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EFFECT OF ARTIFICIAL INTELLIGENCE-EMBEDDED INSTRUCTIONAL PEDAGOGY ON STUDENTS' ACADEMIC ACHIEVEMENT IN CHEMISTRY IN SECONDARY SCHOOLS IN ENUGU STATE

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ABSTRACT

This study examined the effect of Artificial Intelligence-embedded instructional pedagogy on students' academic achievement in chemistry in secondary schools in Enugu State, Nigeria. The quasi-experimental research design was adopted. The study was guided by three research questions and three null hypotheses. A sample of 178 SS2 chemistry students was drawn from 4 public secondary schools in Enugu State using the simple random sampling technique. Data were collected using the Chemistry Achievement Test (CAT), which was validated by experts in Chemistry Education and Measurement & Evaluation. A reliability index of 0.81 was obtained using Kuder-Richardson's formula 20, which shows that the CAT was reliable. Mean and standard deviation were used to answer the research questions, while ANCOVA was used to test the hypotheses at a 0.05 level of significance. Findings revealed that Students taught Chemistry using the AI-embedded instructional pedagogy had significantly better performance than those taught with conventional methods. Moreover, no significant gender difference existed in the students' academic achievement when exposed to AI-embedded instructional pedagogy. Furthermore, there was no significant interaction effect of methods and gender on the students' academic achievement in chemistry. Based on the findings, it was recommended that the Enugu State Ministry of Education should partner with EdTech firms to train Chemistry teachers on AI-driven simulations, adaptive tutoring, and virtual labs like PhET and Labster to improve conceptual understanding and achievement of students.

Keywords: Academic Achievement, Artificial Intelligence, Chemistry, Innovative Pedagogies, Secondary School

Introduction

Education globally is being reshaped by Artificial Intelligence, with UNESCO identifying AI as a key enabler of SDG 4 for inclusive and equitable quality education. In Chemistry, abstract concepts like molecular geometry, reaction kinetics, and electrochemistry often pose comprehension challenges to secondary learners (Okeke & Eze, 2024). These challenges contribute significantly to poor performance and low enrolment in science-related careers across Sub-Saharan Africa (Udu, 2017; Nwagbo, 2009; Ahmed & Abimbola, 2011; UNESCO, 2021; World Bank, 2023). The integration of AI offers a pathway to demystify such content by translating symbolic and sub-microscopic representations into accessible visual formats (Udu, 2020). Consequently, education stakeholders now advocate for AI-driven interventions to reduce cognitive barriers and improve conceptual mastery in Chemistry (Nwachukwu & Ogbu, 2025).

AI in education refers to computer systems that mimic human cognitive functions to adapt content, assess learners, and provide feedback in real time [Holmes et al., 2023]. Innovative pedagogies involve student-centered approaches like flipped classrooms, gamification, project-based learning, and simulation-based inquiry, which become more powerful when driven by AI (Oke & Fernandes, 2024). When AI is embedded in these pedagogies, it enables differentiation by diagnosing learner misconceptions and automatically adjusting task complexity to match individual proficiency levels. This adaptive capability transforms the teacher's role from knowledge dispenser to learning facilitator. Research evidence from Nigeria shows that AI-enhanced pedagogy increases student engagement and reduces achievement gaps between high- and low-performing learners (Ugwuanyi et al., 2024).

AI-driven instructional pedagogies such as intelligent tutoring systems, virtual laboratories, predictive analytics, and natural language processing now offer personalized, visual, and interactive learning experiences that bridge these gaps. According to Nwosu et al. (2024), AI tools like PhET Interactive Simulations and IBM Watson Tutor have improved STEM achievement by 21% in sub-Saharan classrooms when teachers possess adequate pedagogical competence. Such gains are attributed to the affordances of real-time scaffolding and error diagnosis that conventional methods may lack. Moreover, predictive analytics can forecast at-risk students earlier, thereby allowing timely remediation before summative assessments. As a result, education ministries in several African countries are piloting AI integration frameworks to scale these benefits across public schools (Mhlanga, 2024).

In Chemistry, tools such as Labster 3D virtual labs, ChemTutor AI, and Wolfram Alpha allow students to manipulate variables, visualize reactions at the molecular level, and receive instant corrective feedback (Berber et al., 2025). These technologies align with constructivist theory by enabling active discovery rather than rote memorization. By interacting with simulations, learners test hypotheses, observe outcomes, and reconstruct mental models of chemical processes in ways that textbooks cannot provide. Furthermore, AI chatbots integrated into virtual labs offer 24/7 academic support, promoting independent study and reducing teacher workload. Evidence from

WAEC Chief Examiners' Reports (2022–2024) indicates that schools using simulation-based instruction record fewer misconceptions in practical chemistry questions (Daves, 2023).

