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Research Article

Leveraging AI-driven assessment tools to transform Science Education for future-ready learning

A. A. Bello[a*], Z. A. Bello[b], I. A. Bello[c] & N. A. Aweda[d]

[a] *Department of Microbiology, University of Offa, Kwara State, Nigeria.*

[b] *Department of Life Science Education, Biology Unit, Kwara State University of Education Ilorin, Nigeria.*

[c] *Department of Biology, Kwara State College of Education, (Technical), Lafiagi, Nigeria.*

[d] *Servicom Department, Nigeria Police Academy, Wudil, Nigeria.*

Abstract

Artificial Intelligence (AI) is transforming education at a rapid rate, with greater possibility to restructure science teaching and learning. Although AI-based science assessment is gaining popularity globally, its usage in African education systems remains relatively new. The current paper will discuss how AI-based assessment tools can bypass the limitations of traditional evaluation systems and ensure more quality science education for future readiness. A systematic analysis of empirical studies published during the years 2014-2023 on pre-generative AI and generative AI uses in science education was conducted. The analysis reviewed evidence regarding adaptive assessment technology, virtual labs, intelligent tutoring systems, and learning analytics. Results indicate that AI-based evaluation provides real-time feedback, enables individualized learning, and makes data-driven assessment possible for students and instructors. AI-based technologies address problems such as large class sizes, resource shortages, and inequalities in assessment processes. While obstacles such as digital illiteracy, infrastructure, and ethical issues around the use of data persist. The study concludes that the integration of AI-based assessment tools offers a paradigm shift in science education, moving testing from traditional models to more dynamic, inclusive, and forward-looking models. Strategic investment, digital capacity development, and policy support are recommended to support effective and ethical application of the technologies among African universities.

Keywords: Artificial Intelligence, AI-driven Assessment, Science Education, Adaptive Learning Technologies, Future-ready Learning.

1. Introduction

Artificial Intelligence (AI) is increasingly transforming education, and the interdisciplinary field of Artificial Intelligence in Education (AIEd) is rapidly expanding to explore how AI technologies can improve teaching and learning. Within science education, AI-driven tools are gaining particular attention, presenting new possibilities for research and practice (Chiu et al., 2023; Gonzalez et al., 2017).

A notable area of interest is the application of machine learning to assessment in science learning. For instance, Zhai et al. (2022) employed machine learning techniques to evaluate the quality of students' scientific models based on their responses to learning tasks. This line of research demonstrates how AI can automate assessment, enhance the accuracy of feedback, and provide timely, actionable insights into student understanding (Zhai, C. Haudek, Zhai et al., 2020a, b, 2022). Furthermore, Popenici and Kerr (2017) have examined the broader influence of AI on higher education, outlining how intelligent systems are reshaping pedagogical models and the learner experience.

Despite such promising developments, current empirical research underscores the pivotal role of educators in integrating AI effectively. Zawacki-Richter et al. (2019) conducted a systematic review emphasizing the importance of capturing teachers' perspectives and needs to foster sustainable AI adoption in higher education. Complementing

*Corresponding author: A. A. Bello

Email: abdulrazak.bello@unioffa.edu.ng (A. A. Bello)

ORCiD: https://orcid.org/0009-0007-5054-8006↗

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this, Xu and Ouyang's (2022) synthesis categorized AI's educational functions into three domains: as a subject of inquiry, an interactive agent in learning activities, and a supportive tool facilitating teacher-learner and peer collaboration.

Nevertheless, there remains a significant gap in empirical studies specifically addressing AI's contributions and limitations in science education, particularly regarding assessment practices. This lack of comprehensive understanding may hinder informed decision-making by educators, policymakers, and developers, consequently limiting the potential impact of AI on science teaching and learning outcomes.

