ARTIFICIAL INTELLIGENCE AS A CATALYST FOR PERSONALIZED LEARNING IN SCIENCE EDUCATION

Ali Inalegwu George
Department of Computer Science Education,
Federal College of Education Odugbo, Benue State, Nigeria.
E-mail: Aliinalegwu@gmail.com
Telephone Number: 08064784838

&

Opita John Mathew
Department of Integrated Science Education,
Federal College of Education Odugbo, Benue State, Nigeria
E-mail: opitamatthewjohn@gmail.com
Telephone Number: 08068681392

Abstract
Artificial Intelligence (AI) is increasingly reshaping educational practices worldwide, with significant implications for science education. This position paper argued that AI serves as a powerful catalyst for personalized learning by enabling adaptive instruction, real-time feedback, and data-driven decision-making in science classrooms. Traditional one-size-fits-all approaches to teaching science often fail to address learners' diverse abilities, prior knowledge, and learning paces. AI-powered systems such as intelligent tutoring platforms, learning analytics tools, and adaptive assessment technologies offer opportunities to tailor instructional content to individual student needs, thereby enhancing conceptual understanding and engagement. The paper contends that the integration of AI can support differentiated instruction, reduce learning gaps, and foster deeper scientific inquiry by providing customized simulations, virtual laboratories, and interactive problem-solving environments. However, effective implementation requires adequate teacher preparedness, infrastructural support, and ethical safeguards to ensure equitable access and responsible data use. By repositioning AI as a complementary instructional partner rather than a replacement for teachers, science education can move toward more inclusive, responsive, and learner-centered pedagogical practices. The paper concluded that systematic and policy-guided integration of AI technologies is essential to harness their full potential in transforming science education through personalized learning.

Keywords Artificial Intelligence; Personalized Learning; Science Education; Digital Pedagogies

Introduction

Science education remains central to national development, technological innovation, and economic competitiveness in the 21st century. Nations seeking sustainable growth increasingly depend on a scientifically literate workforce capable of critical thinking, problem-solving, and innovation. In Nigeria, science education occupies a strategic position in achieving national aspirations outlined in policy documents such as the National Policy on Education and the Science, Technology and Innovation (STI) framework (Federal Ministry of Education [FME], 2019). Despite its recognized importance, the performance of students in science subjects at both basic and secondary education levels continues to generate concern among policymakers, educators, and researchers. Recent reports from examination bodies such as West African Examination Council and National Examination Council indicate persistent challenges in students' achievement in core science subjects, including Physics, Chemistry, Biology, and Basic Science (WAEC, 2022; NECO, 2023). Several studies conducted within Nigeria attribute this trend to teacher-centered instructional approaches, inadequate laboratory facilities, overcrowded classrooms, and limited opportunities for individualized instruction (Aina & Adedoja, 2020; Okoli & Eze, 2021). Traditional pedagogical models, which often emphasize rote memorization and uniform pacing, fail to accommodate learners' diverse cognitive abilities, prior knowledge, and learning styles. Consequently, many students

develop misconceptions in foundational scientific concepts, leading to reduced engagement and poor academic outcomes.

The growing digital transformation of education presents an opportunity to address some of these longstanding challenges. In recent years, Nigeria has witnessed increased adoption of digital technologies in teaching and learning, particularly following the COVID-19 pandemic, which accelerated the shift toward online and blended learning modalities (Adarkwah, 2021). The experience exposed both the potential of educational technology and the structural gaps in infrastructure and teacher preparedness. It also stimulated renewed discourse on the integration of advanced technologies, including Artificial Intelligence (AI), into classroom practice. Artificial Intelligence refers to computer systems capable of performing tasks that typically require human intelligence, such as learning, reasoning, pattern recognition, and decision-making. Within educational contexts, AI applications include intelligent tutoring systems, adaptive learning platforms, automated assessment tools, predictive analytics, and virtual simulations (Zawacki-Richter et al., 2019; Holmes et al., 2022). In Nigeria, scholarly discussions on AI in education have expanded significantly in the past five years, highlighting its potential to improve instructional delivery, assessment accuracy, and learner engagement (Ogunleye & Fashola, 2021; Eze, Chinedu, & Bello, 2023).One of the most promising contributions of AI to science education lies in its capacity to facilitate personalized learning. Personalized learning is an instructional approach that tailors content, pacing, feedback, and learning pathways to individual students' needs and abilities. Unlike the conventional uniform teaching model, personalized learning recognizes learner variability and seeks to optimize each student's progress (Pane et al., 2020). In science education, where abstract concepts, mathematical reasoning, and experimental procedures require differentiated support, personalization becomes particularly critical.

