INTERNATIONAL JOURNAL OF RESEARCH AND INNOVATION IN SOCIAL SCIENCE (IJRISS)
ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue XII December 2025

Chemistry Education and Artificial Intelligence (AI) In the 21st Century Nigeria: Prospects, Challenges, and the Way Forward. A Review Article

Terngu Paul Ugosor*[1], Asemave Kaana[2], & Winifred Umbur Ukpoko[3]

[1*]Department of Chemistry, College of Education, Katsina-Ala, Benue State, Nigeria

[2]Department of Chemistry, Rev. Fr. Moses Orshio Adasu, University, Makurdi, Benue State, Nigeria

[3]Postgraduate Network in Chemistry, Benue State, Nigeria

***Corresponding Author**

DOI: https://doi.org/10.47772/IJRISS.2025.91200097

Received: 11 December 2025; Accepted: 19 December 2025; Published: 01 January 2026

ABSTRACT

Nigeria stands at a crossroad in modernizing science education. Chemistry, an essential gateway to Science, Technology, Engineering, and Mathematics (STEM) careers continues to show uneven student outcomes, while artificial intelligence (AI) technologies are rapidly changing how Science is taught and learned worldwide. Artificial intelligence (AI) is increasingly recognized as a transformative force in global science education. In Nigerian school chemistry, AI can support conceptual understanding, foster inclusive education, improve evaluation processes, enhance practical competencies, improve instructional efficiency, bridge regional disparities, and expand access to laboratory-like experiences despite infrastructural constraints, digital literacy gaps, data privacy, and security concerns, lack of regulatory framework for integrating AI in Nigerian educational system, and socio-cultural challenges. In addition, the contextualization of AI to align with Nigeria's diverse linguistics, cultural, and pedagogical needs are challenges that need to be addressed. This paper adopts a conceptual and narrative review approach, synthesizing national educational policy, peer-reviewed research, and global Artificial Intelligence in Education (AIED) evidence to address the research problem. The article synthesizes contemporary evidence and policy documents to map the prospects of deploying AI to strengthen chemistry teaching and learning in Nigeria, identify systemic challenges (infrastructure, teacher capacity, assessment integrity, equity, and ethics), and propose a pragmatic, evidence-informed recommendations for implementation. The review covers conceptual foundations, pedagogical applications, National Digital Learning Policy (NDLP), advantages of AI in chemistry education, some AI tools in chemistry education, international systematic reviews of AI in education, challenges, country-specific analyses of AI readiness, and systemic recommendations, targeted at policymakers, teacher educators, school leaders, and donor/industry partners. The paper argues that while national interest in AI-enabled teaching is rising, sustained policy support, improved infrastructure, teacher professional development linked to curricular aims, scalable blended AI tools for simulations and formative assessment, governance for data privacy, assessment validity, and inclusion are paramount. Limitations and avenues for research are also identified.

Keywords: Chemistry education, artificial intelligence, digital learning, Nigeria, STEM pedagogy, teacher development

INTRODUCTION

Chemistry education in Nigeria plays a foundational role in preparing learners for careers in medicine, agriculture, materials science, biochemistry, pharmacy, research, lecturing, and engineering technology sectors. Despite its strategic importance, challenges continue to undermine effective teaching and learning due to weak curriculum implementation (especially inquiry-based pedagogies), lack of laboratories, outdated laboratory resources, poor visualization of abstract concepts, overcrowded classrooms, shortage of qualified teachers, insufficient exposure to digital learning resources, and teacher preparation gaps (Olubunmi and Aarinola, 2022). Artificial Intelligent (AI) technologies such as intelligent tutoring systems, automated feedback tools, virtual laboratories, and content-generation systems offer new opportunities to address these long-standing problems (Holmes,Wieman, & Bonn, 2023; Alaimo and Marriani, 2024).

Global AI-education (AIED) literature identifies adaptive learning systems, intelligent tutoring systems, AI-driven assessment tools, and virtual laboratories as major drivers of improved learning outcomes in STEM subjects (Krenn et al., 2020; Oyetero and Kebukola, 2023; Wang et al., 2024). AI adoption in STEM education has enhanced student engagement, differentiated instruction, and improved assessment accuracy (Triplett, 2023; Sanusi, 2025).

In Nigeria, emerging researches (Offiah, 2024; Aladesuyi and Abidoye, 2025; Adejo, 2025; Sanusi, 2025) document positive teacher attitudes towards AI, but also emphasize low level digital competency, limited access to devices, and absence of national guidelines for AI development in schools. That notwithstanding, Nigeria has begun exploring similar possibilities, particularly after renewed interest in digital learning following the COVID-19 pandemic and recent policy shifts such as the Federal Ministry of Education's National Digital Learning Policy (May, 2023) signals a national intent to expand digital learning tools (including AI), capacity building, and inclusive access into science education across levels of education. The shift in pedagogy, culminating to more of distance learning than the usual face-to-face learning during the COVID-19 pandemic demonstrated how important digital technologies are in education (Federal Ministry of Education, 2025).

Nigeria's National Digital Learning Policy, 2023 articulates goals to bridge the digital divide, build infrastructure, and invest in capacity building for teachers and institutions as a foundation for digital and AI-enhanced learning. The policy explicitly links digital learning ambitions to infrastructure, devices, pedagogical redesign, and monitoring & evaluation, providing an anchor for integrating AI into mainstream education rather than leaving it as ad-hoc pilot projects.

Preliminary efforts to build AI capacity in Nigeria by the National Centre for Artificial Intelligence and Robotics (NCAIR), National Information Technology Development Agency (NIITDA), and AI academy initiatives indicate political will. These Nigerian organizations are focused on promoting research and development in AI, robotics, and other emerging technologies to drive the country's digital economy. Specifically, NIITDA aim to foster innovation, create a thriving ecosystem for innovation-driven entrepreneurship and job creation; develop talents by building capacity for young innovators, startups, and academia as well as promote AI adoption by encouraging responsible AI adoption in key sectors like agriculture, health, education, and sustainability. NCAIR is also working on initiatives like the AI fund in collaboration with Google to support Nigerian AI startups and nurture the next generation of AI-powered solutions (Federal Ministry of Education, 2025). However, classroom-level translation remains limited and uneven.

Concurrently, the literature on artificial intelligence in education has matured rapidly. Recent large systematic reviews show that AI applications span adaptive/personalized tutoring, intelligent assessment, predictive analytics, and simulation-based learning, are being applied in Science, Technology, Engineering, and Mathematics (STEM) subjects where conceptual visualization and formative feedback are critical (Nature Research Intelligence, 2024; Zhou et al., 2024; Nwafor, 2025; Nguyen and Turoung, 2025). These reviews also highlight evidence of positive learning gains under structured implementations, while stressing concerns about equity, data privacy, and teacher roles.

Surveys (Basil et al., 2024; Ogunbanjo et al., 2025; Sokoto State Study Authors, 2025) across various levels of education in Nigeria show high awareness of AI concepts, positive attitudes toward adopting AI, limited hands-on experience, strong willingness to adopt AI if trained, concerns about workload, device access, and exam compatibility. The global acceleration of AI adoption across education systems underscores the urgency for Nigeria to develop structured, evidence driven approach for embedding AI into chemistry instruction. It is worthy of note that digital transformation and national policy commitments are the necessary pathways to modernize education delivery in Nigeria.

This research article provides a broadened context on current status of chemistry education, the global discourse on AI in STEM teaching, and emerging national landscape for AI readiness. It also synthesizes Nigerian and international literature to contextualize opportunities and challenges for AI-enhanced chemistry education as well as present an actionable agenda for chemistry education in the 21st century Nigeria.