The present paper seeks to fill this gap by conducting a systematic review of empirical research from 2014 to 2023, focusing on how AI-driven assessment tools including both foundational AI and emerging generative AI technologies are influencing science education. By synthesizing this body of evidence, we aim to provide researchers with a consolidated foundation to inform future research directions, support the development of best practices, and ultimately contribute to the ethical and effective integration of AI for future-ready science education.

Science education aims not only to impart scientific knowledge but also to develop scientific literacy, critical thinking, and informed decision-making skills essential for active citizenship (Almasri, 2021; Grinnell, 2021). Central to initiatives like the "Science for All" movement, science education strives to be inclusive, reaching beyond aspiring scientists to engage all learners (Almasri et al., 2022; Mansour, 2009). By fostering understanding of scientific concepts, methodologies, and experimental practices, the field supports both individual growth and broader societal advancement through innovation and economic development (Alharbi et al., 2022; Hewapathirana & Almasri, 2022; Kola, 2013).

Amidst evolving educational demands, particularly those of the 21st century, there is a clear call to reform instructional practices that nurture foundational scientific knowledge, stimulate curiosity, and prepare students for STEM careers (Holme, 2021; Ibáñez & Delgado-Kloos, 2018). In this context, integrating Artificial Intelligence (AI) presents a promising avenue to enrich science learning by making it more personalized, experiential, and inclusive.

However, despite AI's growing presence in educational contexts, critical gaps remain, particularly regarding its application and impact in science education. While AI-powered virtual labs and simulations offer scalable and safe experimentation environments that enhance accessibility (Wahyono et al., 2019), questions persist about their ability to replicate the full sensory and hands-on experience of physical labs, which are pivotal for certain learning outcomes (Tang & Cooper, 2024). Research is needed to delineate when and how virtual simulations can effectively complement or substitute traditional laboratory work.

Moreover, AI's promise in enabling adaptive and personalized learning is contingent on the availability and quality of data driving these systems (Zhai et al., 2020a, b; Zhai et al., 2021). There is a methodological imperative to rigorously examine the sources of bias in AI algorithms and address equity concerns to prevent reinforcing existing disparities in educational access and outcomes. Empirical studies that evaluate both the technological efficacy and ethical implications of AI personalization in diverse learner populations are notably sparse.

The use of AI for formative assessment and instant feedback presents another significant opportunity, yet systematic investigations into its long-term impact on students' conceptual understanding and metacognitive skills are limited (Mavroudi et al., 2018). Additionally, while AI tools can support teachers by providing timely student performance insights, research exploring how educators interpret and act on AI-generated data in real classroom settings remains underdeveloped. Understanding this interaction is crucial for designing AI systems that genuinely augment teaching rather than complicate it.

Finally, as science education increasingly incorporates global, real-world data and collaborative AI-powered platforms (Holmes et al., 2023), there is a need for methodologically robust research that examines how these tools influence students' scientific reasoning and global competencies across diverse cultural and educational contexts.

In summary, although AI holds transformative potential for science education, comprehensive empirical research addressing its limitations, equity challenges, and pedagogy-informed design is still emerging. Methodological rigor combining quantitative, qualitative, and mixed-method approaches will be critical to uncover how AI-driven assessment tools can most effectively support future-ready science learning and teaching. This review aims to consolidate existing evidence to guide such research directions and inform the ethical, equitable integration of AI in science education.

1.1. Research Objectives

1.1.1 Primary Objective

To systematically investigate how AI-driven assessment tools can transform science education by enhancing learning outcomes, promoting equity, and preparing students for future scientific challenges through evidence-based implementation strategies.