In the Nigerian context, large class sizes often exceeding recommended teacher-student ratios limit teachers' ability to provide individualized attention (Universal Basic Education Commission [UBEC], 2021). AI-driven systems can complement teachers' efforts by analyzing learner data in real time, identifying misconceptions, and recommending targeted instructional interventions. For instance, adaptive learning platforms can adjust the difficulty level of physics problems or provide additional explanations for complex biological processes based on a learner's performance history. Such responsiveness holds significant promise for reducing learning gaps and enhancing conceptual mastery. Furthermore, AI-powered virtual laboratories and simulations can mitigate the persistent shortage of functional laboratory facilities in many Nigerian schools (Okebukola, 2020). Through simulated experiments, students can manipulate variables, observe outcomes, and test hypotheses in safe and cost-effective environments. This aligns with inquiry-based approaches advocated in contemporary science education reforms. Studies conducted in Nigerian tertiary institutions suggest that digital simulations enhance students' understanding of abstract scientific concepts and increase motivation toward science learning (Ibrahim & Musa, 2022; Adeyemi, 2024).

However, while AI presents transformative potential, its integration into Nigerian science classrooms raises important concerns. Issues of digital divide, infrastructural disparities between urban and rural schools, teacher digital competence, data privacy, and ethical governance require careful consideration (Afolabi & Olanrewaju, 2023). Without deliberate policy direction and equitable investment, AI adoption could inadvertently widen existing educational inequalities. Therefore, AI must be implemented as a complementary pedagogical tool rather than a replacement for teachers. Against this backdrop, this paper argued that Artificial Intelligence serves as a catalyst for personalized learning in science education in Nigeria. By enabling adaptive instruction, real-time feedback, intelligent tutoring, and interactive simulations, AI can transform science classrooms into learner-centered environments that accommodate individual differences. Nevertheless, the realization of this potential

depends on structured implementation strategies, teacher professional development, infrastructural investment, and ethical safeguards. The subsequent sections of this paper examine the conceptual foundations of AI and personalized learning, explore the mechanisms through which AI enhances science instruction, analyze implications for teachers and policy, and propose strategic recommendations for responsible and equitable integration within the Nigerian educational system.

Artificial Intelligence (AI) refers to a branch of computer science that develops systems capable of performing tasks typically requiring human intelligence, including learning, reasoning, prediction, and problem-solving (Holmes et al., 2022). In educational contexts, AI encompasses a range of applications such as intelligent tutoring systems (ITS), adaptive learning platforms, automated assessment tools, natural language processing for feedback, and learning analytics dashboards (Zawacki-Richter et al., 2019). These technologies collect and analyze learner data to customize instructional pathways and support instructional decisions.In Nigeria, several recent studies (Eze, Chinedu, & Bello, 2023; Ogunleye & Fashola, 2021) have begun exploring AI's potential in schooling. Eze, Chinedu, and Bello (2023) observed that AI solutions are increasingly discussed as part of digital transformation strategies in Nigerian education, particularly following pandemic-induced shifts to online and blended learning. Ogunleye and Fashola (2021) found that emerging AI tools in Nigerian classrooms, though still limited by infrastructure, can support teachers with content differentiation and performance tracking. AI is not merely about digital tools; it represents a pedagogical shift from delivering static content to enabling dynamic, responsive learning experiences. This shift is particularly promising for science education, where conceptual complexity and diverse learners demand more nuanced instructional support than traditional methods can offer.

Personalized Learning

Personalized learning is an instructional approach that adapts the content, pace, and pathways of learning to meet individual learners' needs and preferences (Pane et al., 2020). It contrasts with the

conventional one-size-fits-all model, which often ignores learner variability in science classrooms. Personalized learning emphasizes learner agency, continuous formative feedback, and flexible pathways that permit students to progress based on mastery rather than time alone.

Challenges of Artificial Intelligence and Personalized Learning in Science Instruction

In the Nigerian educational context, science instruction continues to face challenges that limit teachers' ability to respond effectively to the diverse learning needs of students. Two prominent challenges are the continued reliance on teacher-centred instructional approaches and overcrowded classrooms, which often reduce opportunities for individualized attention and learner engagement. Okoli and Eze (2021) identified teacher-centred methods and large class sizes as factors that hinder individualized attention in science instruction. Similarly, the Universal Basic Education Commission (UBEC, 2021) reported that overcrowded classrooms constrain teachers' ability to monitor students and respond adequately to individual learning needs.

