

AI-POWERED INQUIRY-BASED LEARNING: TRANSFORMING SCIENCE TEACHING AND LEARNING

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Abstract

Science education continues to experience persistent challenges in many developing contexts, particularly in relation to teacher-centred instruction, limited laboratory facilities, and weak student engagement with scientific processes. At the same time, Artificial Intelligence (AI) is reshaping educational practice by introducing tools that support personalization, simulation, automated feedback, and adaptive learning. This paper examined AI-powered inquiry-based learning as an emerging pedagogical approach for improving science education in the digital age. Grounded in constructivist learning theory, the paper synthesized recent literature from Nigeria and global contexts to explain how AI tools such as intelligent tutoring systems, virtual laboratories, generative AI applications, and learning analytics can support inquiry-based science instruction. The paper argued that AI, when aligned with inquiry pedagogy, strengthens students' scientific reasoning, improves engagement, and expands access to learning resources. However, the effectiveness of this integration depends on teacher competence, infrastructural readiness, and ethical use of AI systems. The paper concludes that AI-powered inquiry-based learning represents a significant shift in science education practice, particularly in resource-constrained environments.

Keywords: Artificial Intelligence, Inquiry-Based Learning, Science Education, Nigeria, Digital Learning

Introduction

Science education is widely regarded as a foundation for national development because it equips learners with the ability to observe, question, investigate, and explain natural phenomena in a structured and evidence-based manner. These competencies are not only important for academic achievement but also for innovation, problem-solving, and scientific literacy in everyday life. However, despite this expectation, the reality of science teaching in many Nigerian classrooms remains far from inquiry-oriented practice.

A considerable body of literature shows that science instruction in Nigeria is still dominated by teacher-centred methods, where emphasis is placed on note copying, memorization of definitions, and preparation for examinations rather than active engagement with scientific processes (Okeke & Nwosu, 2023; Olatunde-Aiyedun, 2024). In such environments, students are often passive recipients of information rather than active participants in knowledge construction. This instructional pattern has been linked to persistent weaknesses in students' understanding of science concepts and poor performance in science-related subjects at both secondary and tertiary levels (Eze & Obi, 2023; Ibrahim & Yusuf, 2024).

The consequences of this approach extend beyond examination outcomes. Studies have consistently shown that limited exposure to inquiry-based science instruction affects the development of science process skills such as observation, classification, measurement, hypothesis formation, and experimentation (Akinwale, 2023; Olatunde-Aiyedun, 2024). These skills are

essential not only for academic success but also for developing critical thinking and problem-solving abilities needed in real-world contexts.

In response to these challenges, Inquiry-Based Learning (IBL) has been widely advocated as a more effective pedagogical approach for science education. IBL emphasizes active student participation in the learning process through questioning, investigation, experimentation, and evidence-based reasoning. Rather than positioning the teacher as the sole authority of knowledge, inquiry-based learning encourages students to construct understanding through guided exploration and interaction with scientific problems (Schwab, 1962; in contemporary applications by Otuturu & Cleopas, 2025).

Empirical studies in science education have demonstrated that inquiry-based approaches improve conceptual understanding, enhance retention, and strengthen learners' ability to apply scientific knowledge in unfamiliar situations (Udo & Akpan, 2023; Nwagbo & Chukwuneke, 2024). However, despite its proven effectiveness, the implementation of inquiry-based learning in many Nigerian schools remains inconsistent. Several structural constraints continue to hinder its full adoption. These include inadequate laboratory facilities, large student populations, limited instructional time, and examination-driven curriculum pressures (Otuturu & Cleopas, 2025; Eze & Obi, 2023).

In many cases, teachers are also constrained by lack of professional development opportunities that would enable them to design and facilitate effective inquiry-based lessons. As a result, inquiry is often reduced to demonstration-based teaching rather than hands-on, student-driven investigation.

In recent years, Artificial Intelligence (AI) has emerged as a significant force reshaping educational practice globally. AI in education refers to the use of intelligent systems capable of performing tasks such as learning analytics, automated feedback generation, adaptive content delivery, and simulation-based learning support. According to UNESCO (2023), AI is increasingly influencing how teaching and learning are designed, delivered, and evaluated, with both opportunities and risks for education systems worldwide.

