

Ai-based Intelligent Tutoring Systems for Facilitating the Mastery of Difficult Biology Concepts among Special Educational Needs Learners

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This study probed the potentials of AI-based Intelligent Tutoring Systems (AI-ITS) in facilitating the mastery of difficult Biology concepts among special educational needs secondary school two (SS2) students. It was guided by three research questions and one hypothesis. A quasi-experimental (non-equivalent pretest–posttest control group) design, augmented with a survey approach was utilized. The population comprised all SS2 learners offering Biology in government secondary schools in Delta state, from which a sample of 240 students was selected using multistage sampling techniques. Two instruments ‘Biology Achievement Test (BAT) and Questionnaire on AI-Based Intelligent Tutoring Systems (QAITS) were utilized for data gathering. They were validated by experts, while reliability coefficients of 0.82 and 0.86 were got for BAT and QAITS utilizing KR-20 and Cronbach Alpha respectively. Data were analyzed using mean, standard deviation, and Analysis of Covariance (ANCOVA). Findings suggest a statistically significant difference in favour of AI-ITS over conventional methods with convincing effect size ($\eta^2 = .668$). This implies

COPYRIGHT STATEMENT:	that AI-ITS can enhance learners' learning outcome. Secondly,
Copyright: © 2026 Authors.	the potentials and challenges of AI-ITS in enhancing
Open access publication under the	participants understanding of difficult Biology concepts were
terms and conditions	acknowledged. Hence, adequate infrastructure, in-service
of the Creative Commons Attribution	training for teachers, and policy rectification is recommended to
(CC BY)	facilitate AI adoption/implemented in Biology instruction.
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Introduction

The drive for an improved learning outcome among students especially those with special educational needs remain a global concern, particularly in science education. In Nigeria, the issue of students' poor mastery of perceived difficult Biology concepts in secondary has continued to attract scholarly attention. According to Benson et al., (2025), Latif et al., (2026) topics such as genetics, cellular processes, and physiological mechanisms are the areas where learners experience significant difficulty. This perceived difficulty toward some Biology concepts has been largely linked to the dominance use of the traditional teacher-centred instructional approaches. Traditional approach, commonly referred to as conventional method (CM) often fail to address learners' individual differences and limit learners' opportunities for active engagement and meaningful learning (Dutta, 2025; Alhassan et al., 2024).

CM is a teacher-led, lecture-based and chalk-and-talk instruction delivery method. It remains widely used due to its clarity, cost effective, and efficiency in content transmission, making it an interesting method for teacher to cover school syllabi. Consequently, making learning a passive exercise void of creativity, engagement and practical application, prioritizing memorization over conceptual mastery. Hence, the growing need for the adoption of technology-driven instruction that support personalized, adaptive, and interactive learning that guarantee students-centred experiences. Example of such innovation is 'the use of Artificial Intelligence (AI)-based Intelligent Tutoring Systems (ITS)'.

The AI-based ITSs are innovative pedagogical tool designed to simulate personalize tutoring by adapting instruction to learners' needs, diagnosing misconceptions, and providing immediate, targeted feedback. Thomas and Sahai, (2026) explained that AI-based ITSs are designed to mimic learners' information processing pattern, identify misconceptions, and deliver immediate and appropriate feedback. Operationally, AI-based ITSs are adaptive instructional systems designed to provide individualized learning experiences, especially in difficult and abstract subject domains like Biology. Vootukuri and Jyothi (2024) opined that the system of education in 21st century is rapidly driven by artificial intelligence.

In the fast-changing education sphere, the potential of AI instruction to encourage learning equity by ensuring flexible and scalable access to adaptive learning is non-negotiable. Suggesting that AI-based ITS guarantees equal learning opportunities, resource control, and the environments that cater to divers' learners' needs and potential, thereby minimizing disparities and fostering inclusivity (Ukala et al, 2024; Roshanaei et al, 2023). According to Seo et al., (2021), Schiff (2021) AI support differentiated instruction, enhance learners' autonomy, and self-regulated learning, which stimulate the development of higher-order-thinking skills and meaningful learning. In addition, AI systems integrate multimedia features like audio/visual simulations, and virtual laboratories, to help learners visualize abstract biological processes that are otherwise difficult to comprehend through conventional teaching methods. The effectiveness of AI-based ITS in improving students learning

outcome especially among special educational needs learners cannot be under estimated.

