ARTIFICIAL INTELLIGENCE AS A CATALYST FOR PEDAGOGICAL INNOVATION IN SCIENCE TEACHING: A MULTIDIMENSIONAL ANALYSIS OF NIGERIAN SECONDARY SCHOOLS

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Abstract

The accelerated advancement of Artificial Intelligence (AI) has greatly influenced science education pedagogical practices and currently redefining classroom interactions in the 21st century. This article explored how Artificial Intelligence (AI) can serve as a catalyst for pedagogical innovation in science teaching in Nigerian secondary schools. It reviewed the current pedagogical and digital environment of many schools, which is often constrained by limited technological infrastructure, unequal access to digital resources, and insufficient teacher preparedness for integrating modern technologies into classroom practice. These factors continue to influence the quality of science instruction and the pace of educational innovation. The paper also explored conceptual and practical pathways for incorporating AI into science pedagogy, highlighting the use of adaptive learning platforms, intelligent tutoring systems, virtual laboratory simulations, and data-informed assessment tools to support more interactive, inquiry-based, and learner-centred teaching. In addition, the article proposes a multidimensional framework that presents AI as a supportive instructional tool capable of improving lesson design, increasing student engagement, and enabling more personalized learning experiences while also providing valuable data to guide instructional decisions. Despite these opportunities, the deployment of AI in Nigerian secondary schools faces several challenges, including digital inequality, ethical considerations, policy gaps, and the cost of implementation. The article therefore emphasizes the importance of strategic policy support, improved digital infrastructure, and continuous professional development for teachers to ensure the effective and sustainable integration of AI in science education.

Keywords: AI, pedagogical innovation, science teaching, multidimensional analysis

Introduction

Science occupies a central place in humanity's effort to understand the natural environment and to improve the conditions of life within it. The advancement of contemporary societies is closely tied to the ability to generate and apply scientific knowledge in addressing real-world challenges. Science, according to Adeoye (2021) is the logical and systematic process of applying a planned series of methods to acquiring knowledge about human and the environment. It is a systematic investigation aimed at obtaining reliable knowledge through careful observation and analysis of natural phenomena (Onoshakpokaiye & Avwiri, 2025). Stanford Encyclopedia of Philosophy (2015) noted that scientific processes such as observation, experimentation, and critical reasoning are targeted towards broadening human understanding and providing solutions to the problems confronting the society.

Beyond its conceptual significance, science exerts a profound influence on everyday life. Its contributions are evident in the improvement of the three fundamental necessities of life that is food, shelter, and clothing and currently shaping developments in medicine, transportation, security and defence, agricultural productivity, and even space exploration. These advancements highlight the indispensable role of science in fostering social progress, technological innovation, and economic growth (Mahardhani, 2023). Consequently, nations that prioritise scientific education and research often experience greater capacity for innovation and sustainable development (Tijani & Adeduyigbe, 2025).

Recognising this strategic importance, science has been firmly embedded within the educational framework in Nigeria. It forms a core component of the curriculum across different levels of formal education with the aim of nurturing scientific literacy, problem-solving skills, and a culture of inquiry among learners (Jolaoluwa et al., 2025). At the secondary school level, which comprise of both the junior and senior secondary school stages science and science-related subjects are systematically integrated into the curriculum to provide students with foundational knowledge and opportunities for further specialization. Table 1 presents science and science-related subjects offered at the junior and senior secondary school levels of education in Nigeria.

