

IMPACT OF AI-DRIVEN SIMULATIONS ON TEACHING CHEMISTRY AND SCIENTIFIC CONCEPTS IN PUBLIC SECONDARY SCHOOLS IN EKPOMA, EDO STATE, NIGERIA

¹BRAIMAH, G. O., & ²ITAMAN, P. I.

¹Department of Science Education and Instructional Technology, Faculty of Education
Ambrose Alli University, Ekpoma, Edo State

Tel: +2348136234545

ohisbraimah75@gmail.com

²Department of Biology, Edo State College of Education
Igueben, Edo State

itamanpati@gmail.com

Abstract

This study examined the perceived impact of AI-driven simulations on the teaching of Chemistry and students' understanding of scientific concepts in public secondary schools in Ekpoma, Edo State, Nigeria. The study adopted a descriptive survey design involving 210 respondents, comprising 180 Senior Secondary II Chemistry students and 30 Chemistry teachers selected through simple random sampling. Data were collected using a researcher-developed instrument titled AI-Driven Simulations and Chemistry Teaching Questionnaire (AIDSCTQ), which recorded a Cronbach's alpha reliability coefficient of .86. Mean and standard deviation were used to analyze the data, with a criterion mean of 2.50. The findings showed that respondents perceived AI-driven simulations as positively influencing Chemistry teaching and students' understanding of scientific concepts (grand mean = 2.95). The strongest perceived benefit was the simplification of difficult Chemistry concepts (mean = 3.26), followed by improved understanding of scientific concepts (mean = 3.14). However, perceived effects on knowledge retention and teachers' classroom effectiveness were comparatively moderate. Major implementation barriers included inadequate ICT facilities (mean = 3.31), poor electricity supply (mean = 3.20), inadequate internet connectivity (mean = 3.09), insufficient government support, limited teacher training and the cost of digital facilities (grand mean = 3.01). The study concludes that AI-supported simulation can strengthen Chemistry instruction when implemented as a complement to teacher-led and laboratory-based learning. It recommends sustained investment in digital infrastructure, teacher professional development, curriculum alignment and responsible, human-centred use of AI-enabled learning technologies.

Keywords: Artificial Intelligence in Education, AI-Driven Simulation, Chemistry Instruction, Conceptual Understanding, Digital Pedagogy, Secondary Science Education, Virtual Laboratory

Introduction

Chemistry occupies a central position in Nigerian secondary education because it provides foundational knowledge for medicine, pharmacy, engineering, agriculture, environmental management and several technology-oriented occupations. It also contributes to the development of scientific literacy and the human capital required for national science, technology and innovation. Yet, learning Chemistry remains challenging for many secondary school students, particularly when instruction requires learners to connect observable phenomena with invisible molecular and sub-microscopic processes. Evidence from the West African Examinations Council (WAEC) continues to point to weaknesses in conceptual reasoning and the application of Chemistry principles, while broader research identifies inadequate practical resources, teacher-centred pedagogy and unequal access to educational technologies as persistent concerns (West African Examinations Council [WAEC], 2023; Almasri, 2024).

Many Chemistry concepts are inherently abstract. Atomic structure, chemical bonding, electrolysis, reaction kinetics, molecular geometry and chemical equilibrium require learners to reason about processes that cannot always be directly observed. Where classroom instruction relies

mainly on verbal explanation and static representations, students may memorize rules without developing robust mental models. Mayer's (2021) Cognitive Theory of Multimedia Learning (CTML) explains why appropriately designed combinations of words, images, animation and interaction can support meaningful learning: learners must actively select relevant information, organize it into coherent representations and integrate those representations with prior knowledge.