In this context, special educational needs (SEN) students refers to learners who requires additional educational support, specialized instructional approaches, assistive technologies, or adapted learning environments due to physical, cognitive, sensory, communication, behavioural, emotional, or learning difficulties that may affect participation and achievement in conventional educational settings. These set of learners require individualized support due to their disabilities in other to meet up with their peers (Okeke & Joseph, 2021). Hence, the utilization of AI-ITS present a valuable opportunity for supporting them because of its ability to provide personalized instruction, adaptive feedback, multimodal representations, and self-paced learning experiences that is mostly required by these learners. Consequently reducing learning barriers, accommodate individual differences, and provide additional scaffolding needed for mastery of difficult Biology concepts.

Although SEN students faces several systemic challenges, including inadequate specialized teachers, limited access to assistive technologies, insufficient instructional materials, overcrowded classrooms, and weak implementation of inclusive education policies (Zawacki-Richter et al., 2019). These realities make this study particularly relevant, as AI-based ITS can provide the much needed individualized learning support in a resource-constrained classrooms like ours. Therefore, the successful adoption of AI-based ITS requires consideration of accessibility, teacher preparedness, affordability, and cultural appropriateness to ensure that AI innovations genuinely promote inclusion rather than create additional educational inequalities.

In Nigeria, student often utilize meta AI, ChatGPT, Google Gemini, SabiTutor, Perplexity AI, and Open TutorAI among others AI-based ITS. According to Thomas and Sahai, (2026) 'AI intelligent systems architectural designs may vary, but have four main components: the domain model (which

encapsulates subject matter expertise), the student model (which tracks the learner's understanding), the tutor model (which determines instructional strategies), and the user interface (which manages communication with the learner)'. AI-based ITS functions the way it does "customize instruction, monitor student progress, and adjust teaching methods" due to the interaction between these components.

Furthermore, AI-based ITS provide a scalable, low-cost access to personalized learning thereby filling the void in the system and improving learning outcomes in such a resource-constrained environment like ours (Ukala et al., 2025). Literatures suggest that AI-based ITS significantly enhance students' conceptual understanding and retention due to its ability to provide a step-by-step guidance, and immediate feedback (Smith, 2024; Kulik & Fletcher, 2016). Also, ITS tools such as virtual laboratories and interactive simulations help students visualize abstract or microscopic biological processes that are almost impossible to comprehend through traditional teaching methods (Ukala et al., 2026). Makransky and Petersen (2021), Radianti et al., (2020) reported that AI-based ITS significantly boost students' conceptual understanding, critical thinking, and knowledge retention.

Despite the growing empirical evidence supporting the effectiveness of AI-based ITS globally, their adoption in sub-Saharan Africa, particularly Nigeria, remains limited. The limitation is largely due to infrastructural deficits, pedagogical, and policy-related constraints. In addition, others challenges to include limited access to digital devices, poor internet connectivity (Mwai & Wanyama, 2024), insufficient teacher preparedness (Akintade & Olaore, 2025), high cost of development, maintenance, and implementation of AI-ITS (Asanre et al., 2024). Unfortunately, these challenges in Nigeria hinder the effective integration of technologies into classroom practice. Furthermore, concerns related to data privacy, ethical considerations, and alignment with existing curricula continue to pose huge limitation to their effective implementation (Zawacki-Richter et al., 2019). Similarly, Bond et

al., (2023) argued that the alignment of AI tools with existing curricula will strengthen its reliability in accurately modelling learners' knowledge and misconceptions. Hence, the effective adoption and implementation of AI-based ITS pedagogy dependent on contextual and institutional preparedness.