Importance of this Review

Despite the global integration of AI in education, its implementation in Nigeria's educational system has been challenging because of infrastructure and access inequalities; teacher capacity and pedagogical integration; assessment integrity and academic misuse; data governance, privacy and ethical concerns, local and language inclusivity concerns among others. The absence of a clear-cut road map towards integration of AI in education in Nigeria has compounded to these challenges. Related literature reviews on AI adoption in chemistry education in Nigeria are also lacking. In addition, the potential of AI to address deep-rooted educational challenges in a developing country like Nigeria is not fully explored.

This review is important because it aims at highlighting a comprehensive and critical analysis of how AI can be used in chemistry education so as to bridge the knowledge gap, challenges hindering its effective integration, future prospects, and a clear road map towards its integration in chemistry education in the Nigerian context. In addition, as Nigeria aspires to meet the Sustainable Development Goal, 4 (quality education for all), knowledge of how AI can be utilized responsibly becomes imperative as a well-articulated road map will enable stakeholders to implement AI tools that are not only innovative, but ethically sound, inclusive, and sustainable.

Aim and Objectives of the Review

By highlighting the advantages, prospects, challenges and a clear road map for the implementation of AI in chemistry education, this paper aims to contribute to the development of an effective, equitable, and inclusive adoption and integration of AI-powered tools in chemistry education that is practical and directly actionable for Nigerian education stakeholders.

The main objectives of this research are to:

(i) Point out the advantages of AI in chemistry education.

(ii) Identify the major challenges hindering the integration of AI in chemistry education in Nigeria.

(iii) Highlight the use of some global AI tools in chemistry education, and

(iv) Present an actionable agenda for the adoption and implementation of AI in chemistry education in the 21st century Nigeria.

METHODOLOGY AND REVIEW SCOPE

This is a conceptual, policy-oriented review that integrates: (a) national policy documents and strategy drafts relevant to digital learning and AI in Nigeria; (b) peer-reviewed empirical studies examining chemistry curriculum implementation and teacher readiness in Nigeria; and (c) major systematic reviews and meta-analyses of AI in education, with emphasis on STEM published between 2019 and 2025.

Literature was retrieved from reputable databases such as ResearchGate, Google Scholar, Web of Science, IEEE Xplore, ScinceDirect, arXiv, ProQuest, JSTOR, EBSCOhost, Crossref, DOAJ, Semantic Scholar, and Scopus using search terms like "application of AI in Science Education," "challenges to integration of AI in science education," "National Digital Learning Policy in Nigeria," "AIED (AI in Education) literature," "country analyses of AI in Nigerian schools," "some AI tools in chemistry education," and "prospects of AI in chemistry education". Approximately, 110 to 120 sources were screened for relevance with 39 references meeting the inclusion criteria. Studies were included if they were conducted in Nigeria or contained data relevant to Nigerian digital learning policy, Nigerian artificial intelligence integration, chemistry education and artificial intelligence, artificial intelligence tools in chemistry, prospects of artificial intelligence in chemistry education, challenges of AI integration in Nigeria, national policy on education, specific areas of application of AI in chemistry, conceptual framework of AI, artificial intelligence in science, technology, engineering, and mathematics (STEM), relevant articles published in peer-reviewed journals, institutional repositories, or credible technical reports. This methodology ensures a comprehensive, context-sensitive review that reflects global AI trends with the Nigerian educational context.

Conceptual Framework: What AI Means for Chemistry Education

Broadly, AI is a branch of computer science concerned with creating systems (machines or software) that can replicate or simulate aspects of human (or intelligent) behavior (Erumit and Sarialioglu, 2025). Because the field is broad and evolving, there is no single universally accepted definition. Rather, definitions vary depending on whether we focus on functional behavior (what the system does), technical architecture (how it's built), or philosophical/ethical implications (what "intelligence" means in machines).

Artificial Intelligence (AI) is also seen as the development of computer systems capable of performing tasks that traditionally require human cognitive abilities such as learning, reasoning, problem-solving, perception, language comprehension, and decision-making (Federal Ministry of Education, 2023; El Fathi et al., 2025). Modern AI integrates computational models, algorithms, and data-driven techniques, particularly machine learning and deep learning to enable computers to learn from experience, recognize patterns, and adapt their outputs accordingly. In contemporary scholarship, AI is viewed not merely as a technological tool but as a sociotechnical system composed of algorithms, data, hardware, human input, and contextual factors. This conceptualization implies that AI supports and augments human capability rather than replacing it.

In some academic definitions, AI is described as systems or "agents" that, upon receiving input (percepts) from the environment, perform actions and infer or decide based on those inputs to maximize a notion of performance or success (Amirbekova et al., 2024; El Fathi et al., 2025). In chemistry education specifically, the concepts of AI are applied to visualize molecular structures, simulate reactions, interpret spectroscopic data, and support inquiry (Russell and Norvig, 2022). Thus, AI serves as both a cognitive partner and instructional aid based learning in modern scientific pedagogy. Within education, AI enhances teaching and learning processes by enabling personalized learning, real-time feedback, automated assessment, and interactive simulations.

Since AI is rapidly advancing, recent scholarship and reviews emphasize that AI should be understood not merely as a technical artifact but as a sociotechnical phenomenon: a combination of algorithms, data, human purpose, social context, and dynamic expectations. A Nature Research Intelligence, 2024 overview of AI in higher education argues that AI (including modern variants like generative AI and large language models) is reshaping how systems support teaching, learning, assessment, and institutional management, highlighting both opportunities and challenges for pedagogy, ethics, and policy.

Likewise, analyses continue to stress that while AI systems can mimic aspects of intelligence, they do not possess consciousness, self-awareness, or human-style understanding. Their "intelligence" stems from algorithms, data, and computational power, not from subjective experience.

AI systems often draw on a mixture of techniques and technologies. Some of the primary capabilities and subfields include:

(i) Learning from data rather than relying only on explicit programming. Many AI systems improve their performance over time via data (e.g. through machine learning).

(ii) Reasoning and problem-solving. AI can be designed to reason logically, make decisions, plan actions, or solve problems.

(iii) Perception and interpretation of inputs, including recognizing patterns in data, interpreting images, language, or sensory inputs (e.g. speech recognition, computer vision, natural language processing). AI can, in many cases, generalize from past experience to handle new or slightly different situations (though generalization remains limited compared to human flexibility).

(iv) Adaptation and generalization. AI can automate repetitive, data-intensive, or complex decision tasks, often faster or more accurately than humans in specific domains (e.g. diagnosis, pattern recognition, prediction) (Nguyen and Turoung, 2025).

Artificial intelligence in education (AIED) can be summed as computer systems able to analyze learning patterns, adapt tasks to learners' needs, interpret student input, and support teacher decision-making. Artificial Intelligence (AI) is transforming how chemistry is taught, learned, and practiced. In chemistry education, AI supports teaching processes, laboratory learning, assessment, personalization, and problem-solving (El Fathi et al., 2025). In professional chemistry, it supports molecular design, reaction prediction, and chemical data analysis (Xu, Lin, and He, 2024; El Fathi et al., 2025).

Advantages of AI in Chemistry Education

Student learning outcomes

Studies conducted (West African Examination Council Report, 2019; Lu et al., 2022; Oyetero and Okebukola, 2023; Holmes et al., 2023; Alaimo and Mariani, 2024; Nguyen and Turoung, 2025) consistently report that AI-enabled chemistry lessons improve:

Adaptive tutoring and personalized learning

AI systems personalize instruction to students' current misconceptions, adapt pathways to these misconceptions, provide targeted scaffolding through multistep problem solving (e.g., stoichiometry, reaction balancing), and give formative feedback that focuses on deep conceptual links rather than rote procedures. Intelligent Tutoring System (ITS) and adaptive platforms model students' knowledge states and then select explanations, worked examples, or conceptual questions tailored to those states. This reduces cognitive overload and helps students restructure mental models (for example, shifting from particulate/molecular explanations to macroscopic observations).