Recent studies confirm strong links between AI-embedded instructional pedagogy and achievement. Ugwuanyi et al. (2024) reported a 26% gain in Chemistry posttest scores among Nigerian students exposed to AI simulations versus control groups. Similarly, Marr (2023) noted that adaptive AI platforms reduce misconceptions in stoichiometry by diagnosing learning gaps and adjusting task difficulty. Despite these benefits, teacher competence remains the mediating factor. Lameras & Arnab (2022) stressed that without Technological Pedagogical Knowledge (TPK), AI tools may be underutilized or misapplied, leading to no significant learning gains. WAEC Chief Examiner's Reports (2022–2024) consistently list chemistry as one of the subjects with below 50% credit pass in Enugu State, citing poor conceptual understanding and lack of practical exposure.

Persistent underperformance in chemistry may be largely attributed to inadequate instructional strategies that rely on abstract lecture methods and the absence of visualization tools to make microscopic chemical concepts accessible (Nwachukwu & Ogbu, 2025). Because concepts such as atoms, molecules and chemical bonding are invisible to learners, they struggle to construct accurate mental models, resulting in misconceptions and low achievement. Artificial intelligence addresses this foundational gap by making the "unseen" visible through simulations and molecular visualizations while providing differentiated pathways for different learners. However, the Nigerian secondary education system still relies heavily on teacher-centered, lecture-based methods with limited technological infusion (Federal Ministry of Education, 2024), and in Enugu State, despite the Smart School Initiative launched in 2023, infrastructural and capacity deficits continue to hinder AI adoption in science classrooms (Enugu State Education Board, 2025). The TPACK framework emphasizes that effective AI-embedded instruction requires teachers to blend technological, pedagogical and content knowledge (Koehler et al., 2013), yet empirical evidence linking AI pedagogy to chemistry performance remains scarce in South-East Nigeria. This study therefore investigates the impact of AI-embedded instructional pedagogy on chemistry students' academic achievement, with gender as a moderating variable, in Enugu State secondary schools.

Purpose of the Study

The purpose of the study is to:

1. Determine the effect of AI-embedded instructional pedagogy on students' academic achievement in chemistry in secondary schools in Enugu State.
2. Ascertain the influence of gender on students' academic achievement in chemistry when exposed to the AI-embedded instructional pedagogy in secondary schools in Enugu State.
3. Determine the interaction effect of teaching methods and gender on students' academic achievement in chemistry in secondary schools in Enugu State.

Research Questions

The following research questions guided the study:

1. What is the effect of AI-embedded instructional pedagogy on students' academic achievement in chemistry in secondary schools in Enugu State?
2. What is the influence of gender on students' academic achievement in chemistry when exposed to the AI-embedded instructional pedagogy in secondary schools in Enugu State?
3. What is the interaction effect of teaching methods and gender on students' academic achievement in chemistry in secondary schools in Enugu State?

Hypotheses

The following null hypotheses were formulated and tested at a 0.05 level of significance:

Ho_1: There is no statistically significant effect of AI-embedded instructional pedagogy on students' academic achievement in chemistry in secondary schools in Enugu State.

Ho_2: There is no statistically significant influence of gender on students' academic achievement in chemistry when exposed to the AI-embedded instructional pedagogy in secondary schools in Enugu State.

Ho_3: There is no statistically significant interaction effect of teaching methods and gender on students' academic achievement in chemistry in secondary schools in Enugu State.

Methodology

The study adopted the quasi-experimental design, precisely the non-equivalent, pretest-posttest control group, design. The population comprised 8,640 SS2 Chemistry students across 134 public secondary schools in Enugu State. A multistage sampling procedure was employed to ensure representativeness. First, the six education zones in Enugu State (Enugu, Agbani, Awgu, Udi, Nsukka and Obollo-Afor) were stratified, and one public secondary school was randomly selected from each zone, giving a total of 6 schools. From the 6 schools, 4 were randomly selected to represent the sample. The selected schools were randomly assigned to experimental (2 schools) and control (2 schools). In each selected school, intact SS2 chemistry classes were purposively selected to avoid disrupting the school timetable and to preserve the natural classroom ecology. This yielded a total of 240 students, experimental group 80 students (male 34, female 46) and control group 98 students (male 47, female 51).

The instrument used in this study was the Chemistry Achievement Test (CAT). The CAT was made up of 2 sections, A and B. Section A contained the bio-data of the students, while section B consisted of 40 multiple-choice items covering chemical bonding and organic chemistry, with each correct answer allocated 1 mark, while incorrect answers had 0, giving a maximum score of 40 marks. The CAT was validated by three experts and a reliability index of 0.86 was obtained using the KR-20, which shows that the instrument was reliable. Treatment lasted 4 weeks. The experimental group was taught using PhET simulations, Labster virtual labs and AI chatbot tutors integrated into daily lessons, while the control group was taught the same topics using the conventional lecture method by their regular teachers who were trained for the study. Data were

analyzed using mean and standard deviation to answer research questions, and the Analysis of Covariance (ANCOVA), with pretest as covariate to test the null hypotheses at a 0.05 level of significance. The ANCOVA helped to correct the error of initial differences arising from the non-randomization of the research subjects. These were calculated using the statistical package for the social sciences (SPSS) software.