Artificial intelligence (AI) has expanded the range of digital learning environments available to teachers and learners. In education, AI can support adaptive feedback, personalized learning, automated assessment and intelligent tutoring, while simulation technologies can provide interactive representations of phenomena that are difficult, expensive or unsafe to reproduce physically (UNESCO, 2021; Almasri, 2024). In Chemistry, AI-enabled or intelligent simulation environments may allow learners to manipulate variables, visualize molecular processes, test hypotheses, receive feedback and repeat activities without consuming physical laboratory materials. Importantly, not every digital simulation is itself an AI system. Accordingly, this study uses the term AI-driven simulations to refer to simulation-based instructional environments that incorporate intelligent, adaptive or AI-supported functions; evidence from conventional computer and PhET simulations is treated as closely related simulation evidence rather than automatically classified as AI.

Research evidence supports the educational value of simulation-based learning. Oladejo et al. (2021) found that senior secondary students taught Chemistry with computer simulation performed better than those taught through a traditional lecture approach, including on higher-order cognitive outcomes. Ibitomi et al. (2022) similarly reported improved performance in chemical equations among students exposed to computer simulation. Ibrahim et al. (2025) found that PhET simulation improved students' performance in selected Chemistry content and reported stronger outcomes for the simulation group. These findings are consistent with the broader literature showing that AI and simulation technologies can strengthen engagement, conceptual learning and access to interactive representations in science education (Almasri, 2024; Iyamuremye et al., 2024).

Within Nigeria, however, the promise of AI-enabled science instruction is constrained by unequal technological readiness. Bali et al. (2024) observed that many Nigerian educational institutions have yet to take full advantage of AI because of infrastructural and technological limitations. In Chemistry education specifically, Bugaje and Madaki (2025) identified computer simulations, virtual laboratories, personalized learning and automated assessment among emerging AI-related applications, while also highlighting challenges relating to resources, teacher competence, data quality, model validation, ethics and security. Ikokwu (2026) found moderate integration of AI in Chemistry teaching and learning in colleges of education in South-East Nigeria and identified high costs, insufficient resources and inadequate training as important barriers. Ugosor et al. (2026) likewise identified infrastructure, teacher capacity, equity, ethics and regulatory gaps as major considerations for AI integration in Nigerian Chemistry education.

The situation warrants particular attention in public secondary schools in Ekpoma, Esan West Local Government Area of Edo State. The setting combines a strong educational presence with the practical constraints experienced by many public schools, including limited access to functional laboratories, digital devices, reliable electricity and high-quality internet connectivity. Under such conditions, simulation-based technologies may provide a useful supplementary route for representing abstract Chemistry processes and extending learning opportunities beyond what can be achieved through physical laboratory resources alone. However, technology should not be treated as a substitute for teachers or authentic laboratory experiences. UNESCO (2023) emphasized that educational technologies should be used where they are relevant, equitable, sustainable and demonstrably supportive of learning, while preserving the central role of human interaction.

Although existing studies provide encouraging evidence, important contextual and methodological gaps remain. Much of the Nigerian evidence has been generated in locations such as Ogun, Kwara and South-East Nigeria, and several studies have focused on academic achievement following experimental exposure to conventional computer simulations. Less attention has been given to public secondary schools in Ekpoma, where infrastructural conditions may shape

whether AI-supported simulation can be meaningfully implemented. There is also limited local evidence that considers both perceived instructional benefits and implementation barriers in the same study. This study therefore investigates the perceived impact of AI-driven simulations on Chemistry teaching and students' understanding of scientific concepts in public secondary schools in Ekpoma, Edo State, while also identifying the major challenges that may limit effective implementation.

Statement of the Problem

Chemistry education requires learners to understand relationships among observable laboratory phenomena, symbolic representations and microscopic explanations. In many public secondary schools, these learning demands are complicated by inadequate laboratory resources, large classes, limited instructional time and uneven access to digital technologies. The result can be a gap between what students are expected to understand and what classroom resources allow teachers to demonstrate. At the same time, AI-supported educational technologies and interactive simulations are increasingly promoted as tools for visualization, adaptive support and learner engagement.