AI selects sequence of examples and questions optimized to close knowledge gaps, resulting to metacognitive prompts. These systems encourage reflection ("why" and "how" questions) that help students build causal schemas and creates immediate, diagnostic and corrective feedback. Corrective feedback targets specific erroneous mental models (e.g., misinterpretation of molecular interactions) produces greater conceptual change than delayed or generic feedback (Basil et al., 2024).

Systematic reviews of AI in science and chemistry education show consistent gains in understanding when AI tools are used to diagnose misconceptions and deliver corrective, stepwise instruction. Recent empirical studies (Basil et al., 2024; Ogunbanjo et al., 2025) report improved post-test conceptual scores (medium effect sizes) when students used AI tutoring environments compared with traditional instruction or static e-learning, particularly for multi-step conceptual topics like stoichiometry, bonding, thermochemistry. Evidence shows improved conceptual mastery when ITS are well designed and integrated with teacher mediation, lab work and formative assessment and not used as standalone replacements.

Motivation and interest

AI-enhanced lessons can increase student motivation and interest by delivering personalized, relevant tasks; reducing frustration through scaffolded help; and providing interactive, game-like, or narrative experiences. Adaptive difficulty and choice (e.g., topic pathways) sustain engagement and promote persistence with challenging chemistry problems.

AI-enabled chemistry learning helps learners to pursue topics of interest or real-world problem scenarios (e.g., environmental chemistry), increasing intrinsic motivation. On-demand hints and private one-to-one practice lower fear of public failure, helpful in high-stakes chemistry topics (Xu et al., 2024). However, motivation gains depend on access and cultural/linguistic fit (Basil et al., 2024). Poorly localized AI materials can reduce motivation for some learners.

Studies on AR/VR and AI-supported platforms by Amirbekova et al, 2024 report higher self-reported interest and situational motivation, especially for abstract molecular topics where students often feel disconnected from real-world relevance. Meta-analyses (Amirbekova et al., 2024; Mhlanga, 2025; Lai et al., 2025) of AI in education indicate improvements in engagement metrics (time-on-task, voluntary practice) when intelligent feedback and personalization are present. However, results vary across age groups and implementation quality.

Visualization of complex ideas

AI augments and automates high-quality visualizations (3D molecular models, animated reaction mechanisms, interactive simulations) and can generate customized visuals from textual prompts or data. When combined with AR/VR, learners can manipulate molecular geometries, observe simulated dynamics, and link representations across macroscopic, submicroscopic, and symbolic levels (e.g. molecular structure, reaction dynamics, and abstract models).

AI also helps convert student explanations into visual scaffolds (e.g., automatically generated step diagrams). Manipulating molecules in 3D improves students' ability to reason about geometry-dependent properties (e.g., chirality, dipole moments), which helps embodied interaction. AI can also help learners to synchronize views (structural ↔ spectral ↔ macroscopic), helping students make cross-level inferences and enhance dynamic linking of representations.

Controlled studies (Amirbekova et al., 2024; Emurit and Sarialioglu, 2024) of immersive visualization (AR/VR) in chemistry show improved spatial understanding and mental rotation skills, better mapping between molecular structure and properties, and stronger retention of three-dimensional concepts than 2D diagrams alone. Reviews indicate that AI-enhancements (e.g., intelligent annotation, automatic highlighting of reactive sites, adaptive simulation speeds) magnify those benefits.

Recent platforms integrate generative AI to create annotated visual scenes and use physics-informed models to simulate realistic molecular behavior. Immersive labs and "molecular metaverse" educational experiences are increasingly reported in the literature (Amirbekova et al., 2024; Offiah, 2024; Sokoto State Author, 2025) as promising for secondary and tertiary chemistry education.

Low-cost experimentation and simulations

AI-enabled simulations allow safe, low-cost experimentation, visualization at atomic/molecular scale, and repeated practice of procedures, addressing laboratory infrastructure gaps common in Nigerian schools. Virtual labs, in particular, help students to practice experiments repeatedly before physical laboratory sessions (Amirbekova et al., 2024; Offiah, 2024). According to Basil et al., 2024 when coupled with pedagogy, simulations increase engagement and transfer to practical skills.

Problem-solving performance

AI supports problem solving by providing stepwise worked examples, scaffolded hints at the right granularity, automated worked-solution comparisons, and by generating adaptive problem sets that progressively build the procedural and conceptual skills needed for complex chemistry problems (Lai et al., 2025). By diagnosing common incorrect solution paths, AI provides corrective sequences (mini-lessons) that repair misconceptions and improve future performance. Large Language Models (LLMs) and ITS can provide hierarchical hints that move from strategic prompts to worked calculations, encouraging independent solution while preventing unproductive struggle (Xu et al., 2024; Lai et al., 2025). AI gradually reduces support as competence develops, promoting transfer to independent problem solving.

Recent experimental studies and systematic reviews report modest to substantial gains in procedural problem solving (e.g., stoichiometry, equilibrium calculations, multi-step synthesis planning) when students receive AI-driven, personalized scaffolds compared with control groups receiving static practice (Basil et al., 2024). Gains are largest when AI feedback targets underlying conceptual errors rather than only arithmetic or algebraic mistakes.

Intelligent formative assessment and feedback

Automated question generation, short-answer scoring, and targeted feedback can increase practice opportunities and reduce teacher marking load while providing data for differentiated instruction (Holmes et al., 2023).

Teacher decision support

Analytics dashboards can highlight class misconceptions, inform pacing, and identify students needing intervention, helping teachers prioritize support in large classrooms (Offiah, 2024). However, LLMs can produce plausible-sounding but incorrect chemistry explanations or numerical errors if not constrained by domain checks. ITS, which is a computer-based system that provide personalized learning experiences, adopt to individual student needs, support learning in various subjects (including chemistry), and offer real-time feedback and assessment require careful alignment between the knowledge model and curricular goals to avoid teaching shortcuts that bypass conceptual reasoning. Human oversight and domain validation remain essential for maximum benefits.

In summary, AI-enabled chemistry lessons, when well designed and integrated can improve conceptual understanding, motivate learners, make abstract molecular ideas tangible through advanced visualizations, and enhance problem-solving performance. However, LLMs may make mistakes and hallucinate chemical facts or incorrect mechanisms. Therefore domain-constrained AI or hybrid systems are a concern. As a result, AI and rule-based checks are safer. The largest benefits come from systems that combine adaptive diagnostics, scaffolded feedback, and immersive, manipulable visual models, all overseen by informed teachers. Continued research should prioritize robust evaluations, domain-constrained generative tools, teacher training, and equity of access.

Specific Areas and Concepts AI can be Applied in Chemistry Education

Artificial Intelligence (AI) is increasingly transforming chemistry education by enhancing interactivity, personalization, and safety in learning environments. Its application in virtual titration laboratories, molecular visualization, stoichiometry tutoring, and safety simulations has significantly improved conceptual understanding and learner engagement.

AI technologies: ITS, generative AI/LLMs, adaptive learning platforms, and immersive visualization: Augmented Reality/Virtual Reality (AR/VR) integrated with AI enhances or create interactive experiences, improving chemistry teaching and learning. These intelligent tutoring systems are often used in virtual labs for scientific education (e.g., chemistry simulations), interactive 3D models for complex concepts visualization (e.g., stereochemistry), and AI-powered training simulations. These technologies boost engagement and understanding in various fields, including chemistry education and research. AI offers a realistic and transformative pathway to improving chemistry education in Nigeria. With strategic investment and policy coordination, AI can enhance access, equity, and quality in school science instruction.