Recent studies further suggest that AI technologies can enhance student learning by providing personalized instruction, real-time feedback, and interactive learning environments that respond to individual learner needs (Holmes et al, 2023; Luckin et al., 2016). In science education specifically, AI-powered tools such as virtual laboratories and intelligent tutoring systems have been shown to improve engagement and support conceptual understanding, particularly in resource-constrained environments (Woolf, 2022; Igberaese & Usman, 2025).

Within the African and Nigerian context, emerging research indicates a growing awareness and adoption of AI tools among students and educators, particularly in higher education institutions (Bali et al., 2024; Menkiti & Benard, 2025). However, this adoption is still uneven and largely informal, with many learners using AI tools without structured pedagogical guidance. This raises important concerns regarding academic integrity, learning quality, and equitable access to technology.

Against this background, AI-powered inquiry-based learning emerges as a hybrid pedagogical approach that integrates the principles of inquiry-based learning with the adaptive and interactive capabilities of artificial intelligence systems. This approach positions AI not as a replacement for teachers or inquiry processes, but as a supportive tool that enhances scientific exploration, scaffolds learning, and extends access to learning resources that may otherwise be unavailable.

Despite increasing global attention on AI in education, there remains limited context-specific research on how AI can effectively support inquiry-based science learning in Nigerian classrooms. Existing studies tend to focus either on general AI adoption in education or on inquiry-based learning in isolation, with little attention to their integration as a unified pedagogical model (Olatunde-Aiyedun, 2024; UNESCO, 2023). This gap in the literature forms the basis for the present study.

Objectives of the Study

The study is guided by the following objectives:

1. To examine the concept of AI-powered inquiry-based learning in science education.
2. To identify AI tools that support inquiry-based science instruction.
3. To analyze the benefits of integrating AI into inquiry-based learning processes.
4. To examine the challenges affecting the implementation of AI-powered inquiry-based learning in Nigeria.
5. To discuss the implications of AI integration for science teaching and learning practices.

Literature Review

Artificial Intelligence in Education

Artificial Intelligence (AI) in education has moved from theoretical discussion to practical implementation across different levels of learning. It is now widely used in intelligent tutoring systems, adaptive learning platforms, automated assessment tools, and generative AI applications that support both teachers and learners. UNESCO (2023) explains that AI is reshaping educational systems by enabling more responsive, data-driven, and personalized learning environments. Holmes et al., (2023) argued that AI has the potential to transform education when it is used to support human teaching rather than replace it. Similarly, Luckin et al. (2016) emphasized that AI systems can act as “learning companions” that respond to student needs, provide feedback, and guide learning processes in real time. In science education, Woolf (2022) noted that AI-powered systems are particularly useful in simulating scientific environments and supporting inquiry-based exploration where physical laboratory access is limited.

Inquiry-Based Learning in Science Education

Inquiry-Based Learning (IBL) is rooted in constructivist learning theory, which emphasizes that learners actively construct knowledge through experience, questioning, and reflection. Rather than receiving information passively, students engage in scientific processes such as hypothesis formation, experimentation, data analysis, and conclusion drawing. Empirical studies have consistently shown that inquiry-based instruction improves students’ achievement and conceptual understanding in science. For example, Udo and Akpan (2023) reported that inquiry-based science instruction enhances retention and improves learners’ ability to transfer knowledge to new situations. However, despite these positive outcomes, implementation remains inconsistent in many developing contexts. Okeke and Nwosu (2023) observed that teacher-centred instruction still dominates science classrooms in Nigeria, limiting opportunities for students to engage in authentic scientific inquiry. Nwagbo and Chukwuneke (2024) found that students taught using inquiry-based approaches demonstrated significantly higher achievement scores compared to those taught using traditional lecture methods.

Empirical Studies on AI in Education (Global and African Evidence)

A growing body of empirical research has examined the impact of AI on teaching and learning outcomes globally. Studies indicate that AI-supported learning environments can improve student engagement, academic performance, and learning efficiency when properly integrated. For instance, Holmes et al. (2023) reported that AI-based adaptive learning systems significantly improve student achievement by providing personalized pathways that respond to individual learning needs. In similar findings, Luckin et al. (2016) highlighted that AI systems enhance learner autonomy by offering continuous feedback and scaffolding during learning tasks.

In science education specifically, Woolf (2022) demonstrated that AI-driven simulations and intelligent tutoring systems improve learners' conceptual understanding by allowing them to visualize and manipulate scientific phenomena that are otherwise abstract or inaccessible.