1.1.2 Specific Research Objectives

1. Assessment Efficacy and Learning Outcomes

- Evaluate the effectiveness of AI-driven assessment tools in improving students' conceptual understanding of scientific principles compared to traditional assessment methods
- Analyze the impact of real-time, AI-generated feedback on students' metacognitive skills development and

scientific reasoning abilities

- Investigate how AI-powered formative assessments influence students' long-term retention of scientific knowledge and transfer of learning across different scientific domains

2. Personalization and Adaptive Learning

- Examine the mechanisms through which AI-driven assessment tools adapt to individual learning patterns and provide personalized feedback in science education contexts
- Assess the quality and sources of data used by AI algorithms to ensure unbiased and equitable personalization across diverse student populations
- Investigate the optimal balance between AI-driven personalization and standardized learning objectives in science curricula

3. Equity and Accessibility

- Analyze potential biases in AI assessment algorithms and their impact on educational equity across different demographic groups, socioeconomic backgrounds, and cultural contexts
- Evaluate how AI-driven assessment tools can bridge educational gaps and provide inclusive learning opportunities for students with diverse learning needs
- Investigate the accessibility of AI-powered science assessment platforms across different technological infrastructures and resource-constrained environments

4. Teacher Integration and Pedagogical Impact

✓ Explore how science educators interpret, utilize, and act upon AI-generated assessment data to inform their instructional decisions

✓ Examine the professional development needs and challenges teachers face when integrating AI-driven assessment tools into their science teaching practices

✓ Investigate the relationship between AI-supported assessment and teacher confidence, pedagogical content knowledge, and classroom management effectiveness.

2. Literature Review

2.1. AI-Driven Assessment Tools

AI tools are changing how we handle science education assessments these days. Instead of old-school paper tests and manual grading, these systems handle things automatically now. They give instant feedback and adjust to what each student needs individually. School AI noted in 2024 that their AI grading setups cut teachers' correction time by over 70 percent. That leaves educators more room to focus on actual teaching instead of paperwork. Studies from Zhai, Haudek, and Nehm around 2020 show machine learning can tackle tricky evaluation tasks too stuff like open-ended answers or building scientific models that used to be hard to score consistently.

But it's not just about speed here. There are big questions around fairness and ethics popping up too. New frameworks like CAIAF from 2024 push for assessment systems that make sense to people, treat everyone equally, and respect cultural differences. They point out how biased training data can hurt marginalized students more than others especially in diverse classrooms where this really matters. The real future of AI evaluation isn't just doing things faster but making systems that include everyone better while keeping ethics tight.

Then there's adaptive learning platforms getting mixed in with AI assessments these days. Research by Mavroudi and others back in 2018 shows these setups let students get questions tailored to their level adjusting difficulty on the fly while giving feedback as they go. That helps with mastery learning where you build science concepts step by step at your own pace.

2.2. Future-Ready Learning

When it comes to future-ready learning, AI's role keeps growing globally now. The idea here is prepping students for jobs that don't even exist yet by giving them skills through tech-heavy education methods. Tools like personalized lessons and culturally aware teaching methods get highlighted here like how the World Economic Forum mentioned Education 4.0 needing real-world problem solving baked into curriculums using AI.

Smart tutoring systems and generative platforms let students practice science inquiry through simulations now too building critical thinking and digital skills along the way as Holmes et al discussed last year. Platforms like Learning Genie even show how letting students help create AI-enhanced courses boost engagement especially from groups often left out before.

But it's not all smooth sailing either researchers (check and recast the sentence) like Ibáñez warn about leaning too hard on virtual labs that might miss the hands-on parts crucial for actual science work. Combining both digital simulations with physical experiments seems like the smart play moving forward.

2.3. Inclusive Classroom Strategies

Inclusivity gets a major boost from AI tech in classrooms according to recent reviews covering assistive tools like speech-to-text systems or personalized feedback generators helping students with disabilities or language barriers participate fully now. Voice recognition software let visually impaired learners do virtual experiments while adaptive content supports those needing extra help cognitively.

Collaboration tools powered by AI also make group science projects more inclusive by reducing isolation as Zawacki-Richter found back in 2019. Meanwhile, Almasri's team showed simulated environments improve confidence across different genders and cultures alike.