AI applications in chemistry span classroom instruction, laboratory practice, problem-solving, assessment, and chemical research. The specific areas include:

(a) Molecular structure recognition and visualization

AI enhances molecular visualization by supporting dynamic three-dimensional representations of molecules and facilitating interaction with complex chemical structures .AI tools convert chemical sketches into 2D or 3D structures (e.g., through Optical Character Recognition, OCR and pattern recognition), interpret chemical structures or molecular geometry (even from handwriting or scanned diagrams), and support visualization of orbitals, hybridization, polarity, and spatial orientation. OCR converts handwritten or scanned texts into digital format, enables text analysis, and processing. OCR is used in applications like document scanning, text extraction, and language translations. These AI-powered tools can be used in topics like atomic structure, chemical bonding, molecular geometry, and organic chemistry structures, thus enhancing conceptual understanding (Nature Research Intelligence, 2024).

Tools integrating artificial intelligence, machine learning, and virtual/augmented reality allow students to manipulate molecular models and explore submicroscopic chemical phenomena, deepening spatial reasoning and insight into bonding, geometry, and electronic structure (Fernandes., Cerqueira, and Sousa, 2021).

(b) Stoichiometry and quantitative chemistry

AI-driven solvers assist students with mole calculations, limiting reagent analysis, gas laws, titration computations, and balancing equations. Intelligent tutoring systems (ITS) powered by AI analyze students' learning patterns, diagnose misconceptions, errors and provide adaptive feedback based on individual learning needs (Liu et al., 2022; Federal Ministry of Education, 2025; Nguyen and Turoung, 2025).

They also offer tailored instruction in quantitative chemistry problems, including mole calculations and limiting reagent scenarios. These adaptive learning platforms provide personalized practice, immediate feedback, and structured problem-solving guidance that support mastery of stoichiometric reasoning in chemistry.

(c) Reaction prediction and mechanistic analysis

Deep learning algorithms predict likely reaction outcomes/products, suggest probable pathways, identify catalysts or reagents, detects student's misconception in mole calculations, solve and explain stoichiometric problems step-by-step, generate personalized practical questions, and model mechanistic steps. This is useful in teaching reaction types, rate theories, mole concept, chemical equations, limiting reagents, concentration, titrations, and organic mechanisms (Birma, 2025).

(d) Spectroscopy and analytical chemistry

AI assists in analyzing and interpreting spectroscopic data such as Infrared (IR), Nuclear Magnetic Resonance (NMR), Ultraviolet-Visible (UV–Vis), and Mass Spectroscopy (MS), pattern recognition for functional group identification, and automated peak assignment. Automated peak identification and spectral pattern recognition enhance students' analytical skills (Lai et al, 2025). AI-powered tools can be applied in topics like analytical chemistry, structure elucidation, qualitative and quantitative analysis.

(e) Virtual laboratories and experimental simulations

AI-powered laboratories simulate experiments such as titrations, neutralization, electrochemistry, equilibrium studies, kinetics, and thermochemistry, provide real-time feedbacks and corrections, and reduce the need for expensive reagents or hazardous chemicals. These simulations improve safety, reduce chemical waste, and provide practice opportunities in resource-limited settings. Areas of application are practical chemistry, acid-base titrations, chemical equilibrium, reaction rates, and energy of reactions (Nature Research Intelligence, 2024).

AI-powered virtual titration labs simulate real laboratory conditions, enabling students to perform experiments such as acid–base titrations without physical reagents or equipment. Intelligent systems can assess students' procedural steps, provide real-time feedback on technique and endpoint detection, and adapt scenarios based on learner performance. Virtual labs have been shown to support inquiry-based learning and provide scaffolds for understanding key experimental conditions, enhancing accuracy and conceptual understanding in titration tasks (Davenport and Jagodzinski, 2022; Chan et al., 2023).

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue XII December 2025

(f) Intelligent tutoring systems

AI-based tutors generate personalized exercises (e.g., adapt lessons to individual students), monitor student progress (e.g., diagnose strengths and weakness of learners), offer tailored practical questions, and provide instant corrective feedback. This can be used for topic across the chemistry curriculum (Jakobsche et al., 2023; Alaimo and Mariani, 2024). This supports self-paced learning and reduces teacher workload.

(g) Chemoinformatics and data-driven chemistry

AI models analyze chemical datasets, predict molecular properties, and classify compounds (e.g., based on activity or toxicity), perform Quantitative Structure-Activity Relationship (QSAR) modeling, and design new materials. These applications introduce students to modern scientific research methods. Topics like organic chemistry, environmental chemistry, drug chemistry, and material science can be taught using AI-powered tools (Paulo, 2025).

(h) Environmental chemistry applications

AI supports pollution monitoring, chemical toxicity prediction, green synthesis planning, and environmental modeling. These tools align with global sustainability goals. Topics like water chemistry, air pollution, and sustainability can be taught using AI-powered tools (Emurit and Sarialioglu, 2025; Paulo, 2025).

(i) Accelerating drug discovery

AI tools like Atomwise and DeepChem are reducing the time and cost of developing new drugs by predicting molecular interactions and identifying promising candidates (Paulo, 2025).

(j) Sustainable chemistry

Platforms like ChemCopilot and Citrine Informatics are helping researchers design eco-friendly materials and processes, contributing to a more sustainable future (Paulo, 2025).

(k) Democratizing research

Open-source tools like DeepChem are making AI accessible to researchers worldwide, fostering collaboration and innovation (Floridi et al 2020; Paulo, 2025).

(l) Safety simulations

AI-enabled simulations create risk-free environments where learners practice laboratory safety procedures and hazard response without exposure to real chemicals. Simulation technologies integrate intelligent decision-making systems to model hazardous situations (e.g., chemical spills, fires, toxic reactions), assess learner responses, and reinforce correct safety behavior, thus strengthening risk awareness and safe practice (Fernandes., Cerqueira, and Sousa, 2021; Davenport, and Jagodzinski, 2022).

The application of AI in virtual titration labs, molecular visualization, stoichiometry tutoring, and safety simulations enhances chemistry education by promoting accessibility, personalization, conceptual clarity, and safety. These tools complement traditional instruction and serve as sustainable pathways for modernizing chemistry teaching, particularly where physical resources are limited.

Some AI Tools in Chemistry Education

Chemistry is a data-rich discipline, involving complex molecular structures, reaction pathways, and vast amounts of experimental data. Traditional methods of analyzing this data can be time-consuming and labor-intensive. Artificial intelligence (AI) is transforming the field of chemistry, enabling researchers, educators, and industry professionals to solve complex problems, optimize processes, and accelerate discoveries (Lai et al., 2025). From drug development to materials science, AI-powered tools are reshaping how chemistry is practiced. AI, particularly machine learning (ML) and deep learning (DL), excels at processing large datasets, identifying patterns, and making predictions. AI capability makes an invaluable tool for tasks such as molecular design and drug discovery, predicting chemical reactions and properties, optimizing chemical processes, analyzing spectroscopic data, and accelerating materials discovery (Russell et al, 2022).

By automating repetitive tasks and providing insights that might be missed by human researchers, AI is helping chemists work faster, smarter, and more efficiently. These tools stand out as cutting-edge platforms designed to streamline chemistry education, research, and development. In this section, we explore the AI tools for chemistry education, their applications, and how they are driving innovation in the field (Ansari and Kumar, 2025).