Similarly, Adayilo et al., (2026), Kestin et al., (2026), Habib et al (2025) argued that although AI-based ITS holds substantial potential for transforming science education, but its success depends on factors like; teacher readiness, technological accessibility, and curriculum alignment. Emerging studies suggest that while AI-based ITS are effective in improving procedural knowledge and short-term learning gains, their impact on higher-order thinking, conceptual change, and long-term knowledge retention remains inconsistent. This raises serious academic alarm especially in a highly abstract subject like Biology, which requires deep conceptual understanding and critical reasoning. Dutta (2025) acknowledge that biology learners find it difficult to master and retain large volumes knowledge, and apply it in real life context due to its abstractness. Hence, the need for to properly align Ai-based ITS with curriculum objectives and instructional strategies, so as not to render it counterproductive (Ukala et al, 2026, & Dutta, 2025)

Furthermore, Kestin et al., (2026), Bond et al., (2023), Makransky and Petersen (2021) theorized that AI-ITS may not be as effective as claimed, that they rely on simple explanation pattern that limit learner's ability to achieve deep thinking skills. Implying that AI lacks the cognitive depth and pedagogical richness of human tutoring. Despite these inherent challenges with AI intelligent system adoption and implementation in Nigeria, most recent literatures in global space applaud Ai-based ITS in positively influencing learning outcomes. The limited literatures on the use and effectiveness of AI tutor in the region also raise serious concern about out preparedness. Therefore, 'there is a need for context-specific empirical studies to examine how AI-based ITS can be

effectively integrated into Biology instruction to enhance meaningful learning outcome's among students without necessarily singling out special educational needs students. This is because, in Nigerian context it would be difficult to filter/separate SEN from normal students. It would raise ethical concern. Thus, this project is not only timely but essential for improving pedagogical strategies and the mastering of difficult biology concepts especially among all learners. Precisely to explore:

1. The effect of AI-based ITS on students' academic achievement in difficult Biology concepts?
2. The perceived potentials of AI-based ITS in Biology learning?
3. The perceived challenges with AI-based ITS in Biology learning?

Hypothesis

1. No difference in academic achievement of participants taught difficult Biology topics using AI-based ITS and those taught using conventional teaching methods

Theoretical Framework

Two theories provide a robust explanation on how AI-based ITS can facilitate learning. They are 'Cognitive Load Theory and the Constructivist Learning Theory'.

'Cognitive Load Theory propounded by John Sweller in 1988 opined that learning is most effective when instructional materials are structured to reduce extraneous cognitive load, while optimizing the processing of relevant information'. The theory aligns with AI-based ITS by providing structured, adaptive, and step-by-step instructional support that minimizes extraneous cognitive load on the learners. Through immediate feedback and personalized learning pathways, AI-ITS allow learners to focus on difficult Biology concepts, which ultimately improve comprehension. Practically, the application of the theory would reduce cognitive overload associated with difficult Biology concepts like genetics and cellular

processes, and allow learners to process information more efficiently and achieve better mastery.

The Constructivist Learning Theory by Vygotsky in 1978 maintain that learners 'actively construct their own knowledge through interaction, exploration, and engagement with learning materials rather than passively receiving information'. The theory focus on learner-centred approaches where students build their understanding based on prior knowledge and experiences. The principles of constructivism and AI instruction align as both encourage interactive learning environments, and problem-solving tasks that actively involve students in the learning process (Yusuf et al 2025). Through adaptive learning pathways and immediate feedback, AI-ITS enable students to explore difficult Biology concepts, thereby promoting critical thinking, and long-term knowledge retention.

These theories provide a comprehensive explanation and theoretical justification to supports the effectiveness AI-based ITS. While Cognitive Load Theory focus on how to enhance information processing efficiency, Constructivist Theory explains how to promote active engagement and meaningful learning.

Methodology

Design: This project adopted a 'quasi-experimental (non-equivalent pretest-posttest control group) and augmented with a survey approach'. This designs enabled the researchers to compare the academic achievement of students exposed to AI-based ITS and those instructed using CM, while also examining their perceptions of the potentials and challenges associated with AI-ITS, without random assignment of participants. On the other hand, a survey research design allows for a large group to be studied by using the perception of small representative (sample) to make generalization on an existing situation.