These challenges highlight the need for instructional approaches that can provide greater opportunities for learner differentiation, individualized support, and continuous monitoring of students' progress. Personalized learning offers a framework for addressing differences in learners' abilities, interests, pace, and learning needs, while Artificial Intelligence (AI) provides digital capabilities that can potentially support the implementation of personalized learning through adaptive content delivery, learner monitoring, feedback, and differentiated instruction. Thus, integrating AI with personalized learning may provide a strategic response to persistent instructional challenges in Nigerian science classrooms. However, the extent to which AI-supported personalized learning can improve students' learning experiences and outcomes remains an area requiring empirical investigation, particularly in the context of Basic Science instruction.

Within science education, personalized learning can help learners

engage with complex phenomena at a pace suited to their cognitive readiness. For instance, AI-enabled platforms can adjust the difficulty of physics problems or scaffold chemistry concepts based on formative assessment data, empowering learners to build confidence and mastery incrementally (Adeyemi, 2024).

AI as a Catalyst for Personalized Learning in Science Education
Artificial Intelligence can facilitate personalized learning in science education through adaptive instruction, real-time feedback, virtual simulations, and differentiated pathways that respond to learners' unique profiles. These mechanisms address key limitations in traditional science classrooms particularly in contexts like Nigeria where resource constraints and teacher overload are common.

Adaptive Instruction and Intelligent Tutoring Systems
Adaptive instruction enables content delivery to be dynamically adjusted based on real-time analysis of student performance. Intelligent Tutoring Systems (ITS) are a key example: they provide individualized guidance, scaffolded explanations, and customized practice tasks. ITS can identify specific misconceptions in science concepts and deliver remediation at the moment of need (Holmes et al., 2022).

In Nigeria, adaptive systems are gaining attention for addressing instructional inequities. Ogunleye and Fashola (2021) found that adaptive e-learning platforms helped learners navigate content at their own pace, reducing cognitive overload associated with uniform pacing. Similarly, Adeyemi (2024) reported that physics learners using AI-guided tutorials demonstrated improved conceptual understanding compared to peers in traditional classrooms. These findings suggest that adaptive instruction not only supports mastery of complex science content but also accommodates differences in learners' prior knowledge and processing speeds.

Real-Time Feedback and Learning Analytics
Real-time feedback is a crucial component of personalized learning and one of AI's most impactful contributions to science education. Traditional assessments often summative and delayed fail to provide

timely insight into learners' misunderstandings. AI systems, in contrast, can instantly evaluate responses and deliver actionable feedback, helping learners correct errors and deepen understanding during the learning process (Zawacki-Richter et al., 2019).

Learning analytics extend this value by aggregating learner data to inform teachers' instructional decisions. Analytics dashboards can highlight patterns such as common misconceptions in chemistry or areas where students repeatedly struggle in biology. Nigerian researchers have noted the potential of analytics to support teacher decision-making, especially in large classes where individualized attention is difficult (Eze, Chinedu, & Bello, 2023). These data-informed insights help educators tailor subsequent instruction and provide targeted support where it is most needed.

Virtual Laboratories and Interactive Simulations
Science education inherently involves inquiry and experimentation. However, many Nigerian schools lack functional laboratories, leaving students with limited opportunities for hands-on experimentation (Okebukola, 2020). Virtual laboratories and interactive simulations powered by AI offer viable alternatives by enabling learners to engage with scientific phenomena in a safe, scalable, and cost-effective environment.

Through virtual labs, students can manipulate variables, observe outcomes, and test hypotheses, fostering deeper engagement and scientific reasoning. Ibrahim and Musa (2022) reported that students who used digital simulations in biology demonstrated higher retention of concepts than peers confined to textbook and lecture formats. Moreover, simulations can visualize abstract or inaccessible processes, such as molecular interactions in chemistry, which often challenge learners constrained by limited physical resources.

Supporting Differentiated Instruction
Differentiated instruction involves tailoring teaching strategies and learning activities to accommodate diverse learner profiles. AI can facilitate differentiation by grouping learners based on proficiency, recommending tailored content, or adjusting task complexity. For

example, some platforms might allocate additional practice in foundational topics for learners who need remediation while advancing others to more challenging tasks.

In Nigeria's science classrooms often characterized by high student-teacher ratios and limited instructional time AI-assisted differentiation can expand teachers' capacity to support diverse learners. UBEC (2021) highlighted that most Nigerian basic schools struggle to provide individualized attention due to class size and workload constraints. AI tools can supplement teacher efforts, offering leveled content and personalized pathways that help bridge attainment gaps.