Table 1: *Science and Science-related Subjects in the Nigerian Secondary School Education*

Stage of Secondary Education	Structure	Science fields of Studies	Related Science Subjects
Junior Secondary Education	Basic Education	Basic Science and Technology	Basic Science Basic Technology Information Technology Physical and Health Education
Senior Secondary Education	Post-Basic Education	Science and Mathematics	Biology Chemistry Physics Further Mathematics Health Education Agriculture Physical Education Computer Studies

Note: Adapted from the *National Policy on Education,* by Federal Republic of Nigeria, 2014

Table 1 shows that at the junior secondary school level in Nigeria, science is offered under the title 'Basic Science and Technology,' whereas at the senior secondary school level it is presented as 'Science and Mathematics.' Each level comprises distinct subjects designed to develop students' scientific literacy, analytical reasoning, and critical thinking skills. However, the rapidly evolving nature of scientific knowledge and technological advancement has begun to reshape the way science is taught and learned in a typical science classroom. Traditional teacher-centred instructional approaches are increasingly considered insufficient for preparing learners to thrive in a knowledge-driven and technology-oriented world (Darling-Hammond et al., 2020). This reality has prompted growing interest in innovative pedagogical practices that can make science learning more interactive, inquiry-driven, and responsive to the demands of the twenty-first century. Within this context, emerging digital technologies particularly Artificial Intelligence (AI) is increasingly being recognised as a transformative tool capable of supporting personalized learning, enhancing instructional strategies, and expanding opportunities for meaningful engagement in science classrooms.

Exiting literature in different fields of studies have highlighted the growing potential of AI in reshaping pedagogical practices across different educational contexts. For instance, research by Adayilo, et al. (2025) emphasised the capacity of AI-driven systems to support personalised learning, adaptive feedback, and intelligent tutoring in classroom environments. Similarly, Zawacki-Richter et al. (2019) observe that AI technologies can assist teachers in analysing learning data, identifying students' learning needs, and designing more responsive instructional strategies. Reports from UNESCO (2023) and other global education bodies further underscore the transformative potential of AI in improving teaching effectiveness, expanding access to educational resources, and enhancing student engagement in the teaching and learning of science and related subjects. In addition, previous researchers such as Olaleye and Salami (2024) and Ugosor et al. (2025) have explored the nexus between artificial intelligence and different science subject like basic science and chemistry. In the same vein, Lawal et al. (2025) investigated the impact of integrating Artificial Intelligence (AI) tools into STEM classrooms on the critical thinking and problem-solving skills of secondary school students in Zaria Education Zone, Northern Nigeria.

Although, there is an increasing global discourse on AI-supported pedagogy with most existing literature examining AI in higher education or in technologically advanced educational systems, leaving a significant gap in understanding how AI can be harnessed to support pedagogical innovation within the realities of developing educational contexts. It is against this backdrop that the present study explores Artificial Intelligence as a catalyst for pedagogical innovation in science teaching, with particular attention to Nigerian secondary schools.

Status of Nigerian Secondary School Pedagogical and Digital Ecosystem

Nigeria's secondary education faces serious quality based challenges which has resulted in only about 39% of students (42% boys, 36% girls) completing secondary school education and reflecting persistent learning gaps (Nwoke, et al., 2024). Similarly the federal allocations to education have hovered well below international targets, the 2025 budget dedicated ₦3.52 trillion (7% of total spending) to education, which is far below UNESCO's recommended 15–20% (Shehu & Onunwa, 2025). In addition, many secondary school classrooms lack reliable power or Internet. Nigeria's national connectivity (Ademola & Adesina, 2025). Consequently, most e-learning

initiatives are pilot-scale. For example, Lagos State in 2021 distributed tablets to secondary pupils and kits to teacher to bridge the gap of the digital divide (Oxford Business Group, 2024). However, there remains pockets of issues that has remained unaddressed out which digital education remains very important especially at the secondary school level. Overall, the digital ecosystem is nascent because most Nigerian secondary schools have often outdated computer system and software, minimal internet access, and no routine use of online resources (Agbeyangi et al., 2024).