The problem, therefore, is not simply whether AI exists as an educational innovation, but whether AI-driven simulation can provide meaningful instructional value within the resource realities of public secondary schools in Ekpoma. Without local evidence, claims about its usefulness may remain largely aspirational. A study focused on Ekpoma is justified because it can generate context-specific evidence on two connected issues: the instructional value perceived by the principal users of Chemistry education and the practical barriers that may prevent that value from being realized. The inclusion of both teachers and students strengthens the study by bringing together pedagogical and learner perspectives.

The study is further justified by the need to distinguish technology enthusiasm from evidence-informed implementation. A descriptive survey cannot establish a causal treatment effect; it can, however, document how teachers and students perceive the instructional contribution and feasibility of AI-driven simulations within their actual school environment. This distinction is important for responsible educational decision-making and prevents the findings from being interpreted as proof that AI alone causes improved achievement. The study consequently contributes contextual evidence for school administrators, curriculum planners and policymakers considering phased, human-centred adoption of AI-enabled simulation in Chemistry education.

Theoretical and Empirical Literature Review

Cognitive Theory of Multimedia Learning

This study is anchored on Mayer's Cognitive Theory of Multimedia Learning (CTML). The theoretical foundation should not be attributed to 2021 as the year in which the theory was first developed. Rather, Mayer's 2021 third edition of *Multimedia Learning* provides the current authoritative formulation and synthesis of the theory used in this study. CTML explains how learners process information from words and pictures through separate but interacting representational channels, subject to limited cognitive capacity and requiring active cognitive processing. Meaningful learning occurs when learners select relevant information, organize it into coherent verbal and pictorial models and integrate those models with prior knowledge (Mayer, 2021).

CTML is directly relevant to Chemistry because many Chemistry concepts require learners to move between macroscopic observations, symbolic equations and sub-microscopic representations. AI-enabled simulations can provide dynamic visualizations, interactive manipulation, multiple representations and immediate feedback that may help learners construct more coherent mental models. From a CTML perspective, however, multimedia is not automatically beneficial. Poorly designed animation, excessive information or unnecessary interaction can increase cognitive load. Thus, the value of AI-driven simulation depends on purposeful instructional design and teacher guidance rather than technological novelty alone.

The theoretical linkage guiding this study is therefore straightforward: AI-driven simulation provides multimedia and interactive representations; these representations can support the selection and organization of relevant information; improved integration of representations with prior knowledge can strengthen conceptual understanding; and teacher guidance can help learners interpret simulation outputs correctly. The framework also explains why simulations should complement rather than replace teacher explanation and physical laboratory activities. This theoretical position is consistent with UNESCO's (2023) emphasized on evidence-based, learner-centred technology use and with recent reviews of AI in science and Chemistry education (Almasri, 2024; Iyamuremye et al., 2024).

Empirical Review

Oladejo et al. (2021) investigated the use of computer simulation in senior secondary Chemistry in Ogun State using a quasi-experimental design. Students exposed to computer simulation outperformed those taught through the traditional lecture method, including on higher-order cognitive outcomes. The study provides relevant Nigerian evidence that simulation can support Chemistry learning, although it involved conventional computer simulation rather than an explicitly AI-driven platform.

Ibitomi et al. (2022) examined computer simulation in learning chemical equations among senior secondary students in Offa, Nigeria. Their quasi-experimental study reported differences in performance favouring students exposed to computer simulation. The relevance to the present study lies in the capacity of simulation to make otherwise invisible chemical processes more representationally accessible, while the methodological difference reinforces the need to distinguish simulation technology from AI technology.

Ibrahim et al. (2025) examined PhET simulation as a platform for improving students' performance in Chemistry content among senior secondary students in Kwara State. Their findings indicated improved performance and retention among students exposed to the simulation. PhET is appropriately treated here as evidence for simulation-based Chemistry instruction; it should not be represented as an AI system merely because it is digital or interactive.