Within African contexts, empirical evidence is still emerging but increasingly relevant. Bali et al. (2024) conducted a study on AI adoption trends in Nigerian education and found that while awareness of AI tools is increasing among educators and students, structured integration into pedagogy remains limited. Their findings further revealed that most AI usage occurs informally, particularly among university students who use generative AI tools for academic support without institutional guidance.

Menkiti and Benard (2025) examined undergraduate science education students' perceptions of AI use in mathematics and science learning. Their study revealed that students generally perceive AI as helpful for explaining difficult concepts and improving understanding. However, concerns were raised about dependency on AI tools and reduced effort in independent problem-solving.

Similarly, Igberaese and Usman (2025) investigated AI-driven adaptive learning systems in higher education and found that personalized AI platforms significantly improved student engagement and participation in science-related courses. Their study also noted that students preferred AI-supported learning environments because they provided immediate feedback and reduced learning anxiety.

Empirical Evidence on AI and Inquiry-Based Learning Integration

Although research on AI in education and inquiry-based learning exists separately, studies integrating both are still limited, particularly in Nigerian contexts. However, emerging evidence suggests that combining AI with inquiry-based pedagogy can enhance learning outcomes.

Olatunde-Aiyedun (2024) found that integrating AI tools into science education curricula in Nigerian universities improved students' engagement with scientific concepts and supported more flexible instructional approaches. The study emphasized that AI tools can enhance inquiry processes by helping students generate hypotheses, analyze data, and interpret results more effectively.

Otuturu and Cleopas (2025) further argued that AI integration in science education supports sustainable development goals by improving access to scientific learning resources in under-resourced environments. Their study highlights the potential of virtual laboratories and AI simulations in enabling inquiry-based learning where physical laboratory infrastructure is inadequate.

In a related perspective, Akpan et al. (2024) explored human-chatbot interaction in educational contexts and found that generative AI tools can support student inquiry by providing real-time explanations and assisting with academic problem-solving. However, they caution that excessive reliance on AI may weaken critical thinking skills if not properly guided by instructors.

Methods

This study adopts a qualitative conceptual review design aimed at examining the intersection between Artificial Intelligence (AI) and Inquiry-Based Learning (IBL) in science education. A conceptual review is appropriate for emerging interdisciplinary fields where empirical data may still be fragmented but theoretical and applied literature is rapidly expanding. The study draws data from a wide range of secondary sources, including peer-reviewed journal articles, conference proceedings, educational policy documents, and authoritative reports on AI in education. The selection of literature followed a purposive approach, focusing on studies that address at least one of the following areas:

- Artificial Intelligence applications in education
- Inquiry-Based Learning in science education
- Digital pedagogy and science teaching innovations
- Educational technology adoption in Nigeria and Africa

The analysis involved thematic synthesis, where recurring patterns, relationships, and contradictions in the literature were identified and grouped into conceptual themes. These themes formed the basis for discussing how AI can support inquiry-based science learning, particularly within resource-constrained educational environments.

Discussion

AI Support for Scientific Inquiry

Artificial Intelligence offers multiple layers of support that can significantly strengthen inquiry-based science learning. One of the most impactful contributions is the use of virtual laboratories and simulation-based environments. These systems allow learners to conduct scientific experiments in a controlled digital space where variables can be manipulated safely and repeatedly. This is particularly important in many Nigerian schools where physical laboratory equipment is either insufficient or outdated.

Intelligent Tutoring Systems (ITS) also play a critical role in supporting inquiry. These systems provide structured guidance during learning activities by offering hints, step-by-step explanations, and corrective feedback. In inquiry-based contexts, ITS helps learners stay engaged in the investigative process without removing the cognitive challenge required for scientific reasoning.

Generative AI tools further extend the possibilities of inquiry learning. They support learners in formulating research questions, refining hypotheses, interpreting experimental results, and exploring alternative explanations. Instead of replacing student thinking, these tools can function as cognitive partners that scaffold reasoning and reduce cognitive overload during complex tasks.

When combined, these AI tools create a learning environment where inquiry becomes more accessible, flexible, and interactive, particularly for learners who may struggle with traditional abstract science instruction.

Learning Enhancement through AI Integration

The integration of AI into inquiry-based science education has been associated with multiple learning benefits. One of the most consistently reported outcomes in the literature is increased learner engagement. AI-supported environments tend to encourage active participation by making learning more interactive and responsive to individual student needs.