Participants/Sample: The population of the study comprised all Senior Secondary School Two (SS2) students offering Biology in public secondary schools in Delta State. A sample of

240 was selected using a multistage sampling technique. Four schools were purposively selected based on the availability of basic ICT facilities. Thereafter, intact classes were randomly assigned to experimental and control groups to minimize selection bias. Only the 120 SS2 students in the experimental group participated in the survey. This is because of their first hand experience of AI-based ITS. Although the study intended to use only special educational need learners, but was unable to due to lack of verifiable data and minimal number of the identifiable ones. The school administrators discouraged separating the identifiable few SEN and encourage that SS2 students offering Biology should participate in the study at will to avoid discrimination.

Instruments: Two folds of instruments developed by the researchers were used for data gathering: The Biology Achievement Test (BAT) and (ii) a Questionnaire on AI-Based Intelligent Tutoring Systems (QAITS). The BAT consisted of 28 multiple-choice items designed to measure students' mastery of selected difficult Biology concepts, while the QAITS assessed students' perceptions using a four-point Likert scale. Face and content validity were established by three experts, their inputs guided the modification and refinement of the instruments to align with the stated objectives. BAT's reliability was determined using the Kuder-Richardson Formula 20 (KR-20), yielding a reliability coefficient of 0.82, while the QAITS was subjected to Cronbach's Alpha reliability analysis, resulting in a coefficient of 0.86, indicating a strong reliability.

Procedure: This procedure was conducted in three phases: 'pre-intervention, intervention, and post-intervention'. *Pre-intervention phase:* Prior to the treatment, permission was sorted from the school authorities, and the participants were duly briefed on the purpose of the study. The commencement of the project saw the administration of a pretest to both groups (experimental and control) using the developed instrument to establish their baseline knowledge equivalence in the selected difficult Biology concepts. *The intervention phase;* this phase

commenced with experimental group been exposed to AI-based ITS, where participants engaged with interactive, adaptive, and self-paced learning materials designed to address identified difficult Biology topics, providing immediate feedback, guided explanations, and personalized learning pathways. On the other side, the same content was taught using the conventional teacher-centred instructional approach. The project lasted for five weeks, with both groups receiving instruction under similar classroom conditions, except for the mode of delivery. *The post-intervention phase:* A posttest was administered to both groups using a reshuffled version of the instrument to measure their mastery of the selected concepts. In addition, participants in the experimental

Results

The results were presented in tables and interpreted accordingly:

Table 1: Descriptive analysis on the Difference in Learners Mean Achievement Score

Methods of Instruction	N	Before-test		After-test		Mean Gain
		Mean	SD	Mean	SD	
AI-based ITS	116	14.00	1.12	34.11	3.16	20.11
CM	124	12.53	3.90	24.79	3.35	12.26

The result in table 1 suggest that the group instructed with AI-based ITS outperformed those taught with CM of instruction. This was anchored on the differences in their mean gain,

while the former had mean gain of 20.11, the latter had 12.26 showing a clear difference in their learning outcome. Table 2 reveals if the difference is statistically significant or not.

Table 2: ANCOVA to establish the significant difference between students learning outcome based on method of instruction

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	5245.635 ^a	2	2622.817	246.128	.000	.675
Intercept	17461.806	1	17461.806	1638.633	.000	.874
Pre_Tes_Ach	.285	1	.285	.027	.870	.000
Method	5088.416	1	5088.416	477.502	.000	.668
Error	2525.548	237	10.656			
Total	215806.000	240				
Corrected Total	7771.183	239				

a. R Squared = .675 (Adjusted R Squared = .672)

The results revealed that students exposed to AI-based ITS demonstrated higher mean achievement scores compared to those taught using conventional methods. The ANCOVA results indicated that this difference was

statistically significant ($p < .000$), in favour of AI-based ITS, with a large effect size (partial $\eta^2 = .668$), suggesting that the intervention had a substantial impact on students' learning outcomes.