Adeyele (2024) reported that simulation games, blended learning and interactive multimedia can produce differential learning outcomes in Basic Science, demonstrating the broader instructional value of interactive representations. Although the participants were younger Basic Science learners rather than senior secondary Chemistry students, the study reinforces the principle that multimedia effectiveness depends on instructional design and learner context.

At the broader AI level, Almasri (2024) synthesized empirical research on AI in science education and reported evidence of benefits across learning environments, assessment, student support and other instructional functions, while also identifying contextual and implementation challenges. Iyamuremye et al. (2024) similarly reviewed AI and machine learning in Chemistry education and identified opportunities for personalized learning, active learning, virtual laboratories and real-time support, alongside concerns relating to infrastructure, ethics, validation and teacher readiness.

Nigerian studies published more recently strengthen the contextual argument. Bugaje and Madaki (2025) identified computer simulation, virtual laboratory, personalized learning and automated assessment as important AI-related applications in Chemistry education and highlighted the need for teacher professional development. Ikokuwu (2026) found moderate AI integration in Chemistry education in South-East Nigerian colleges of education, with inadequate resources, high costs and poor training among the major challenges. Ugosor et al. (2026) similarly argued that AI has potential to strengthen Chemistry education in Nigeria but that infrastructure, teacher capacity, equity, ethics and regulatory preparedness must be addressed.

Taken together, the empirical literature supports the plausibility of simulation and AI-supported tools for Chemistry learning, but it also reveals a clear evidence gap. Much of the available evidence either examines conventional simulations under experimental conditions or addresses AI

at a broad conceptual level. There is comparatively little evidence from public secondary schools in Ekpoma that simultaneously considers perceived instructional benefits and implementation barriers. The present study addresses this gap by combining teachers' and students' perceptions within a specific local context.

Research Questions

1. To what extent do AI-driven simulations improve the teaching of Chemistry and students' understanding of scientific concepts in public secondary schools in Ekpoma, Edo State?
2. What challenges influence the effective use of AI-driven simulations in teaching Chemistry in public secondary schools in Ekpoma, Edo State?

Methods

This study adopted a descriptive survey research design. The design was appropriate because the study sought to document respondents' perceptions of the instructional contribution and implementation challenges of AI-driven simulations without manipulating an intervention or assigning participants to treatment groups. This methodological choice is important because the study's findings concern perceived impact rather than a causal treatment effect.

The study was conducted in public secondary schools in Ekpoma, within Esan West Local Government Area of Edo State, Nigeria. The population comprised Senior Secondary School Two (SS II) students offering Chemistry and Chemistry teachers in public secondary schools in the study area. SS II students were selected because they had encountered several fundamental and abstract Chemistry concepts and could therefore provide informed responses regarding simulation-supported learning.

A sample of 210 respondents, comprising 180 SS II Chemistry students and 30 Chemistry teachers, was selected through simple random sampling. The inclusion of both teachers and students provided complementary perspectives on instructional usefulness and implementation constraints. The sampling procedure was intended to reduce selection bias and provide a reasonable representation of the study population.

Data were collected using a researcher-developed instrument titled AI-Driven Simulations and Chemistry Teaching Questionnaire (AIDSCTQ). The instrument was structured into three sections: Section A collected demographic information; Section B measured perceived instructional benefits of AI-driven simulations for Chemistry teaching and scientific-concept understanding; and Section C measured challenges affecting implementation. Items were rated on a four-point scale of Strongly Agree (4), Agree (3), Disagree (2) and Strongly Disagree (1).

Face and content validity were established by three experts: two specialists in Science Education and one specialist in Educational Technology from Ambrose Alli University, Ekpoma. Their observations were incorporated into the final instrument. Reliability was established through a pilot study involving 20 respondents from a public secondary school outside the study area but with similar characteristics. Cronbach's alpha produced a reliability coefficient of .86, indicating high internal consistency.

