result of resonance with modern trends for digital natives, which impacts students' learning styles, complementing the instructional strategy. This is probably because students come to class with different learning needs, for which AIATAS may have satisfied. The findings of the study resonate with those of Hofferber et al. (2014), Wang et al. (2017), Hagger et al. (2020), Tilga et al. (2021), Sun et al. (2021), Brandisauskiene et al. (2022), Yang et al. (2022), Zhou et al. (2023), González-Cutre et al. (2023), Li et al. (2024), Patzak and Zhang (2025), who found that TAS significantly enhances students' academic achievement. However, the findings of this study disagree with the findings of Gurganious (2017) and Admiraal et al. (2022) who found that TAS has no significant effect on students' academic achievement. This finding of the study calls to mind the superior role of AIATAS instructional strategy in improving the academic achievement of students in mathematics-related biology topics.

The findings of the study showed that students in single-sex schools taught mathematics-related biology topics using the AIATAS instructional strategy had higher academic achievements than their counterparts in mixed-sex schools. However, the difference in the mean achievement scores of students in both the single-sex and mixed-sex schools who were taught using the AIATAS instructional strategy was not found to be significant. The slightly higher achievement of students in the single-sex schools may be due to the supportive school environment, which has students of the same gender, enhancing understanding among students for improved collaboration when compared with students in the mixed-sex schools. This may have helped increase students' focus to better appreciate the learning materials from the perspective of their same sex while adopting the AIATAS instructional strategy. It is also possible that the single-sex school students may have been more motivated to pursue inclinations for the sciences, especially the mathematics-related biology topics, unlike the students in the mixed-sex school. However, the interplay of intelligence may have watered down the impact of the motivation and environment, resulting in an insignificant mean difference in the academic achievement of students. Possibly, the difference in the sample size, especially the much smaller sample size for the AIATAS group may have contributed to dilating the effect of the intervention from reaching a statistically significant level. The insignificant mean difference observed in the academic achievement of single-sex and mixed-sex school students in mathematics-related biology topics may have been due to the implementation of the same biology curriculum in both the single-sex and mixed-sex schools, coupled with the adoption of the same instructional strategy. This may have buffered the environmental uniqueness of the school types, especially with the implementation of a single instructional strategy, the TAS, in both school types (Movchan, 2018). Within existing literature, the findings of this study agree with those of Busari (2016) and Ogundiwin and Olusa (2017), who found that school type influences students' academic achievement in science subjects, which biology is one. The findings also agree with the findings of Eleje et al. (2021) and Okonkwo and Samuel (2024) to the extent that there is no significant difference in students' academic achievement in mixed-sex and single-sex school types.

Also, the findings of the study revealed a significant interaction effect of instructional strategy and school type on students' academic achievement in mathematics-related biology topics. The result of the study may have been so because school type could have influenced students' acceptance of the instructional strategy, leading to a significant interaction effect between instructional strategy and school type on students' academic achievement in the mathematics-related biology topics.

CONCLUSION

Based on the findings of the study, it was concluded that the AIATAS instructional strategy significantly improves students' academic achievement in mathematics-related biology topics. Single-sex school students do not significantly achieve better in mathematics-related biology topics than mixed-sex school students when exposed to the AIATAS instructional strategy. Furthermore, the instructional strategy and school type interact with the academic achievement of students in mathematics-related biology topics.

Educational Implications of the Findings of the Study

The educational implication of the findings of the study asserts the role of innovative learner-centered instructional strategies, such as the AIATAS, on students' academic achievement in biology. The findings of the study suggest that the use of the AIATAS instructional strategy seriously influences students' academic achievement in mathematics-related biology topics, especially in single sex schools. When teachers fail to adopt innovative learner-centered instructional strategies that incorporate AI technology to augment teachers' autonomy instructional strategy, they fail to support students to develop capacities that foster students' achievement in mathematics-related biology topics. Teachers who fail to tailor instructional content to emphasize students' specific learning in this increasingly digitalized world risk denying students the discipline they require to take responsibility for their own learning of mathematics-related biology topics. Also, school administrators who fail to encourage and make a conducive learning environment where AIATAS is optimized for supporting students in learning mathematics-related biology topics may undermine teachers' efforts and the power of AI technology in fostering students' academic progress in mathematics-related biology topics. The findings of the study draw the attention of curriculum planners to the risk of neglecting the beneficial role of the AIATAS instructional strategy when designing or upgrading the Nigerian biology curriculum. This may discourage teachers from efforts to incorporate the AIATAS instructional strategies in instructional procedure, thereby denying students the opportunity to improve in their academic achievement in mathematics-related biology topics.

Recommendations

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

1. Teachers should adopt the AIATAS instructional strategy for teaching the mathematics-related biology topics to improve students' achievement in biology.
2. School administrators of mixed-sex schools should group students of the same sex when learning about mathematics-related biology topics for higher academic achievement in biology.
3. School administrators should invest in AI technology devices, infrastructure and training to support teachers and students in the adoption of AIATAS.
4. The government should support teachers and invest in the use of AI for augmenting the teaching and learning of mathematics-related biology topics to ensure students improve on their biology achievement.

Limitations of the Study

The following limitations were encountered in the study.

1. The design for the study did not allow for full randomization of the participants in the study, in which case, the outcome of the study may have turned out differently.
2. The regular biology teachers of the students were the research assistants, who directly interacted with the participants in the study; therefore, any personal biases between research assistants and participants were not accounted for in the study.
3. The study relied on the use free versions of the Gemini and ChatGPT AI chatbots, hence, the findings may not be the same with other AI tools.

Suggestion for Further Study

Based on the limitations of the study, the following suggestions were made for further studies.

1. Future studies in this direction should consider research designs that permit full randomization of participants.
2. Future studies should consider recruiting neutral research assistants who are acquainted with the students shortly before the actual experiment.
3. Future studies should consider the use of paid versions of Gemini and ChatGPT AI chatbot, as well as other AI tools.

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Ethics approval: This study was approved by the Human Research Ethics Committee at the University of Nigeria, Nsukka on 10 January 2025. This study was conducted according to the Declaration of Helsinki. Also, participants and school principals gave their informed consent before the commencement of the study.

AI statement: During the preparation of this research report, the authors used Gemini AI tool for clarifying gray constructs, and the authors took responsibility for the content of the publication.

Availability of data: All data generated or analyzed during this study are available for sharing upon request. Interested parties are encouraged to direct their inquiries to the corresponding author, who will facilitate the provision of the data in a timely and appropriate manner.

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