

Utilizing AI Products for Teaching and Learning Complex Biology Model Concepts within the Nigerian Educational Context

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Abstract

The effective instruction of complex, abstract biological concepts, such as genetic pathways, cellular respiration, and ecological dynamics, remains a persistent pedagogical challenge in the Nigerian educational system. Traditional teaching methods often struggle to provide the necessary visualization and personalized feedback required for deep conceptual mastery. This paper explores the transformative potential of Artificial Intelligence (AI) products specifically Intelligent Tutoring Systems (ITS), AI-powered simulations, and AI-driven assessment tools as a strategic intervention. Drawing on empirical research in science education and contextual analysis of the Nigerian landscape, the study proposes a theoretical framework for AI integration. The analysis highlights significant opportunities for personalized learning and enhanced visualization, which are critical for model-based reasoning in biology. Simultaneously, it addresses the unique implementation challenges posed by the Nigerian context, including infrastructural deficits, teacher capacity gaps, and the need for relevant policy frameworks.

Keywords: Artificial intelligent Products, Teaching and Learning, Biology complex models concepts

Introduction

The study of biology is fundamentally rooted in the understanding of complex, dynamic models. Concepts like the intricate steps of the Krebs cycle, the non-linear interactions within an ecosystem, or the probabilistic nature of genetic inheritance are often invisible, abstract, or too vast to be directly experienced in a typical classroom setting (Usak, 2025). This challenge is particularly acute in the Nigerian educational context, where resource constraints often limit access to modern laboratory equipment and high-quality instructional materials (Adenubi & Samuel, 2025). Consequently, many students struggle to move beyond rote memorization to achieve genuine conceptual understanding and model-based reasoning.

Artificial Intelligence (AI) presents a paradigm-shifting opportunity to address this pedagogical gap. AI products, ranging from sophisticated simulations that visualize molecular processes to Intelligent Tutoring Systems (ITS) that provide personalized, adaptive feedback, offer tools capable of demystifying complex biological models (Lawal et al., 2025). These tools can adapt to individual student needs, provide infinite opportunities for practice, and offer immediate, diagnostic feedback capabilities that far exceed the capacity of a single human teacher in a crowded classroom.

The Role of AI in Teaching Complex Scientific Concepts

Empirical research consistently supports the effectiveness of AI-driven tools in enhancing learning outcomes, particularly in science and mathematics education (Strobl *et al.*, 2019). The core strength of AI in this domain lies in its ability to handle complexity and provide personalization.

Intelligent Tutoring Systems (ITS): ITS are computer-based platforms that use AI to mimic the one-on-one interaction of a human tutor. They are designed to diagnose a student's knowledge state, select appropriate instructional content, and provide targeted feedback (EBSCO, n.d.). Studies have shown that ITS can significantly improve student performance by ensuring mastery before progression, a feature especially valuable for sequential subjects like biology where foundational concepts are critical (IEEE, 2014). For complex biology, ITS can be programmed with sophisticated cognitive models to track student understanding of, for example,

the regulatory steps in a gene pathway, providing remediation precisely where misconceptions occur (Springer Open, 2025).

AI-Powered Simulations and Virtual Labs: Abstract concepts like cellular processes (e.g., osmosis, protein synthesis) and genetic mechanisms (e.g., gene expression) are difficult to teach using static diagrams. AI-powered simulations offer dynamic, interactive, and risk-free environments where students can manipulate variables and observe the consequences in real-time (CSI CUNY Library, 2025). The integration of AI allows these simulations to be adaptive, adjusting the complexity or introducing unexpected variables based on the student's performance, thereby promoting deeper engagement with the model (Cell, 2024).

The Nigerian Educational Context: Challenges and Opportunities

The Nigerian education system is characterized by a high student-to-teacher ratio, inadequate funding, and a significant digital divide (Egede & Asabor, 2019).

The Nigerian Educational challenges and opportunities include: Nigerian educational context presents notable opportunities that make AI integration not only desirable but strategically necessary. Given the chronic shortage of well-equipped laboratories, AI-powered simulations and virtual labs offer a viable alternative for visualizing complex biological processes such as cellular respiration, genetic inheritance, and ecological interactions. In this sense, AI provides a means of bypassing long-standing material constraints rather than merely supplementing existing resources.

Additionally, Nigeria's high student-teacher ratio makes personalized instruction difficult to achieve through conventional methods. AI-driven tutoring and assessment systems offer the possibility of individualized feedback and adaptive learning at scale, addressing a core weakness of the current system. When properly implemented, these tools can help learners progress beyond rote memorization toward deeper conceptual understanding and model-based reasoning in biology.