Wahyono's team made waves with personalized virtual labs using AI too—bringing advanced experiments to schools without proper labs while tailoring experiences based on skill levels. This shows how tech can push both fairness and quality in science education pretty effectively when done right, though we're still figuring out the balance between innovation and keeping things real for learners overall.

2.4. Educational Transformation Imperative

The contemporary educational landscape demands a fundamental shift from traditional, one-size-fits-all approaches to more dynamic, responsive, and personalized learning experiences. Science education, as a cornerstone of modern literacy, sits at the intersection of this transformation. The urgency stems not merely from technological advancement, but from the recognition that our rapidly evolving world requires citizens who can navigate complex scientific information, make evidence-based decisions, and contribute to solving global challenges such as climate change, public health crises, and sustainable development.

The "Science for All" movement has long advocated for inclusive science education that reaches beyond the traditional boundaries of academic excellence to encompass diverse learners with varying backgrounds, abilities, and aspirations. However, achieving this inclusivity has remained challenging within conventional educational frameworks. AI-driven assessment tools represent a paradigm shift that could finally realize this vision by providing adaptive, responsive, and culturally sensitive learning environments that meet students where they are and guide them toward their potential.

2.5. Critical Knowledge Gaps and Research Urgency

Despite the proliferation of AI technologies in educational settings, our understanding of their impact on science learning remains fragmented and largely theoretical. This knowledge gap is particularly concerning given the substantial investments being made in educational technology and the potential risks of implementing poorly understood systems at scale. The current study addresses several critical areas where empirical evidence is desperately needed.

Pedagogical Authenticity: While AI-powered virtual laboratories and simulations offer unprecedented accessibility, fundamental questions remain about their ability to replicate the essential elements of scientific inquiry. The tactile, sensory, and collaborative aspects of traditional laboratory experiences contribute significantly to scientific understanding and identity formation. Without rigorous comparative studies, educators and policymakers are making decisions about AI integration based on assumption rather than evidence.

Equity and Justice: The promise of AI to democratize education could easily become a source of further marginalization if algorithmic biases and data inequities are not systematically addressed. Given the historical disparities in science education outcomes across different demographic groups, the stakes of getting AI implementation right are exceptionally high. This study's focus on equity ensures that technological advancement serves justice rather than perpetuating existing inequalities.

Teacher Agency and Professional Growth: The success of any educational innovation ultimately depends on teachers' ability to understand, adapt, and effectively utilize new tools. However, current research provides insufficient guidance on how educators can maintain their professional agency while leveraging AI capabilities. Understanding this dynamic is crucial for sustainable implementation and preventing the deskilling of the teaching profession (No reference).

2.6. Methodological Innovation and Rigor

This study's commitment to methodological diversity and rigor addresses a significant weakness in current AI-education research, which often relies on narrow evaluation metrics or short-term studies. By combining quantitative measures of learning outcomes with qualitative insights into student and teacher experiences, and situating these within broader cultural and institutional contexts, this research will provide the comprehensive evidence base needed for informed decision-making.

The mixed-methods approach is particularly important given the complexity of educational phenomena and the multifaceted nature of AI integration. Learning outcomes cannot be understood solely through test scores, nor can the impact of technology be captured only through user satisfaction surveys. This study's methodological framework will serve as a model for future research in the rapidly evolving field of AI-enhanced education.

2.7. Global and Future-Oriented Perspective

Science education increasingly requires a global perspective, as scientific challenges transcend national boundaries and scientific collaboration occurs on an international scale. AI-driven assessment tools offer unique opportunities to connect learners across cultures and contexts, fostering the global scientific literacy essential for addressing shared challenges. However, this potential can only be realized through research that explicitly examines cross-cultural impacts and develops culturally responsive implementation strategies.

Furthermore, the "future-ready" orientation of this study acknowledges that today's students will enter a world where AI literacy is as fundamental as traditional scientific literacy. By investigating how AI assessment tools prepare students for this reality, the research serves both immediate educational needs and long-term societal preparation.