According to Paulo (2025) the best AI tools currently available for chemistry, include the following:

(1) ChemCopilot

ChemCopilot is an innovative AI-driven platform designed to assist chemists in optimizing chemical processes, improving efficiency, and reducing costs. It leverages advanced machine learning algorithms to analyze chemical data, predict outcomes, and provide actionable insights.

Key feature of ChemCopilot are AI-driven process optimization for chemical manufacturing, predictive analytics for reaction outcomes and yield improvement, real-time monitoring and decision support, and integration with laboratory and industrial systems.

Applications of ChemCopilot include research and design of chemical product, chemical manufacturing, process optimization, and sustainable chemistry.

Chemcopilot's AI-driven approach enhances efficiency, safety, and sustainability from chemical processing to advanced materials recovery.

(2) IBM RXN for Chemistry

IBM RXN is a cloud-based platform that uses AI to predict chemical reactions and retrosynthetic pathways. It leverages deep learning models trained on millions of chemical reactions to help chemists design synthetic routes for target molecules.

Key features of IBM RXN include reaction prediction and retrosynthesis planning, user-friendly web interface and integration with other chemistry tools.

IBM RXN is applied in drug discovery, organic synthesis, and chemical education.

(3) Schrödinger Materials Science Suite

Schrödinger's suite of tools combines physics-based modeling with AI to accelerate materials discovery and drug design. Its platform includes solutions for molecular dynamics, quantum chemistry, and ligand docking.

Key functions include AI-driven molecular modeling and simulation, high-throughput virtual screening, and predictive analytics for material properties.

This AI tool is applied in drug discovery, materials science, and catalysis.

(4) DeepChem

DeepChem is an open-source library for deep learning in chemistry. It provides a flexible framework for building and training AI models on chemical data, including molecular structures, reactions, and biological activity with key features such as pre-built models for drug discovery and materials science, support for cheminformatics and bioinformatics tasks, active community, and extensive documentation. This tool is applied in drug discovery, toxicity prediction, and materials design.

(5) Atomwise

Atomwise uses AI to accelerate drug discovery by predicting the binding affinity of small molecules to target proteins. Its platform, AtomNet, employs deep learning to screen billions of compounds and identify potential drug candidates. Its key features include virtual screening and lead optimization, AI-driven drug discovery pipelines, and collaboration opportunities for researchers. **Atomwise** is applied in drug discovery and protein-ligand interaction studies.

(6) Citrine Informatics

Citrine Informatics specializes in AI-driven materials discovery and optimization. Its platform combines machine learning with materials science data to accelerate the development of new materials. Its key features include predictive modeling for material properties, customizable AI workflows, data management, and analysis tools. This AI-powered tool finds application in materials discovery, process optimization, and sustainability.

(7) Molecule.one

Molecule.one is an AI-powered platform for retrosynthesis planning and chemical synthesis. It helps chemists design efficient synthetic routes for complex molecules. Key features of Molecule.one are AI-driven retrosynthesis planning, integration with laboratory workflows, and real-time collaboration tools. It is applied in organic synthesis, drug discovery, and chemical manufacturing.

(8) ChemGPT

ChemGPT is an AI-driven tool for chemistry-related queries and tasks, offering problem-solving, concept explanations, and predictive modeling.

(9) CheIntelligence

ChemIntelligence analyzes chemical structures, predicts properties, and suggest retrosynthesis routes.

(10) Syntelly

Syntelly is a modular AI platform for organic and medicinal chemistry, offering molecular property predictions and database access.

(11) Chemistry Assistant by Hyperwrite

This AI tool answers chemistry questions, solves complex problems, and provides explanations.

(12) Graph2SMILES

Grapgh2SMILES predicts chemical reactions and design synthetic routes using graph-to-sequence models.

(13) AlphaFold

AlphaFold predicts 3D protein structures, revolutionizing structural biology.

It is worthy of note that AI is revolutionizing chemistry education by personalizing learning, virtual labs, and interactive simulations, offering powerful tools to accelerate research, optimize processes, and drive innovation .The integration of AI into chemistry education is not just about improving efficiency; it’s about enabling new possibilities.

Prospects of AI in Chemistry Education in Nigeria

AI offers substantial opportunities for transforming the Nigerian chemistry education landscape, particularly given long-standing challenges such as overcrowded classrooms, insufficient laboratories, limited resources, invisible or complex concepts visualization, and uneven teacher expertise. According to Oyetoro et al., 2023, Nwanfor, 2025; Birma, 2025, key prospects of AI in Chemistry education include:

(a) Improved access to quality laboratory experiences

AI-powered virtual labs can compensate for Nigeria's lack of well-equipped chemistry laboratories by allowing students to conduct experiments digitally in a safe (e.g., reduce reliance on expensive reagents and outdated apparatus), low-cost environment.

(b) Strengthening teacher capacity

AI can support chemistry teachers with automated lesson planning, content creation, and assessment tools, reduces time spent marking assignments and preparing materials. These systems provide real-time analytics that help teachers identify student misconceptions and intervene early. AI does not replace teachers but extends their capacity, particularly in resource-limited contexts common across Nigerian educational systems.

(c) Personalized learning for diverse learners

With AI tutoring systems, regardless of region or socio-economic background can receive individualized instruction, help low-performing students catch up, challenge high-performing students, differentiated practice, and feedback tailored to their learning pace.

(d) Enhancing curriculum delivery through simulations

Chemistry concepts that are abstract or difficult to demonstrate physically (e.g., molecular bonding, equilibrium, thermodynamics) can be effectively visualized using AI simulations and models.

(e) Promoting STEM interest and innovation

AI-enhanced learning environments are engaging and interactive, motivating students to pursue chemistry, engineering, and other STEM-related careers.

(f) Bridging educational inequality

AI tools have the potential to reduce the urban-rural digital divide by making high-quality chemistry instruction accessible to underserved schools.

(g) Aligning Nigeria with global trends

AI integration in chemistry education supports Nigeria's goal of joining the Fourth Industrial Revolution (4IR) and improving technological competitiveness.

Challenges Facing AI Adoption in Nigerian Chemistry Education

A review of related literature (Floridi et al, 2020; Adejo, 2025; Nwanfor, 2025 and Birma, 2025) on the challenges militating against the effective integration of AI in chemistry education in Nigeria remains pronounced as outlined below:

(i) Irregular electricity supply

Digital learning tools and AI-powered platforms require stable power to function. Irregular electricity supply disrupts access, causing equipment damage, data loss, connectivity issues, and limited access to online resources. This hinders effective integration of AI in chemistry education, impacting student engagement and learning outcomes.

(ii) Poor internet infrastructure

AI-powered tools and digital resources require stable, high-speed internet connectivity and devices. Out dated devices, poor or inadequate internet infrastructure leads to slow loading items, disrupt access to online resources, ineffective use of virtual labs and simulations, and limited access to cloud-based AI tools. The National Digital Learning Policy, 2023 recognizes these gaps and prioritizes infrastructure and broadband alignment, but implementation requires sustained financing and subnational coordination as schools in rural and low-income urban areas remain vulnerable. This limits effective integration of AI in chemistry education, hindering student engagement and learning outcomes.

(iii) Few computer laboratories

Limited computer labs means insufficient devices for students, inadequate hand-on practice, limited access to AI software and tools, and inadequate learning opportunities.

(iv) Minimal digital teaching resources

Insufficient digital resources (e.g., interactive simulations, virtual labs, AI-powered tutorials) limit engaging learning experiences, personalized learning opportunities, access to real-world applications, and effective use of AI-driven tools. This restricts AI integration, impacting student understanding and interest in chemistry.