Furthermore, the growing local Educational Technology ecosystem in Nigeria represents an important opportunity for contextualized AI development. Locally designed AI products can be aligned with national curricula, cultural

realities, and infrastructural limitations, particularly through low-bandwidth, mobile-first solutions. Such localization increases relevance, affordability, and sustainability, while reducing dependence on imported technologies that may not reflect Nigerian classroom realities.

In summary, the Nigerian educational context is characterized by a complex interplay of constraints and possibilities. While infrastructural limitations, teacher capacity gaps, and policy weaknesses pose significant challenges to AI integration, these same conditions underscore the urgency of adopting innovative, context-sensitive solutions. A critical, strategic approach that acknowledges these realities is therefore essential if AI products are to meaningfully enhance the teaching and learning of complex biology concepts in Nigeria.

The model highlights three core AI components essential for teaching complex biology concepts:

The framework emphasizes that successful implementation is contingent upon two key factors: **Teacher Capacity Building (K)** and navigating the **Infrastructural and Policy Constraints (L)**. The ultimate goal is **Improved Conceptual Mastery (I)**, which feeds back into the system for continuous AI refinement and teacher adaptation (J).

Enhanced Conceptual Mastery through Visualization

Complex concepts like the three-dimensional folding of proteins or the dynamic interactions of a signaling pathway are notoriously difficult to convey through two-dimensional textbooks. AI-powered simulations overcome this by generating interactive, 3D models (Cell, 2024). For instance, a student struggling with the concept of allosteric regulation in enzymes could use an AI simulation to dynamically alter substrate concentration and observe the resulting conformational changes in the enzyme molecule, leading to a deeper, intuitive understanding of the model.

Navigating the Nigerian Implementation Context

The success of this theoretical framework hinges on addressing the contextual realities of Nigeria.

Infrastructural Optimization: Instead of relying on high-end, cloud-based solutions, implementation must prioritize low-bandwidth, offline-capable AI tools. This could involve local servers hosting ITS and simulations that only require occasional synchronization with the cloud. Mobile-first AI applications are also essential, given the higher penetration of mobile devices compared to desktop computers (Adeniran *et al.*, 2023).

Teacher as Facilitator: The teacher's role must shift from being the sole source of knowledge to a **pedagogical facilitator** and **AI curator**. Teacher training programs must be reformed to focus not on coding, but on AI literacy, data interpretation (understanding ITS diagnostic reports), and the pedagogical integration of AI tools (Okunade, 2024). This capacity building is the single most critical factor in translating the theoretical potential of AI into practical classroom impact.

Ethical and Policy Considerations: As AI tools collect vast amounts of student data, the Nigerian government and educational bodies must establish clear policies on data privacy, security, and algorithmic bias to ensure equitable access and ethical use (Ukala & Ukala, n.d.).

Conclusion

The integration of AI products represents a transformative strategy for addressing the persistent challenges associated with teaching complex biology concepts in the Nigerian educational context. By harnessing the adaptive personalization of Intelligent Tutoring Systems and the dynamic visualization capabilities of AI-driven simulations, educators can facilitate deeper conceptual understanding and guide students toward genuine mastery. While the theoretical advantages of such technologies are substantial, their practical implementation necessitates a strategic, context-sensitive approach that directly addresses the infrastructural limitations and human capacity constraints prevalent in Nigeria. The proposed AI-Enhanced Biology Education Model provides a structured roadmap for this integration, underscoring that successful technological adoption must be accompanied by comprehensive teacher training and supportive policy frameworks to ensure sustainable impact.

Suggestions

To strengthen the Nigerian educational sector, AI should be positioned primarily as an assistant to educators and researchers rather than as an autonomous researcher. Its role can include supporting tasks such as data analysis, content creation, and simulation, while leaving critical decision-making and interpretation to human professionals. To address infrastructural limitations, investment should focus on AI-powered tools optimized for low-bandwidth and offline use, particularly on mobile devices.

Equally important is the integration of AI literacy and pedagogical training into both pre-service and in-service teacher education programs, enabling teachers to leverage AI-generated insights effectively without ceding professional judgment.

At a policy level, the Federal Ministry of Education should develop a comprehensive framework to guide the ethical deployment, data governance, and curriculum integration of AI in schools, reinforcing its role as a supportive tool. Finally, localized pilot studies across the urban and rural, public and private should be conducted to generate empirical evidence on the effectiveness of AI in enhancing teaching and research, providing a foundation for informed national-scale implementation.

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