Pedagogical quality in Nigerian science classrooms is uneven. Large classes and exam-driven curricula predominate. Traditional lecture methods are common, partly due to limited training and resources. Teachers often lack formal information and communication technology (ICT) training (Anyanwu, 2026). A 2024 survey of 316 secondary school science teachers in Anambra State found most were aware of many innovative teaching methods but used only about half of them, citing lack of funds, insufficient time, and resistance to change (Nwuba et al., 2024). In practice, computer-based and inquiry methods are still rare because only a few teachers employ technologies like simulations or formative assessment tools (Nwuba et al., 2024). Hence, in-service training programmes are limited, and pre-service education often fails to instill modern pedagogy in would be teachers.

The 2019 Nigerian *National Policy on ICT in Education* explicitly calls for a standardized and coordinated deployment of ICT across all levels and envisions that ICT integration should speedily transform teaching, learning, research and administration (Federal Ministry of Education Nigeria, 2019). Subsequent frameworks including the 2023 National Digital Literacy Framework and the 2023 Digital Learning Policy further stress digital skills and devices. In October 2025, the federal government of Nigeria launched a *Digitalization of Public Schools* initiative, distributing interactive smart boards and 60,000 tablets to teachers, and mandating broadband connectivity and digital pedagogy training through UBEC (Anaja, 2025). However, financing remains a barrier because despite the many policies, financing is fragmented and largely faced with weak monitoring of outcomes (Anyanwu, 2026).

Conceptual Pathways to Integrating AI into Science Pedagogy

Conceptual integration of AI into science pedagogy aligns with Constructivist Pedagogy, inquiry-based learning, cognitive apprenticeship, and personalized instruction model (Holmes et al., 2019).

a. **AI within a Constructivist Pedagogical Framework:** Constructivism model is a learner-centered theory that encourages learners to actively construct their own understanding and knowledge of the world through experiences and reflection. It emphasis on building on learners' prior knowledge by engaging in active inquiry, and social interaction with Teachers as main facilitators. Constructivist AI-powered simulations and adaptive pedagogies support experiential learning by allowing students to manipulate variables and observe outcomes (Holmes et al., 2019). According to Chen et al. (2020), AI systems can personalize learning pathways, thereby supporting deeper conceptual understanding, In-depth, hands-on investigations, Collaborative learning etc.
b. **Personalized Learning Theory:** Personalized learning pedagogical approach tailors instruction, pacing, and learning paths to individual learners' needs, skills, and interests. It utilizes technology (e.g., adaptive systems) to foster autonomy and mastery. This approach emphasizes active knowledge construction through experience often

supported by digital tools. It focuses on fostering learner autonomy, competence, and relatedness. For instance, AI systems analyze learners' performance data to tailor content and instructional pacing. Evidences in literature indicates that adaptive AI systems improve learning outcomes by identifying misconceptions and delivering targeted remediation (Celik et al., 2022). Zawacki-Richter et al. (2019) emphasize that personalized AI systems reduce achievement gaps and support mastery learning in STEM disciplines.

c. **AI-Enhanced Inquiry Learning**: Inquiry-Based Learning emphasizes exploration, critical thinking, and enhances learners' active engagement with concepts. AI integration enhances this learning model by providing personalized pathways that guide students through complex problem-solving task. Brown et al. (2023) asserted that AI driven platforms could simulate real-world scenarios, enabling students to test hypotheses and explore various outcomes in a safe and controlled environment. He and Krajcik (2026) stated that AI tools improve students' ability to interpret scientific evidence and strengthen inquiry competencies when integrated within the structured pedagogy.

d. **Cognitive Apprenticeship Model:** Intelligent tutoring systems simulate expert thinking processes by modeling step-by-step reasoning in problem-solving contexts (Roll & Wylie, 2016). Such systems scaffold learners' understanding and gradually reduce support as competence develops. Matsuo (2024) enumerate phases involve as modeling, coaching, scaffolding, articulation, reflection and exploration as a useful and effective instructional method. Holmes et al. (2019) concludes that AI can function as a digital mentor, guiding learners through complex scientific reasoning tasks.