The questionnaires were administered personally by the researcher with the assistance of two trained research assistants, and all administered copies were retrieved. Data were analyzed using mean and standard deviation. A criterion mean of 2.50 was used for decision-making: mean scores of 2.50 and above were interpreted as agreement, whereas mean scores below 2.50 were interpreted as disagreement. Because the study is descriptive, the results are interpreted as respondents' perceived impact and perceived barriers rather than evidence of causal effects.

Results

Research Question 1: To what extent do AI-driven simulations improve the teaching of Chemistry and students' understanding of scientific concepts in public secondary schools in Ekpoma, Edo State?

Table 1

Mean Ratings on the Impact of AI-Driven Simulations on the Teaching of Chemistry and Students' Understanding of Scientific Concepts (N = 210)

S/N	Item	Mean ($\bar{x}$)	SD	Rank	Decision
1	AI-driven simulations make difficult Chemistry concepts easier to understand.	3.26	.74	1 st	Agree
2	AI-driven simulations improve students' understanding of scientific concepts.	3.14	.81	2 nd	Agree
3	Virtual simulations improve students' participation during Chemistry lessons.	3.02	.85	3 rd	Agree
4	AI simulations increase students' interest in learning Chemistry.	2.91	.89	4 th	Agree
5	Students remember Chemistry concepts better after using AI simulations.	2.76	.93	5 th	Agree
6	AI-driven simulations improve teachers' classroom effectiveness.	2.58	.97	6 th	Agree
Grand Mean		2.95	.87		Agree

The results in Table 1 show an overall favourable perception of AI-driven simulations, with a grand mean of 2.95, above the criterion mean of 2.50. The highest-rated item was the view that AI-driven simulations make difficult Chemistry concepts easier to understand (mean = 3.26), followed by improved understanding of scientific concepts (mean = 3.14). Participation during Chemistry lessons also received a relatively high rating (mean = 3.02). However, the lower ratings for retention (mean = 2.76) and teachers' classroom effectiveness (mean = 2.58) suggest that respondents did not perceive the benefits as uniformly strong across all outcomes. The pattern is therefore best interpreted as positive but moderate perceived influence rather than proof of a causal effect.

Research Question 2: What challenges influence the effective use of AI-driven simulations in teaching Chemistry in public secondary schools in Ekpoma, Edo State?

Table 2

Mean Ratings on Challenges Affecting the Use of AI-Driven Simulations in Teaching Chemistry (N = 210)

S/N	Item	Mean($\bar{x}$)	SD	Rank	Decision
1	Most public secondary schools lack adequate ICT facilities.	3.31	.71	1 st	Agree
2	Poor electricity supply affects the use of AI technologies.	3.20	.76	2 nd	Agree
3	Internet connectivity is inadequate in many schools.	3.09	.82	3 rd	Agree
4	Government support for AI integration remains inadequate.	2.96	.88	4 th	Agree
5	Many teachers require additional training on AI applications.	2.82	.91	5 th	Agree
6	The cost of digital facilities limits AI implementation.	2.67	.95	6 th	Agree
Grand Mean		3.01	.84		Agree

The findings in Table 2 indicate that implementation barriers were consistently perceived as important, with a grand mean of 3.01. Inadequate ICT facilities ranked first (mean = 3.31), followed by poor electricity supply (mean = 3.20) and inadequate internet connectivity (mean = 3.09). Government support, teacher training and the cost of digital facilities were also rated above the criterion mean. The results suggest that the feasibility of AI-driven simulation in the study area

depends first on basic technological readiness and teacher capacity rather than on the availability of AI software alone.

Discussion of Findings

The first finding indicates that respondents perceived AI-driven simulations as beneficial to Chemistry teaching and students' understanding of scientific concepts. The strongest perceived benefit was the simplification of difficult Chemistry concepts, followed by improved conceptual understanding and classroom participation. This pattern is consistent with CTML because dynamic visual and interactive representations can help learners organize information and connect it with prior knowledge (Mayer, 2021). It is also consistent with evidence from Nigerian simulation studies, including Oladejo et al. (2021), Ibitomi et al. (2022) and Ibrahim et al. (2025), which reported improved learning outcomes following exposure to computer or PhET simulations.