(v) Inadequate funding for software licensing and maintenance

Inadequate funding means unaffordable software licenses, outdated AI tools, limited technical support, and inability to upgrade or maintain systems. This restricts access to cutting-edge AI technology, hindering effective integration and student learning.

(vi) Low digital literacy among teachers or minimal professional development in AI pedagogy

Model Technological Pedagogical and Content Knowledge (TPACK) is important in bridging the gap between content, teacher and AI-powered tools. Effective integration requires teachers to combine chemistry content knowledge, understanding of students' learning needs, and mastery of AI tools suitable for the curriculum. TPACK-based training helps chemistry teachers design lessons where AI complements physical experiments, demonstrations, and collaborative learning.

Low digital literacy among teachers leads to ineffective use of AI tools, limited integration in lessons, inability to troubleshoot issues, and reduced student engagement. Insufficient training and support for AI teachers means limited AI pedagogical skills, ineffective integration strategies, missed opportunities for innovation, and reduced confidence in using AI tools. These hinder AI adoption, impacting student learning outcomes and future readiness.

Furthermore, many AI models, particularly deep learning models, are often seen as "black boxes" and difficult to interpret. Understanding how they arrive at their predictions is crucial for trust and adoption. Therefore, most teachers need extensive training in AI-assisted pedagogy and professional development must focus on not just on tool operation but on curriculum-aligned pedagogical design.

(vii) Cost and sustainability

High cost of AI software and hardware, maintenance and upgrades, training, and support means schools may struggle with device purchase, maintenance, and software subscriptions. This makes it challenging for institutions to sustain AI integration, limiting access to benefits and impacting long-term adoption.

(viii) Poor policy and regulatory structures

Robust legal/regulatory frameworks and school-level governance are required to protect minors and other users. However, national and state policies on AI integration remain unclear. Unclear or inadequate policies hinder AI adoptions and implementation, data protection and security; infrastructure development; collaborations, and partnerships. This creates uncertainty, slowing AI integration and innovation in chemistry education. For example, the use of AI in chemistry, particularly in drug discovery, raises ethical questions about data privacy and the potential for misuse. The National AI Strategy draft and school policy translations should include clear data protections and consent procedures to guard against algorithmic bias and misuse.

(ix) Persistent performance and curriculum implementation gaps

Multiple investigations report that material/resource shortages and inadequate mastery of subject matter are recurring problems as a substantial number of chemistry teachers do not fully implement prescribed curriculum themes, often skipping topics perceived as difficult (Olubunmi & Aarinola, 2022). These implementation deficits are reflected in national examination performance trends which show years of underperformance in chemistry among secondary-level candidates, indicating systemic rather than episodic issues.

(x) Assessment integrity and academic misuse

Generative AI and answer-producing chatbots raise concerns about academic integrity, particularly for high-stakes examinations in Nigeria. Policies and assessment redesign (e.g., performance tasks, laboratory practicums, and oral defenses) will be needed to preserve validity in an AI-augmented environment. In addition, overreliance on AI-generated answers lowers academic integrity and promotes dishonesty.

(xi) Rigorous longitudinal evidence

While short-term gains are documented of AI integration in education, longer-term impacts (retention, transfer, equitable outcomes) need more controlled longitudinal studies for meaningful impact.

(xii) Local relevance and language inclusivity

AI tools trained on global datasets may not reflect local curricula, contexts, or languages. Nigerian efforts to build multilingual Language Learning Models (LLMs) and local datasets must be encouraged so content and examples are culturally and linguistically relevant.

Overall, studies suggest that AI can significantly enhance chemistry learning only when combined with teacher mediation, reliable infrastructure, and structured implementation models.

Conceptual Framework Linking AI tools, Pedagogical Practices, Policy Enablers, and Learning Outcomes in Chemistry Education in Nigeria

A conceptual framework for integrating artificial intelligence (AI) in chemistry education positions AI tools, pedagogy, policy enablers, and learning outcomes as interdependent components of an educational ecosystem. At the core are AI tools such as intelligent tutoring systems, virtual laboratories, adaptive assessment platforms, and learning analytics that provide personalization, simulation, and real-time feedback (El Fathi et al., 2025; Huwer et al., 2025). These tools do not function in isolation; their effectiveness depends on alignment with pedagogical practices grounded in constructivism, inquiry-based learning, problem-based learning, and formative assessment. According to Amirbekova et al., 2024, when pedagogy leverages AI for scaffolding, visualization of abstract chemical concepts, and iterative practice, it enhances conceptual understanding and skills development.

Policy enablers form the structural layer that sustains integration include curriculum standards that legitimize AI use, professional development for teachers, ethical and data-governance guidelines, infrastructure investment, and equitable access policies. Supportive policies enable teachers to adopt AI-informed pedagogy confidently and responsibly while ensuring inclusivity and accountability.

The interaction among these elements leads to improved learning outcomes in chemistry, encompassing cognitive gains (concept mastery, higher-order thinking), practical competencies (experimental design, data interpretation), and affective outcomes (motivation, engagement, self-efficacy). Feedback loops are essential: learning analytics inform pedagogical refinement; classroom evidence informs policy adjustments; and policy support enables continuous innovation in AI tools.

Overall, the framework emphasizes alignment and feedback across system levels, ensuring that AI adoption in chemistry education is pedagogically meaningful, policy-supported, and outcome-driven rather than technology-led.

The Way Forward Towards Integration of AI in Chemistry Education in Nigeria

Based on the synthesis of recent studies and policy signals, the following multi-level policy and system level recommendations are proposed for the integration of AI into chemistry education in Nigeria:

(1) National strategy and guidelines

The Federal Ministry of Education should formalize guidelines for AI in schools (policy on data privacy, acceptable use, procurement standards). Recent ministry statements indicate movement in this direction.

(2) Targeted infrastructure investment

Prioritize power and connectivity upgrades for clusters of schools (hub model) to enable shared use of AI-rich resources.

(3) Capacity building

Scalable teacher professional development is important to sustain practice-based training, focusing on TPACK for chemistry teachers, combining conceptual AI literacy with hands-on lesson co-planning and classroom coaching. There should be a mandatory AI/ICT training for all chemistry educators and incorporation of AI pedagogy into teacher education institutions. In addition, there is need to create short, modular professional learning: micro-credentials co-designed by teacher educators and AI developers, covering pedagogy for AI tools, assessment design, and data ethics.

(4) Curriculum and assessment

There is the need for the National Digital Learning Policy, 2023 to revise chemistry syllabi to include AI-enabled learning pathways and explicit competencies for practical reasoning, laboratory skills (augmented by virtual labs), and data literacy.

(5) School and classroom

Nigeria need to blend implementation model with the use of AI tools to supplement teacher instructions with AI simulations, but not to replace teacher instruction (e.g., virtual lab prep before physical lab; adaptive practice as homework with teacher review) and create digital learning hubs to share devices across departments to address device access gaps.

(6) Ethics and sustainability

Nigeria need to develop hybrid assessments that combine AI-supported practice with authentic performance tasks (practicals, projects, oral vivas) and academic integrity protocols for simple school-level rules about acceptable AI use, anonymized data practices, and teacher oversight to prevent misuse.

(7) Infrastructure funding windows

Nigeria need to mobilize blended finance (government, development partners, and private sector) to supply solar-backed device kits to tackle epileptic power supply and offline-capable AI applications for lowbandwidth contexts, aligned with the National Broadband Plan.