Practical Pathways for Integrating AI into Science Pedagogy

According to Celik et al., (2022) AI supports adaptive learning systems, intelligent tutoring systems; virtual laboratories, automated assessment, and data-driven instructional decision-making are the Practical AI integration path in science

a. **AI-Powered Adaptive Learning Platforms:** Adaptive learning offers learner the potential to transform learning experience through personalized content delivery (Strielkowski et al., 2025). Adaptive learning platforms analyze learner responses and adjust instructional content accordingly. Chen et al., (2020) study revealed Adaptive learning platforms have been found to improve student engagement and performance in science subjects. In addition, Celik et al. (2022) asserted that AI-supported platforms enhance formative assessment by providing real-time feedback and progress analytics.

b. **Virtual Laboratories and Simulations:** Virtual laboratories enable students to conduct experiments in safe and cost-effective digital environments. Virtual laboratories enriches learning experiences, deepening conceptual understanding, and providing more flexible and safer access to experiments (Meronda, et al., 2025) Research demonstrates that AI-enhanced simulations promote conceptual understanding and experimental reasoning (He & Krajcik, 2026).

c. **Intelligent Tutoring Systems:** Intelligent tutoring systems provide individualized feedback and guided instruction. It is capable of modeling expert reasoning and improving student problem-solving skills. Bouchard (2021) defines Intelligent Tutoring Systems as computer-based educational tools that leverage artificial intelligence to provide personalized instruction and support tailored to individual learners' needs. It assess

student's knowledge and adapt instructional strategies accordingly for targeted remediation and tracking of progress. It promotes active engagement, helping learner retain and apply knowledge more effectively as well as a promising avenue for delivering individualized education at scale.

d. **AI in Science Assessment:** Artificial Intelligence (AI) has improved assessment practices in science education by facilitating automated grading and producing detailed diagnostic feedback on students' performance. According to Zawacki-Richter et al. (2019), AI-powered learning analytics provide educators with meaningful data about students' learning behaviours, thereby supporting evidence-based instructional decisions. Such analytics enable teachers to identify learning difficulties and modify their teaching approaches to address students' needs. In addition, Chen et al. (2020) explain that AI-driven predictive analytics can detect students who may be at risk of academic failure at an early stage. This early identification allows educators to provide timely interventions, personalized assistance, and remedial support to improve learning outcomes. As a result, AI-supported assessment systems enhance the efficiency of evaluation while also promoting adaptive and responsive teaching strategies.

e. **AI and Teacher Professional Development:** Effective integration of Artificial Intelligence in science education depends largely on teachers' preparedness and their ability to utilize AI-based tools. Aravantinos et al. (2026) highlight that professional development is a key element in the successful adoption of AI technologies in educational contexts. Ongoing training programs equip teachers with the technological and pedagogical competencies required to effectively incorporate AI into their teaching practices. Similarly, Nja et al. (2023) found that the adoption of AI among science teachers in Africa is influenced by several factors, including access to professional training, the availability of adequate technological infrastructure, and teachers' perceptions of the usefulness of AI tools for improving teaching and learning. These findings indicate that the benefits of AI in science education can only be fully achieved when educators receive adequate training and institutional support.

Artificial Intelligence as a Transformative Pedagogical Tool for Science Teaching: A Multidimensional Framework.

Artificial intelligence has been largely adopted and employed by many institutions, particularly educational institutions, in a variety of contexts and settings (Ashraf Alam 2021). In fact, teachers will comprehend AI's educational benefits better if they have greater expertise about how to work with AI-based solutions (Ismail Celik, 2023). AI has the potential to improve the effectiveness of science teaching, student engagement, and overall educational outcomes. Artificial intelligence is revolutionizing science education through a range of special applications, including personalized learning experiences, automated contentious assessments, interactive simulations, and smart tutoring systems. Personalized learning experiences for students can be offered using AI-powered tools, taking into cognizant their unique needs, and shortcomings (Božić, 2023). Virtual teachers, intelligent voice assistants, smart content, presentation with translators, global courses ware in sciences automatic assessment, personalized learning, science educational games, and most smart intelligent tutoring systems among few of the educational technology platforms where artificial intelligence has been extensively used (Fitria, 2021). Examples of AI-based learning environments that are science related include virtual mentor, voice assistants and