The finding also aligns with broader reviews of AI and science education. Almasri (2024) found evidence that AI-supported technologies can contribute to learning outcomes, engagement and instructional support across science education contexts, while Iyamuremye et al. (2024) identified virtual laboratories, personalized learning and intelligent support as promising applications in Chemistry. The present result therefore has theoretical and empirical support. Nevertheless, the descriptive design means that the finding should be stated as a perceived positive influence rather than a demonstrated causal impact.

The relatively moderate ratings for retention and teacher effectiveness are important. They suggest that simulation does not automatically produce deep or durable learning. Learners still require purposeful tasks, teacher explanation, opportunities for retrieval and practice, and appropriate assessment. Similarly, a digital tool can enhance a teacher's repertoire without necessarily making classroom instruction effective in the absence of pedagogical competence. This interpretation is consistent with UNESCO's (2023) position that educational technology should complement, rather than displace, human interaction and sound pedagogy.

The second finding shows that inadequate ICT facilities, electricity and internet connectivity constitute the most prominent barriers. This result closely reflects the Nigerian context described by Bali et al. (2024), who identified infrastructural and technological constraints as important limitations on AI adoption. It also agrees with Bugaje and Madaki (2025), who highlighted resource limitations and teacher competence, and with Ikokwu (2026), who reported high costs, insufficient resources and inadequate training as major barriers to AI integration in Chemistry education. Ugosor et al. (2026) similarly emphasized infrastructure, teacher capacity, equity, ethics and policy readiness.

The implication is that schools should not pursue AI adoption as a stand-alone procurement exercise. Devices, connectivity and electricity must be accompanied by teacher development, curriculum alignment, technical support, clear guidance on responsible use and opportunities for learners to engage critically with AI-generated outputs. In resource-constrained schools, phased implementation using low-bandwidth or offline-capable simulations may be more realistic than immediate dependence on sophisticated cloud-based systems. At the same time, simulation should complement physical Chemistry practicals because virtual environments cannot fully reproduce the psychomotor, safety and collaborative competencies developed through real laboratory work.

Conclusion and Recommendations

This study examined the perceived impact of AI-driven simulations on Chemistry teaching and students' understanding of scientific concepts in public secondary schools in Ekpoma, Edo State. The respondents reported a generally positive perceived influence, particularly in simplifying difficult Chemistry concepts, supporting conceptual understanding and increasing classroom participation. However, the perceived benefits were moderate for knowledge retention and teachers' classroom effectiveness. The study also identified inadequate ICT facilities, poor electricity supply, weak internet connectivity, limited government support, insufficient teacher

training and the cost of digital facilities as important barriers. The central conclusion is that AI-driven simulations have meaningful potential as a complementary instructional resource, but their educational value depends on infrastructure, teacher competence, curriculum alignment and responsible pedagogical use. Given the descriptive design, the findings should not be interpreted as evidence of a causal treatment effect.

1. Government and relevant education authorities should improve the basic digital infrastructure of public secondary schools, including functional ICT facilities, reliable electricity and appropriate internet connectivity.
2. Chemistry teachers should receive sustained professional development on AI literacy, simulation-based pedagogy, verification of AI-generated content, digital ethics and the integration of simulation with existing Chemistry curriculum requirements.
3. School administrators should adopt AI-driven simulations as complementary resources alongside teacher-led instruction and physical laboratory practicals rather than as substitutes for teachers or authentic laboratory experiences.
4. Curriculum planners and teacher-education institutions should provide practical guidance on the pedagogically appropriate use of AI-enabled simulation, including activities that connect macroscopic observations, symbolic representations and sub-microscopic Chemistry concepts.
5. Schools should consider phased implementation strategies, including low-bandwidth and offline-capable simulation resources, where full digital infrastructure is not yet available.
6. Future researchers should employ quasi-experimental, experimental or mixed-methods designs to determine the causal effects of specific AI-enabled simulation platforms on Chemistry achievement, retention, scientific reasoning and practical skills over longer periods.