Table 3: Descriptive Analysis of the Perceived Potentials of AI-based ITS

S/N	Items Potentials	N	Mean	SD	Remark
1	AI-based tutoring systems make learning Biology more interesting and engaging	116	3.45	.60	Accept
2	AI-based ITS provide personalized learning experiences that improve students' learning outcomes.	116	3.44	.62	Accept
3	The use of AI-based ITS improve learners' understanding of difficult Biology concepts.	116	3.49	.62	Accept
4	The immediate feedback from AI-based tutoring systems helps to correct students' misconceptions in Biology	116	3.47	.69	Accept
5	The integration of AI-based tutoring systems can improve the overall quality of Biology instruction	116	3.32	.73	Accept
6	AI-based tutoring systems support independent learning among students	116	3.15	.93	Accept
7	The use of AI-based ITS increases students' motivation to learn Biology	116	3.27	.71	Accept
8	AI-based tutoring systems facilitate better visualization of abstract Biology concepts	116	3.54	.51	Accept
Grand mean			3.39		Accept

The analysis in table 3 showed that participants accept all the items in the cluster revealing the potentials of AI-Based ITS. This was anchored on their mean score ranging from 3.15 to 3.54 which is conspicuously higher than the 2.5 criterion mean for the study. In addition, the

result revealed a grand mean of 3.39 which is also higher than the 2.5 criterion mean, suggesting that AI-based ITS has a huge potential in facilitating the mastery of difficult Biology concepts among students.

Table 4: Descriptive Analysis of the Challenges of AI-based ITS

S/N	Items Challenges	N	Mean	SD	Remark
1	Limited access to digital devices hinders the effective use of AI-based tutoring systems	116	3.61	.55	
2	The high cost of accessing AI-based tutoring systems limits their widespread adoption	116	3.05	.97	
3	Poor internet connectivity affects the use of AI-based ITS in learning Biology	116	3.12	.78	

4	Teachers' limited competence in AI tools affects their integration into Biology teaching	116	3.30	.86	
5	Technical issues (e.g., system errors or software malfunction) disrupt the use of AI-based tutoring systems	116	3.31	.83	
6	Lack of adequate training prevents students from effectively using AI-based tutoring systems	116	3.25	.99	
7	AI-based tutoring systems may not adequately address all students' learning needs	116	3.16	.74	
8	Over-reliance on AI-based tutoring systems may reduce students' critical thinking abilities	116	2.95	.99	
Grand mean			3.21		

Table 4 revealed that participants accepted all the items in the cluster as the possible challenges of AI-Based ITS. This was anchored on their mean score ranging between 2.95 to 3.61 which is conspicuously higher than the 2.5 criterion mean for the study. In addition, the result revealed a grand mean of 3.21 which is also higher than the 2.5 criterion mean, suggesting that the elements mutually accept these were the challenges encountered while receiving instruction with AI-based ITS. Hence, proffering solution to them would help in facilitating the mastery of difficult Biology concepts among students.

Discussion

The findings of this project revealed that AI-based ITS yield a higher academic achievement than teacher centered conventional method. Implying that AI instruction due to its personalized learning experiences, immediate feedback, and interactive content supports critical thinking and the mastery of difficult Biology concepts. The finding aligns with several report that adaptive learning technologies facilitate active students' engagement, reduce cognitive overload, and improve learning outcomes. For example, studies by Adayilo et al (2026), Ukala et al., (2025), Dutta (2025) and Alhassan et al., (2024) reported that AI-based learning environments significantly enhance students' engagement, understanding, and academic achievement and over all learning outcome compared to

traditional teaching approaches. Similarly, González-Montesino et al., (2026) reported that when AI pedagogy is integrated in a didactic manner, it serves as an effective tool for enriching the training of learners.