(8) Research needs

Nigeria need to develop local content ecosystems (e.g., Nigeria-specific AI chemistry tools) to meet local context: localizing and open-sourcing high-quality chemistry simulations, datasets, and teacher resources as well as longitudinal studies on learning outcomes and cost-effectiveness of AI integration in chemistry education and invest in, encourage universities and tech hubs to co-create resources.

(9) Monitoring and research

Nigeria need to establish a Monitoring and Evaluation (M&E) framework embedded in the NDLP to monitor learning outcomes, teacher uptake, equity of access, and ethical compliance; fund longitudinal studies to detect cohort effects and labor-market alignment. Bias audits for any AI scoring system, and regular evaluations to detect differential outcomes for gender, region, or language groups have to be in place.

(10) Affordability mandates

Public provision of core educational AI tools under open licenses; device lending schemes for disadvantaged students; and offline modes for low-connectivity contexts need to be encouraged.

The above recommendations can be categorized into short-term, medium-term and long-term for AI Integration in Chemistry Education in Nigeria as follows:

A) Short-Term Recommendations (1–2 Years)

Short-term strategies should focus on foundational capacity building, awareness creation, and pilot implementation, using existing resources and minimal infrastructural changes.

(i) Teacher awareness and capacity development

There is the need to organize nationwide workshops, seminars, and in-service training programs to introduce chemistry teachers to basic AI concepts and applications in teaching and learning. Emphasis should be placed on practical use of AI tools such as virtual laboratories, molecular visualization software, and AI-assisted problem solvers aligned with the Nigerian secondary school chemistry curriculum. In addition, teachers, lecturers, and instructors should be encouraged to undertake self-directed professional development through free or low-cost online AI training platforms.

(ii) Pilot use of AI tools in selected schools

Nigeria need to implement pilot AI-supported chemistry lessons in selected urban and semi-urban schools to test feasibility, use low-cost or open-source AI tools that can function offline or with minimal internet connectivity, and evaluate student engagement, conceptual understanding, and teacher usability during pilot phases.

(iii) Curriculum awareness and supplementation

There is the need to integrate AI-supported learning activities as supplementary tools rather than full curriculum replacements, encourage teachers to use AI tools for revision, homework support, and laboratory preparation, and align AI use with existing West African Examination Council (WAEC), National Examination Council (NECO), and other external examinations chemistry syllabi to avoid curriculum conflict.

(iv) Ethical and responsible use guidelines

Nigeria needs to develop basic school-level guidelines for responsible AI use, focusing on academic integrity, data privacy, and teacher supervision. Sensitization of students on ethical AI usage to prevent over-dependence

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue XII December 2025

or misuse is required.

(B) Medium-Term Recommendations (3–5 Years)

Medium-term actions should aim at systematic integration, infrastructure development, and policy alignment.

(i) Curriculum and assessment alignment

A review and update of the Nigerian secondary school chemistry curriculum to explicitly include AI-supported learning outcomes, collaboration with WAEC and NECO to gradually incorporate digital and AI-assisted practical assessments, and introduction of project-based learning tasks that require responsible use of AI tools for problem-solving are paramount.

(ii) Infrastructure improvement

There is the need to expand access to ICT facilities, including computer laboratories, stable electricity (solar-powered systems), and internet connectivity as well as promote shared digital learning hubs where multiple schools can access AI-enabled resources.

(iii) Teacher professional certification

The need to establish structured AI-in-Education certification programs for chemistry teachers through universities, colleges of education, and teacher training institutes and integrate AI pedagogy into pre-service teacher education programs can facilitate AI integration in Chemistry education in the country.

(iv) Public–private partnerships

The need to encourage collaboration between government, educational institutions, and EdTech companies to develop affordable, localized AI chemistry platforms and support the development of AI tools tailored to Nigerian classroom realities, languages, and curriculum needs are important toward AI integration in the county.

(C) Long-Term Recommendations (5–10 Years)

Long-term strategies should focus on institutionalization, sustainability, innovation, and global competitiveness.

(i) National AI-in-education policy framework

Nigeria needs to develop and implement a comprehensive national policy guiding AI adoption in education, with specific provisions for science and chemistry education, and also establish regulatory standards addressing data security, ethical use, accessibility, and quality assurance.

(ii) Nationwide AI-enabled chemistry learning ecosystem

The country needs to deploy standardized AI-powered virtual laboratories across all public secondary schools, integrate AI tutoring systems into national digital learning platforms, and ensure equitable access for rural and underserved schools to minimize digital inequality.

(iii) Research and innovation support

Fund long-term research on AI effectiveness in chemistry learning outcomes, equity, and cost-efficiency and encouragement of Nigerian universities and research institutes to develop indigenous AI chemistry tools and learning models are required to meet Nigeria specific context and local content policy.

(iv) Continuous teacher and student development

Institutionalization of continuous professional development in AI pedagogy for teachers and equipping of students with AI literacy skills to prepare them for careers in chemistry, engineering, medicine, and technology are required for effective integration of AI in chemistry education in Nigeria.

(v) Global alignment and sustainability

Alignment of Nigeria's chemistry education system with global best practices in AI-enhanced STEM education and promotion of sustainability by using AI to support green chemistry education and environmental monitoring initiatives are necessary for effective integration of AI in Chemistry education in the country.

Limitations and Research Gaps of AI in Chemistry Education

This paper synthesizes policy documents and contemporary literature but is not a systematic meta-analysis of Nigerian randomized controlled trials (RCTs) of AI interventions in chemistry specifically, such RCTs are limited. Further empirical work is needed to measure learning effect sizes of AI tools in Nigerian chemistry classrooms, long-term impacts on STEM pathways, and the cost-effectiveness of scaled implementations. Rigorous, context-sensitive research (including mixed methods and longitudinal designs) should accompany any roll-out.

CONCLUSION

AI presents a timely, pragmatic set of tools to help Nigeria tackle longstanding weaknesses in chemistry education if deployed within a coherent national digital learning strategy, coupled with teacher capacity building, infrastructure investment, ethical governance, and curricular realignment. The National Digital Learning Policy (2023) provides the policy scaffolding. The challenge now is to operationalize AI in ways that are evidence-based, locally relevant, and equitable.

The successful integration of Artificial Intelligence into chemistry education in Nigeria requires a phased, strategic approach. Short-term efforts should focus on awareness and pilot implementation, medium-term actions on systemic integration and infrastructure development, and long-term strategies on policy institutionalization and innovation. With coordinated efforts from government, educators, and industry stakeholders, AI can significantly enhance the quality, equity, and relevance of chemistry education in Nigeria. A deliberate blend of pilots, research-driven scale-up, and institutional capacity development can make chemistry a demonstrable showcase for AI-augmented STEM education in Nigeria.

Competing Interests

Authors have declared that no competing interests exist.

REFERENCES

1. Adejo, L. O. (2025). Evaluating the effectiveness and challenges of artificial intelligence tools in chemistry education. FNAS Journals. https://fnasjournals.com/index.php/FNAS-JMSE/article/view/907/1044.
2. Aladesuyi, D., & Abidoye, F. O. (2025). Artificial intelligence (AI) problems on chemistry curriculum implementation in Kwara State. Wilberforce Journal of the Social Sciences, 10(1), 63–73.
3. Alaimo, S., & Mariani, F. (2024). Artificial intelligence for chemistry education: Tools, trends, and pedagogical implications. Chemistry Education Research and Practice, 25(2), 145–162.
4. Amirbekova, E., Naliya,S, & Ekaterina, M. (2024). Teaching chemistry in the metaverse: the effectiveness of virtual and augmented reality for visualizations. Frontiers in Education. Sec. Digital Learning Innovations, 8. https://doi.org/10.3389/feduc.2023.1184 768
5. Ansari, R., & Kumar,V. (2025). Impact of digital tools and stimulation in science education. Journal of Research in Chemistry, 6(1), 92-98.