smart content. In order to improve the teaching and learning of sciences, artificial intelligence tools are being progressively incorporated into a variety of science pedagogy, including practical. AI assessment technologies also facilitates personalized feedback for students, increased assessment efficiency and accuracy, and the ability for science teachers to modify their lesson notes to suit the individual student needs (Owan et al., 2023). By utilizing AI educational platforms, teachers have been able to carry out various academic tasks, such as assessing and grading students' continuous assessment test, assignments, more successfully and efficiently, and provide higher-quality teaching activities (Chen, 2020). Application of AI tools in education can be structured around several key components: *AI-Powered Learning Platforms, Intelligent Tutoring Systems (ITS), Data Analytics, Insights, and Predictive Analytics.*

Effectiveness of AI-Powered Learning Platforms: The extent to which artificial intelligence-powered science learning platforms powered by technologies improve educational outcomes, make pedagogy more easy in delivery, and enable customized and personified learning experiences is referred to as their efficacy. These mentioned platforms include a variety of many tools and parts, such as data analytics platforms, the automated assessment tools, adaptive learning systems, and smart intelligent tutoring and mentor systems. The impact of AI-powered learning platforms on science student learning outcomes, the science teacher engagement, efficiency gains, data-driven knowledge, and the ethical standards compliance can all be used to measure their efficacy and ultimately help enhance innovation and constant improvement in the field of science education.

Engagement: AI-powered platforms always have interactive and gamming features including real-time feedback system to boost student enthusiasm, feeling, anxiety, lesson engagement, and a very active participation in class and practical activities.

Learning Outcomes: AI-driven platforms no doubt enhance knowledge retention, foster critical thinking, and improve problem-solving skills of learners.

Efficiency: AI solutions save lecturer time, help in maximize resource allocation, and totally simplify educational procedures by helping to automating administrative and academics activities, very good in assessment grading if adopted, easy and fast data analysis, and enhance even material distribution where necessary.

Data-Driven Insights: teachers may quickly identify students who are not doing well, then proceed to monitor their progress, know timing to intervene, and also know how to improve on his teaching methods based on research-based practices with the aid of AI-powered data analytics and predictive modeling tools.

Personalization: AI systems allow for adaptive feedback mechanisms, material recommendations, and individualized learning pathways based on the needs, learning preferences, and skill levels of each individual learner

Prospects and Constraints of Deploying Artificial Intelligence for Science Teaching in Nigeria

The following are the prospects of AI in Science Education;

- **Personalized Learning and Adaptive Instruction:** AI can tailor science lessons to each student's level. Studies highlight that adaptive learning systems and intelligent tutoring can customize pacing and content, improving understanding (Okunade, 2024; Eke, 2024). For example, virtual lab simulations enable students to conduct experiments digitally, making abstract concepts concrete.

- **Intelligent Tutoring and Automated Feedback:** AI-driven tools (e.g. virtual tutors, automated grading systems) offer immediate feedback on problems, freeing teachers to focus on deeper instruction. Nigerian research notes that educators see these tools as opportunities to enrich learning, personalize instruction, and build critical thinking skills in students (Eke, 2024).
- **Teacher Support and Professional Development:** AI platforms can generate lesson plans, suggest experiments, and identify student misconceptions. Large-scale programmes (like the Naija Teacher AI platform) are being introduced precisely to bridge pedagogical gaps by upskilling teachers with AI-based supports (Ndjama, 2025).
- **Curriculum and Innovation:** Integrating AI prepares students for future careers. Nigeria has piloted AI Clubs in secondary schools, providing extracurricular labs where students and teachers collaborate on AI projects (Yakubu, 2025). Such initiatives, supported by education boards, indicate growing prospects for student engagement and cross-disciplinary learning.
- **Industry Partnerships:** Collaboration with tech companies e.g., Google, Mastercard Foundation, GMind AI is injecting resources into schools. These partnerships fund teacher training and deploy AI platforms at large scales (UNESCO, 2025). This public–private support can accelerate adoption of sophisticated tools that would otherwise be out of reach for underfunded schools.