Similarly, Radianti et al., (2020), Chen et al., (2020), and more recent extensions by Kestin et al., (2026), Thomas and Sahai (2026), Habib et al (2025) Asanre et al., (2024), suggest that AI-driven ITS can produce moderate to high learning gains, particularly in conceptually demanding subjects like Biology. On the contrary, evidence shows that the superiority of AI-driven ITS over CM is not always consistent or universally applicable. For example, Adesope et al., (2014) found no significant difference between learning from ITS and learning from individualized human tutoring. Also, Kestin et al., (2026), Bond et al., (2023), Makransky and Petersen (2021) argue that AI-Based instruction may improve short-term performance, but their effectiveness on improving deep thinking and long-term retention remains unseen. Despite the attributes of AI-instructional system's ability to diagnose learners' misconceptions and provide targeted remediation, adequate infrastructure, digital literate personnel, with good AI pedagogical skill are required to facilitating deeper conceptual understanding in Biology.

Furthermore, the potentials and challenges associated with AI-based ITS in the mastery of difficult Biology concepts was also revealed. The findings show a strong positive perception of

the potentials of these systems in enhancing the learning of difficult Biology concepts. Similarly, participants accepted all the items in the cluster on the challenges of AI-Based ITS. This is an indication of a strong consensus among participants regarding the notable barriers experienced while using these technologies in Biology learning. Also, it suggests that despite recognizing the potentials AI-driven ITS, learners are equally aware of constraints such as limited access to digital devices, poor internet connectivity (Mwai & Wanyama, 2024), high cost of deployment, and lack of technical support.

These result is consistent with recent studies which highlight infrastructural and pedagogical limitations as major impediments to the successful integration of AI in education (Chen et al., 2020; Bond et al., 2023). Furthermore, Thomas and Sahai (2026), Ukala, (2018) emphasized that the efficacy of AI tools is often limited by teacher readiness and institutional support, while Asanre et al., (2024) noted that issues related to data privacy, system reliability, and learner over-dependence can further hinder its educational value. Although, the effectiveness of AI-based ITS has been established, however, it is advisable to generalize these findings with caution, considering the limited content scope, population and location coverage of the study.

Conclusion

The project conclude that AI-based ITS significantly promote the mastery of difficult Biology concepts than traditional conventional method. The participants also acknowledged the potentials of AI instruction in understanding difficult Biology concepts. Similarly, the study revealed that despite the unanimous acceptance of the potentials of AI instructions, they also acknowledge some challenges associated with AI instruction. This realistic appraisal of AI-based ITS by participants, suggest that its effectiveness is contingent upon adequate infrastructural support, teacher preparedness, and proper integration into the curriculum.

Implication of Findings

The project found positive implications for Biology education. The significant improvement recorded due to AI-ITS implies that, with proper integration of adaptive and personalized technologies into classroom instruction, students' mastery of difficult Biology concepts can be enhanced. Similarly, the identified potentials of AI-ITS imply that its integration in classroom can promote engagement, independent learning, and conceptual understanding, and ultimately improving academic achievement. However, while AI-ITS was found to hold strong promise for improving Biology education, challenges were also acknowledging. This implies that the successful implementation of adaptive and personalized technologies into classroom instruction requires adequate infrastructure, teacher training, and supportive policies.

Recommendation

1. Stakeholders in the system (government, school administrators, non-governmental organizations, well-meaning Nigerians) should collaborate to provide adequate technological infrastructure to ensure the effective implementation of AI-based ITS in Biology instruction.
2. Teachers and students should at regular interval undergo professional training and capacity-building programs on the integration and effective use of AI-based ITS to enhance instructional delivery, improve learning outcome and minimize implementation challenges.
3. Curriculum planners cum policymakers should ensure proper alignment of AI-driven instruction with the Biology curriculum, and at the same time regulate its use to avoid over reliance, data privacy, and ethical concerns.

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and interpretation of findings, which culminated in the successful completion of the research.

Ethical Considerations

“This study involved humans’ participation, as a result, an approval was sorted and granted by the University of Nigeria, Nsukka committee on research ethics. The study was executed in line with the institutional regulations. The subjects were assured of confidentiality and anonymity, and they gave consent to fully join the project. At this stage of approval, no code was given. This is in line with the approved guideline by the ethical review board of universities in educational research”.

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