6. Basil, C.E., Agnes, O.O., Valentine, O.A., Cliff, I.O., Carol, I.O, and Victoria, D.E. (20240. Application of Artificial Intelligence in Education: Challenges and Prospects, AJSTME, 10(4): 687-692. https://www.ajstme.com.ng
7. Birma, A. I. (2025). Artificial intelligence in education: A comprehensive review of trends, challenges and future directions in Nigeria and sub-Saharan Africa. HRMARS / ResearchGate.
8. Chan, P., Van Geren, T., Dubois, J.L., & Bernaerts, K. (2021). Virtual chemical laboratories: A systematic literature review of research, technologies and Engineers instructional design. Computers and Education Open, 2, 100053. https://doi.or/10.1016/j.caeo.2021.100053
9. Davenport, J., & Jagodzinski, P. (2022). Virtual reality in chemistry education: Outcomes and trends. Chemistry Education Research and Practice. (review on VR tools supporting safety and laboratory procedures).
10. El Fathi, T., Saad, A., Larhzil, H., Lamri, D, & Al Ibrahim, E.M. (2025). Integrating AI into STEM Education: Enhancing conceptual understanding, addressing misconceptions, and assessing student acceptance. Disciplinary and Interdisciplinary Science Education Research, 7 (6). https://doi.org/10.1186.s43031-025-00125-z
11. Erümit, A. K, & Sarialioglu, R.O. (2025). Artificial intelligence in science and chemistry education: A systematic review. Discover Education, 4, 178. https://doi.org/10.1007/s442 17-025-00622-3
12. Federal Ministry of Education. (2023). National Digital Learning Policy (Final draft). Federal Ministry of Education, Nigeria. https://education.gov.ng/wp-.
13. Federal Ministry of Education. (2025, January 24). Nigeria embraces AI-driven education on International Day of Education [Press release]. fmino.gov.ng. https://fmino.gov.ng.
14. Fernandes, H. S., Cerqueira, N. M. F. S. A., & Sousa, S. F. (2021). Developing and using BioSIMAR, an augmented reality program to visualize and learn about chemical structures. Journal of Chemical Education, 98(5), 1789–1794.
15. Floridi, L., & Chiriatti, M. (2020). GPT-3: Its nature, scope, limits, and consequences. Minds and Machines, 30, 681–694.
16. Holmes, N. G., Wieman, C., & Bonn, D. (2023). Using AI-powered tools to enhance laboratory learning in secondary science education. Journal of Chemical Education, 100(4), 1671– 1682.
17. Huwer, J., Maurer, N., Mundt, P., Belova,N. (2025). AI in chemistry and chemical education. International Journal of Physics and Chemistry Education, 17(1), 1-4. https://doi.org/10.51724/ijpec.v17i1.403
18. Jakobsche, C.E., Kongsomjit, P., Milson, C., Wang,W., & Ngun, C.K. (2023). Incorporating an intelligent tutoring system into the Discover of chemistry learning platform. Journal of Chemical Education, 100(8), 3081-3088. https://doi.or/10.1021/acs.jchemed.3c00117
19. Krenn, M., Häse, F., Nigam, A., Friederich, P., & Aspuru-Guzik, A. (2020). Self-driving laboratories for accelerated discovery. Nature Reviews Chemistry, 4(12), 709–722.
20. Lai, C. H and Cheng-Yueh, L. (2025). A Case Study of an ITS powered by an LLM: immediate feedback and hierarchical learning. Applied Sciences (MDPI), 14(4), 1922.
21. Liu, L., Ling, Y., Goa, Q., & Fu, Q. (2022). Supporting students' inquiry in accurate precipitation titration conditions with a virtual laboratory tool as learning scaffold. Education for Chemical, 38, 78–85. https://doi.org/10.1016/j.ece.2021.11.001
22. Lu, H., Li, Y., Chen, M., Kim, H., & Serikawa, S. (2022). Brain-inspired AI: Progress and challenges. Neurocomputing, 475, 21–34.
23. Mhlanga, D. (2023). Open AI in education: The emergence of ChatGPT and generative AI. Education and Information Technologies, 28, 1–20.
24. Nature Research Intelligence. (2024). Virtual reality and augmented reality in molecular visualization and interactive modeling. https://www.nature.com/research-intelligence/nri- topic-summaries/virtual-reality-and-augmented-reality-in-molecular-virsualization-and- interactive-modelling-micro-90053
25. Nguyen, T.N, & Turoung, H.T. (2025). Trends and emerging themes in the effects of generative artificial intelligence in education: A systematic Review. Eurasia Journal of Mathematics, Science, and Technology Education, 21(4), em2613. https://doi.org/10.29333/ejmste/16124

26. Nwafor, S. C, & Tsakeni, M. (2025). Examining the integration of artificial intelligence in chemistry education programmes: challenges and prospects. African Journal of Science, Technology, Mathematics, and Education (AJSTME). 11(2), 219-228.
27. Offiah, L. E. (2024). Utilization of AI-based tools and students' academic engagement in secondary school chemistry. AJSTME. https://www.ajstme.com.ng/admin/img/paper/Paper%2039.pdf.
28. Ogunbanjo, S.S., Ayuba, Yohanna, D., Odofin, B, and Ogbaini, A.C. (2025). Adapting Artificial Intelligence (AI) Models to The Nigerian Context in Education: Challenges and Opportunities, IRE Journals, 8(3): 699-712. https://doi.org/10.64388/IREV913-1710553- 159
29. Olubunmi, O. A., & Aarinola, A. M. (2022). Implementation of chemistry curriculum in Nigeria: Challenges for the 21st century. World Journal of Educational Research, 9(2), 36–51. https://doi.org/10.22158/wjer.v9n2p36.
30. Oyetoro, I. P., & Okebukola, P. A. (2023). Artificial intelligence and the future of science education in Nigeria. African Journal of Science, Technology, Mathematics and Education, 13(1), 55–70.
31. Paula de Jesus. (2025). The Best AI Tools for Chemistry Research and Formulation. www.chempilot.com/blog/chemistry-research-and-formulation.
32. Russell, S., & Norvig, P. (2022). Artificial intelligence: A modern approach. A leading textbook defining AI’s evolution, models, and applications (4th ed.) Pearson.
33. Sanusi, I. T. (2025). Artificial intelligence in school education: The case of Nigeria. Revue internationale d’éducation de Sèvres (HS-4). https://doi.org/10.4000/146vp.
34. Sokoto State study authors. (2025). Teachers’ awareness and perception on utilization of artificial intelligence as tools for teaching and learning of chemistry at secondary schools in Sokoto State. RIJESSU, 3.
35. Triplett, W. J. (2023). Artificial intelligence in STEM education. Cyber security and Innovative Technology Journal, 1(1), 23-29.
36. Wang, S., Wang, F., Zhu, Z., Wang, J., Tran, T., & Du, Z. (2024). Artificial intelligence in education: A systematic literature review. Expert Systems with Applications, 252, Article 124167. https://doi.org/10.1016/j.eswa.2024.124167.
37. West African Examinations Council. (2019). Chemistry — WASSCE resources & examiner reports. https://www.waeconline.org.ng/e-learning/Chemistry/chemmain.html.
38. Xu, Y., Lin, K., & He, J. (2024). Deep learning applications in chemical reaction prediction and molecular design. Nature Communications, 15, 1125.
39. Zhou, Y., Chen, X., & Lin, J. (2024). Advances in generative AI and its implications for STEM Learning. Journal of Educational Technology, 18(3), 145-162.