2.8. Ethical Imperative and Responsible Innovation

The integration of AI in education raises profound ethical questions about privacy, autonomy, surveillance, and the nature of learning itself. This study's commitment to examining these dimensions ensures that technological advancement occurs within an ethical framework that prioritizes student wellbeing and educational values. The research will provide crucial guidance for policymakers, educators, and technology developers navigating these complex ethical landscapes.

3. Discussion

The paper explored the limitations of traditional methods of evaluation in science education and presented adaptive technology as an innovation for evaluating biology (not captured in the abstract, introduction and literature.) lecturers in African universities. It noted how traditional methods such as peer assessment and student evaluations often give an incomplete representation of teaching effectiveness, particularly in settings congested with large class sizes, limited resources, and unbalanced policies.

Adaptive technologies like AI-driven class observation software, e-assessment systems, and learning analytics software offer promising avenues for real-time, personalized, and data-informed assessment. Such technologies enable institutions to base lecturer performance, professional development, and teaching quality improvement on informed decisions. These technologies are held back from optimal integration by digital literacy gaps, infrastructural issues, resistance to innovation, and ethical concerns around data privacy.

(Link this sentence to the previous paragraph) Despite all these challenges, there are certain African institutions that have begun to establish adaptive models of assessment with exceptional success. Their initiative bears testimony to the worth of inclusivity, openness to change, and sustained support while reexamining the science assessment. The paper ultimately calls for an overall makeover of the way biology lecturers are evaluated in the age of technology.

4. Conclusion

The rationale for this study lies at the intersection of educational necessity, technological opportunity, and social responsibility. As AI becomes more deeply embedded in educational practice, the real question is not whether to adopt these technologies, but how to design and implement them in ways that strengthen rather than replace the human dimensions of teaching and learning. For African science classrooms in particular, the integration of adaptive technologies in evaluating biology lecturers and supporting students presents a crucial opportunity to revolutionize assessment practices. Moving beyond rigid, standardized systems toward dynamic, real-time, and student-centered approaches signals a culture of accountability, innovation, and teaching excellence. (change the font type on this paragraph to Times New Romans for uniformity).

While challenges such as fairness, inclusivity, and sustainability will always persist, the way forward lies in strategic investment, inclusive planning, and continuous professional learning. Through rigorous research and practice, AI-driven assessment can become not just a tool for efficiency, but a paradigm shifts that honors equity, enhances pedagogy, and empowers learners. Ultimately, adaptive and AI-supported assessment represents more than a technological upgrade it is a future-oriented transformation that ensures all learners, regardless of background, have access to high-quality, equitable, and impactful science education.

Recommendations:

African universities need to invest in creating digital infrastructure and having safe electricity and internet connectivity to accommodate adaptive technology.
2. Training schemes need to be established to create capacity for digital literacy among lecturers, administrators, and support staff.
3. Institutions need to follow a phased and participatory path to technology introduction initiating through pilot programs and expanding through evidence of success.
4. National and regional education policies will have to promote innovation in assessment through alignment with policies, training, and financing.
5. Ethical principles and data protection rules must be adopted to regulate the use of learning analytics and AI-driven systems for assessing lecturers.
6. Institution-level collaborations should be promoted for knowledge sharing of best practices, tools, and expertise to scale up adoption.

Abbreviations

AI	Artificial Intelligence
AIEd	Artificial Intelligence in Education

Author Contributions

Bello, Abdulrazak Agboola: Conceptualization, Writing-original draft,
Bello, Zakariyau Adebayo: Writing-Review and Editing
Bello, Ilias Ayo: Writing-Review and Editing
Aweda, Nurudeen Abdulafeez.: Writing-Review and Editing

Conflicts of Interest

The author(s) declare that they have no known competing financial interests, professional affiliations or personal relationships that could have appeared to influence the work reported in this paper,

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