Challenges and Ethical Considerations

While Artificial Intelligence (AI) presents significant opportunities for advancing personalized learning in science education, its integration into Nigerian classrooms is accompanied by critical challenges and ethical concerns. These challenges must be carefully addressed to ensure that AI contributes positively to educational transformation without reinforcing existing systemic inequalities. Key concerns include equity and access, data privacy and security, and algorithmic bias.

Equity and Access Issues

ne of the most pressing challenges facing AI integration in Nigerian science education is the issue of equitable access. AI-powered learning systems depend heavily on stable electricity, reliable internet connectivity, digital devices, and technical support infrastructure. However, significant disparities exist between urban and rural schools in Nigeria regarding access to these essential resources (UBEC, 2021; Afolabi & Olanrewaju, 2023).Recent reports indicate that many public secondary schools, particularly in rural areas, lack functional computer laboratories and consistent internet connectivity (Federal Ministry of Education [FME], 2022). Consequently, large segments of learners may be excluded from benefiting from AI-driven personalized learning tools. This digital divide risks widening the achievement gap between students in well-resourced private or urban schools and those in underserved

communities. Furthermore, socioeconomic inequalities among students influence access to personal digital devices outside school environments. Ogunleye and Fashola (2021) noted that while digital learning platforms expanded during the COVID-19 pandemic, many students from low-income households were unable to participate fully due to limited device ownership and data affordability challenges. If AI-based science learning platforms are implemented without deliberate equity strategies, they may inadvertently privilege already advantaged learners.

To mitigate these concerns, policymakers must prioritize infrastructural investment, subsidized internet access for schools, and inclusive digital education policies that ensure no learner is marginalized in the transition toward AI-enhanced science education.

Data Privacy and Security

AI systems function through the collection, storage, and analysis of large volumes of learner data, including academic performance records, behavioral patterns, and sometimes biometric or interaction data. While such data are essential for personalization, they raise serious concerns regarding privacy, data protection, and ethical governance. Nigeria enacted the Nigeria Data Protection Regulation (NDPR) in 2019 to safeguard personal data, yet enforcement and institutional compliance within the education sector remain uneven (National Information Technology Development Agency [NITDA], 2019). Schools may lack adequate cybersecurity infrastructure or clear data management policies, increasing vulnerability to data breaches or misuse.Eze, Chinedu, and Bello (2023) emphasize that AI implementation in Nigerian education must be accompanied by transparent data governance frameworks that define data ownership, consent procedures, storage duration, and accountability mechanisms. Without strong regulatory oversight, sensitive student information could be exposed to unauthorized access or commercial exploitation. Moreover, students and parents must be adequately informed about how their data are collected and used. Ethical AI deployment requires informed consent, anonymization where possible, and secure storage protocols. Teachers also require training to understand data privacy principles to ensure responsible use of AI

systems within science classrooms. Thus, safeguarding data privacy is not merely a technical issue but a moral obligation to protect learners' rights and dignity in the digital learning environment.

Algorithmic Bias

Algorithmic bias represents another significant ethical challenge in AI integration. AI systems are trained on datasets that may reflect existing social, cultural, or economic inequalities. If not carefully designed and monitored, AI algorithms can inadvertently reproduce or amplify these biases in educational decision-making processes (Holmes et al., 2022).In the context of science education, biased algorithms could influence recommendations for learning pathways, assessment interpretations, or predictive analytics outcomes. For example, if AI systems are trained predominantly on data from high-performing or urban schools, they may inaccurately evaluate learners from different backgrounds, thereby reinforcing disadvantage. Afolabi and Olanrewaju (2023) caution that developing countries must critically examine imported AI technologies to ensure cultural and contextual relevance. AI models developed outside Nigeria may not adequately account for local curriculum structures, linguistic diversity, or socio-cultural dynamics within Nigerian classrooms. This misalignment may lead to inaccurate feedback or inappropriate learning recommendations. Addressing algorithmic bias requires transparency in AI design, continuous evaluation of system outputs, and the inclusion of diverse datasets reflective of Nigeria's educational realities. Collaboration between technologists, educators, policymakers, and ethicists is essential to ensure fairness and contextual sensitivity in AI deployment.