Empirical findings by Olatunde-Aiyedun (2024) indicated that students exposed to AI-supported science instruction demonstrate improved conceptual understanding and greater willingness to participate in classroom activities. This suggests that AI not only supports cognition but also influences learner motivation and attitude toward science.

AI systems also contribute significantly to the development of science process skills. These include observation, classification, interpretation, prediction, and analysis. By providing real-time feedback and interactive simulations, AI tools allow learners to repeatedly practice these skills in meaningful contexts. In addition, adaptive learning systems help learners progress at individualized paces. This reduces learning gaps and ensures that students who struggle with specific concepts receive additional support, while advanced learners are challenged with more complex tasks.

Contextual Realities in Nigeria

In Nigeria, the integration of Artificial Intelligence into education is still in a developmental stage. While awareness is increasing, especially in tertiary institutions, the level of structured implementation remains limited. Bali et al. (2024) observed that many educators and students are already familiar with AI tools, particularly generative AI applications. However, this familiarity has not yet translated into systematic pedagogical integration within classroom instruction.

Infrastructure remains a major constraint. Unstable electricity supply, limited internet connectivity, and inadequate access to digital devices continue to hinder effective use of AI technologies in many schools. These challenges are more pronounced in rural and underserved communities, further widening the digital divide.

Menkiti and Benard (2025) further highlighted that students are already engaging with AI tools informally for academic tasks such as assignment writing and concept clarification. However, this usage often occurs without institutional regulation or pedagogical guidance, raising concerns about academic integrity and learning quality. This situation reveals a critical paradox: AI is already part of the learning ecosystem in Nigeria, but its integration into formal educational practice remains underdeveloped and unregulated.

Challenges Affecting Implementation

The implementation of AI-powered inquiry-based learning in Nigeria is influenced by several interrelated challenges:

1. Many science teachers lack adequate training in AI-supported instructional strategies and digital pedagogy.
2. Frequent power outages, weak internet connectivity, and limited access to digital devices restrict effective classroom integration.
3. Unequal access to AI-enabled tools creates disparities in learning opportunities among students.
4. Issues such as data privacy, algorithmic bias, and academic dishonesty pose significant risks if AI is not properly regulated.
5. There is a lack of clear institutional and national frameworks guiding the ethical and pedagogical use of AI in education.

Implications for Science Education

The integration of AI into inquiry-based learning represents a shift in the nature of science teaching and learning. The traditional role of the teacher as the sole source of knowledge is gradually evolving into that of a facilitator, guide, and learning designer who supports students in navigating AI-enhanced learning environments. This transformation requires teachers to develop new competencies in areas such as:

- digital pedagogy
- AI literacy
- instructional design for inquiry-based environments
- ethical use of educational technologies

Curriculum development also needs to reflect this shift by ensuring that AI tools are aligned with science learning objectives rather than replacing core scientific reasoning processes. The emphasis should remain on developing learners' ability to think scientifically, even when using advanced technological tools. Despite technological advancement, the teacher remains central in maintaining pedagogical balance, ensuring that AI enhances rather than dominates the learning process.

Conclusion

AI-powered inquiry-based learning represents a significant advancement in science education, offering a pathway to more interactive, personalized, and engaging learning experiences. By combining inquiry pedagogy with AI-driven support systems, science learning can become more accessible and responsive to diverse learner needs. However, the effectiveness of this approach is highly dependent on contextual realities. Infrastructure, teacher readiness, ethical considerations, and policy support play critical roles in determining its success. Without careful and structured integration, AI risks reinforcing existing inequalities rather than transforming science education.

Suggestions

The following recommendations are proposed:

1. Teacher training institutions should incorporate AI literacy and digital pedagogy into science education curricula to prepare future educators for AI-supported classrooms.
2. Regular workshops and training programs should be organized to equip practicing science teachers with skills for integrating AI tools into inquiry-based instruction.
3. Government and educational stakeholders should prioritize the provision of stable electricity, internet access, and digital devices to support effective AI integration in schools.
4. National and institutional policies should be established to guide ethical, responsible, and pedagogically sound use of AI in education.
5. Efforts should be made to reduce digital inequality by ensuring that students in rural and underserved areas also benefit from AI-supported learning resources.
6. Guidelines should be developed to address issues such as academic integrity, data privacy, and responsible use of generative AI tools in learning environments.
7. More classroom-based studies should be conducted in Nigerian schools to test the effectiveness of AI-powered inquiry-based learning models in real teaching and learning environments.

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