Constraints and Challenges

- **Infrastructure and Connectivity Gaps:** Many Nigerian schools lack the basic ICT needed for AI. Nationwide audits show that device availability is extremely limited (World Bank, 2025). Without reliable electricity and internet, advanced AI applications (like cloud-based simulations) cannot function. UNESCO observers note that teacher capacity deficits, unreliable power and last-mile connectivity have so far limited tech-enhanced curricula (Anyanwu, 2026).
- **Limited Resources and Funding:** The education sector in Nigeria is chronically underfunded constraining investment in new technology (Shehu & Onunwa, 2025). Even where AI tools are introduced, ongoing costs of software, maintenance, and subscription of data pose challenges. Schools often struggle to upgrade or maintain even basic computer labs, so investing in cutting-edge AI hardware/software is difficult without earmarked funding.
- **Teacher Training and Capacity:** Although educators generally express positive attitudes toward AI (seeing its benefits), most lack sufficient training and confidence to implement it. A survey of Nigerian teacher educators found *high readiness and positivity* but also highlighted barriers: inadequate infrastructure, insufficient training, and ethical concerns as key obstacles (Eke, 2024). In practice, many science teachers have not been formally trained in using AI tools. The new AI training programs are a start, but they cover only a fraction of teachers and need to be scaled up continuously.
- **Digital Divide and Equity:** There is a stark urban-rural disparity. Ordinarily, urban schools have more computer equipment than rural ones (World Bank, 2025). As a result, students in remote areas might never see AI-enhanced lessons. Gender and socioeconomic gaps

also risk widening if only well-resourced students access AI learning. Without explicit policies to target underserved schools, AI could exacerbate educational inequalities.

- **Curriculum and Implementation Lag:** Updating curricula is complex. While policies now mandate AI literacy, many schools are still aligning their actual lessons. Many teachers have continued with traditional methods due to inertia or lack of resources. Integrating AI meaningfully into day-to-day science classes requires time, support, and experiment.
- **Ethical and Pedagogical Concerns:** some of the valid ethical issues raised by educators include data privacy (protecting student information), academic integrity (preventing over-reliance on AI for answers), and cultural suitability of AI content (Afable, 2025). There is also skepticism that AI tools might reduce human interaction or oversimplify complex science concepts. Effective deployment must address these concerns through guidelines and teacher oversight.

Conclusion

Artificial Intelligence offers a powerful opportunity to rethink how science is taught in Nigerian secondary schools. When used effectively, it can adapt learning to individual students, encourage active inquiry, and make assessment more responsive and meaningful, thereby deepening students' understanding and interest in science. Yet, these benefits cannot be achieved without confronting existing challenges such as poor infrastructure, limited funding, inadequate teacher preparation, and unequal access to digital tools. To make AI truly impactful, efforts must focus on realistic and well-coordinated strategies strengthening school infrastructure, equipping teachers with relevant skills, and ensuring policies are implemented in ways that include all learners. With this balanced approach, AI can shift from being an emerging concept to a practical solution for improving science teaching and learning in Nigeria.

Suggestions

- Science teachers should be encouraged to integrate the use of AI into their classroom instruction.
- Government and cooperate bodies should provide improved digital infrastructures for teachers and schools.
- There should be continuous professional development for teachers to ensure the effective and sustainable integration of AI in science education.

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