Policy and Implementation

The successful integration of Artificial Intelligence (AI) into science education in Nigeria requires coherent policy direction and structured implementation strategies. While digital transformation initiatives have expanded in recent years, AI adoption remains largely fragmented and experimental (Federal Ministry of Education [FME], 2022). For AI to effectively catalyze personalized learning, national and state-level policies must move beyond general ICT integration to specifically address AI governance, infrastructure,

curriculum alignment, and teacher capacity development. Nigeria's National Digital Economy Policy and Strategy (2020–2030) provides a foundation for digital innovation; however, explicit guidelines on AI integration in basic and secondary education remain limited. Scholars argue that policy frameworks must clearly articulate standards for AI procurement, data protection compliance, ethical oversight, and system evaluation (Eze, Chinedu, & Bello, 2023). Without such frameworks, schools may adopt AI tools inconsistently, leading to disparities in quality and access. Implementation should follow a phased approach. First, pilot programs can be introduced in selected science classrooms to evaluate feasibility and contextual relevance. Second, infrastructure upgrades particularly in public schools must precede large-scale adoption to avoid widening the digital divide (UBEC, 2021). Third, monitoring and evaluation mechanisms should be embedded to assess impact on student achievement, engagement, and equity. Importantly, AI tools must align with the Nigerian science curriculum to ensure relevance to national educational goals. Localization of AI systems adapting them to curriculum content, assessment standards, and linguistic diversity is critical to their effectiveness (Afolabi & Olanrewaju, 2023). Policy coherence, stakeholder collaboration, and sustainable funding are therefore central to responsible implementation.

Implications for Science Teachers

The integration of AI in science education significantly reshapes the professional roles and competencies required of science teachers. Contrary to concerns about technological replacement, AI repositions teachers as facilitators of inquiry, interpreters of learning analytics, and designers of personalized learning experiences (Holmes et al., 2022).First, teachers must develop digital pedagogical competence to effectively integrate AI tools into instruction. This includes the ability to interpret analytics dashboards, evaluate AI-generated feedback, and adapt lesson plans based on learner data. Ogunleye and Fashola (2021) emphasize that teacher readiness remains a major determinant of successful technology adoption in Nigerian schools. Second, AI reduces routine administrative burdens such as grading objective assessments,

thereby allowing teachers to focus on higher-order instructional tasks mentoring, scaffolding inquiry, and fostering scientific reasoning. However, teachers must maintain professional judgment in reviewing AI outputs to ensure accuracy and fairness. Third, ethical literacy becomes a core professional responsibility. Teachers must understand data privacy principles, informed consent requirements, and risks of algorithmic bias to safeguard students' interests (NITDA, 2019). Continuous professional development (CPD) programs must therefore integrate AI literacy training into science teacher education curricula. Ultimately, AI enhances not replaces the teacher's role by supporting differentiated instruction and enabling more responsive pedagogical practices.

Conclusion

Artificial Intelligence (AI) represents a transformative force in science education, offering unprecedented opportunities to facilitate personalized learning, enhance student engagement, and support teachers in delivering differentiated instruction. In the Nigerian context, where traditional teacher-centered methods, overcrowded classrooms, and limited laboratory facilities have constrained science learning outcomes, AI presents a viable solution for bridging these systemic gaps. Through adaptive instruction, real-time feedback, intelligent tutoring systems, virtual laboratories, and learning analytics, AI can tailor educational experiences to individual learners' needs, fostering deeper understanding, motivation, and mastery of scientific concepts. However, the successful integration of AI into Nigerian science classrooms requires careful attention to challenges and ethical considerations, including equity and access disparities, data privacy and security, and the mitigation of algorithmic bias. Without deliberate policies and infrastructural support, AI adoption risks reinforcing existing educational inequalities rather than reducing them. Equally, teachers' professional roles are evolving, demanding digital literacy, ethical awareness, and the capacity to interpret AI-generated insights to enhance pedagogy. To maximize AI's potential, policymakers, school leaders, and educators must collaborate to develop inclusive and contextually relevant frameworks that support infrastructure, professional development, and ethical governance. Future research

should focus on evaluating the impact of AI on student outcomes, equity, and teacher readiness within Nigerian science classrooms. In conclusion, when implemented thoughtfully and ethically, AI can serve as a catalyst for personalized, learner-centered science education in Nigeria, transforming classrooms into dynamic environments where every student has the opportunity to thrive, and teachers are empowered to deliver high-quality, data-informed instruction.

Recommendations

Based on the analysis presented, the following recommendations are proposed to ensure effective and ethical integration of AI as a catalyst for personalized learning in science education in Nigeria.

Policymakers should established clear guidelines on ethical standards, procurement processes, data governance, and evaluation metrics.

School Leaders should facilitate workshops and CPD programs focused on AI literacy and digital pedagogy.

Teachers educate students about responsible use of AI technologies and digital citizenship.

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