References

- Adeyele, V. O. (2024). Relative effectiveness of simulation games, blended learning, and interactive multimedia in basic science achievement of varying ability pupils. *Education and Information Technologies*, 29, 13653–13677. <https://doi.org/10.1007/s10639-023-12414-z>
- Almasri, F. (2024). Exploring the impact of artificial intelligence in teaching and learning of science: A systematic review of empirical research. *Research in Science Education*, 54, 977–997. <https://doi.org/10.1007/s11165-024-10176-3>
- Bali, B., Garba, E. J., Ahmadu, A. S., Takwate, K. T., & Malgwi, Y. M. (2024). Analysis of emerging trends in artificial intelligence for education in Nigeria. *Discover Artificial Intelligence*, 4, Article 110. <https://doi.org/10.1007/s44163-024-00163-y>
- Bugaje, B. M., & Madaki, S. M. (2025). Qualitative study on integration of artificial intelligence tools in Chemistry education programs and research for sustainable development in Nigeria. *Federal University Gusau Faculty of Education Journal*, 5(4), 168–174. <https://doi.org/10.64348/zije.2025104>
- Ibitomi, O. O., Oyelekan, O. S., & Olorundare, A. S. (2022). The effect of computer simulation on student performance in high school Chemistry learning on chemical equations. *Indonesian Journal of Science and Mathematics Education*, 5(3), 341–358. <https://doi.org/10.24042/ij sme.v5i3.12071>
- Ibrahim, A., Bolaji, H. O., & Oyeyemi, W. T. (2025). PhET simulation: A platform to improve students' performance in Chemistry content. *Journal of Chemistry Education and Integration*, 4(1), 1–14. <https://doi.org/10.24014/jcei.v4i1.32555>
- Ikokwu, P. I. (2026). Integration of artificial intelligence (AI) for effective teaching and learning of Chemistry in colleges of education in South-East Nigeria. *Innovations in Science Education and Practice*, 3(1), 30–39. <https://doi.org/10.20961/t781pj75>
- Iyamuremye, A., Niyonzima, F. N., Mukiza, J., Twagilimana, I., Nyirahabimana, P., Nsengimana, T., Habiyaemye, J. D., Habimana, O., & Nsabayezu, E. (2024). Utilization of

artificial intelligence and machine learning in Chemistry education: A critical review. *Discover Education*, 3, Article 95. <https://doi.org/10.1007/s44217-024-00197-5>

Mayer, R. E. (2021). *Multimedia learning* (3rd ed.). Cambridge University Press. <https://doi.org/10.1017/9781316941355>

Oladejo, A. I., Akinola, V. O., & Nwaboku, N. C. (2021). Teaching Chemistry with computer simulation: Would senior school students perform better? *Crawford Journal of Multidisciplinary Research*, 2(2), 16–32.

Ugosor, T. P., Kaana, A., & Ukpoko, W. U. (2026). Chemistry education and artificial intelligence (AI) in the 21st century Nigeria: Prospects, challenges, and the way forward. A review article. *International Journal of Research and Innovation in Social Science*, 9(12), 1315–1334. <https://doi.org/10.47772/IJRISS.2025.91200097>

UNESCO. (2021). *AI and education: Guidance for policy-makers*. UNESCO. <https://doi.org/10.54675/PCSP7350>

UNESCO. (2023). *Global education monitoring report 2023: Technology in education—A tool on whose terms?* UNESCO. <https://doi.org/10.54676/UZQV8501>

WAEC. (2023). *Chief examiners' reports on the West African Senior School Certificate Examination (WASSCE): Chemistry*. West African Examinations Council.