Furthermore, the researchers made efforts to control extraneous variables such as teacher effect, subject interaction, Hawthorne effect, Novelty effect, etc. For instance, to control subject interaction, the experimental and control groups were located in different schools. Teacher effect was addressed by conducting a training conference/workshop for the teachers used for the study. While the Hawthorne effect was controlled by using the regular chemistry teachers in the schools for the experiments.

Presentation of Results

Research Question 1: What is the effect of AI-embedded instructional pedagogy on students' academic achievement in chemistry in secondary schools in Enugu State?

Table 1: Descriptive Statistics of Students' Academic Achievement when Taught Chemistry with AIEIP and CM

Method (Treatment)	N	Pre-test		Post-test		Gain Score
		Mean	SD	Mean	SD	
Experimental (AIEIP)	80	16.79	3.11	24.95	2.96	8.16
Control (CM)	98	17.00	2.37	24.00	2.32	7.00
Total/Gain Score Difference	178	16.90	2.72	24.43	2.66	1.16

Table 1 shows the pre-test and post-test mean achievement scores and the standard deviations of the experimental and control groups. The Table shows that the students in the experimental group taught with the AI-embedded instructional pedagogy had a pre-test mean score and standard deviation of 16.79 ± 3.11, with a post-test mean score and standard deviation of 24.95 ± 2.96. The result shows a mean gain score of 8.16. Similarly, the students in the control group, who were taught using the conventional method, had a pre-test mean score and standard deviation of 17.00 ± 2.37, with a post-test mean score and standard deviation of 24.00 ± 2.32. The result shows a mean gain score of 7.00. These results show that the experimental group, which was taught biology using the AI-embedded instructional pedagogy, had a higher mean achievement gain score than their counterparts in the control group, which was taught using the conventional method, with a mean achievement gain score difference of 1.16. However, it could not be determined from the Table whether the observed difference in the mean achievement gain scores of the two groups (experimental and control) was statistically significant or could be attributed to a sampling error. Therefore, the corresponding null hypothesis 1 was tested inferentially with ANCOVA statistics as shown in Table 2 below to establish the statistical significance or otherwise of the observed mean difference, to determine the effect of the instructional methods on the students' academic achievement in chemistry. Furthermore, the standard deviation score of the control group in the post-test was lower than that of their experimental group counterparts. This implies that the

achievement scores of the individual students in the control group were clustered around their sample mean more than those of the individual scores of the experimental group.

Null Hypothesis One: There is no statistically significant effect of AI-embedded instructional pedagogy on students' academic achievement in chemistry in secondary schools in Enugu State.

Table 2: Summary of ANCOVA Results of Mean Achievement Scores of Students taught Chemistry with AIEIP and CM

Tests of Between-Subjects Effects

Dependent Variable: Post-test

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	641.647[a]	4	160.41	45.20	0.00	0.51
Intercept	747.797	1	747.80	210.73	0.00	0.55
Pre-test	593.796	1	593.80	167.33	0.00	0.49
Method	49.117	1	49.12	13.84	0.00	0.07
Error	613.904	173	3.55			
Total	107464.000	178				
Corrected Total	1255.551	177				

a. R Squared = 0.51 (Adjusted R Squared = 0.50)

Table 2 summarizes the results of the Analysis of Covariance (ANCOVA) statistics conducted on the achievement tests of the experimental and control groups to compare the effect of the AI-embedded instructional pedagogy and the conventional method on students' academic achievement in chemistry, while controlling for the pre-test effect. The Table shows a statistically significant difference in the mean achievement scores of the experimental and the control groups at F (1, 173) = 13.84, $p = 0.00 < 0.05$. The partial Eta squared value of 0.07 indicates the effect size, which, when compared with Cohen's guidelines, was considered a small effect. Therefore, the null hypothesis one (Ho1), which states that there is no statistically significant effect of AI-embedded instructional pedagogy on students' academic achievement in chemistry in secondary schools in Enugu State, was rejected at a 0.05 alpha level. This implies that the observed difference in the mean academic achievement scores of the students in Table 1 above was significant. This further shows that the AI-embedded instructional pedagogy had a significant effect on the students' academic achievement in chemistry more than the conventional method in secondary schools in Enugu State.

Research Question 2: What is the influence of gender on students' academic achievement in chemistry when exposed to the AI-embedded instructional pedagogy in secondary schools in Enugu State?

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Table 3: Descriptive Statistics of the Academic Achievement of Male and Female Students taught Chemistry with the AI-embedded Instructional Pedagogy

Gender	N	Pre-test		Post-test		Gain Score
		Mean	SD	Mean	SD	
Male	34	17.12	2.93	24.91	2.99	7.79
Female	46	16.54	3.24	24.98	2.96	8.19
Total/Gain Score Difference	84	16.79	3.11	24.95	2.96	0.40

Table 3 contains the pre-test and post-test mean achievement scores and standard deviations of the male and female students in the experimental group who were taught chemistry with the AI-embedded instructional pedagogy. The Table shows further that the male students had a pre-test mean score and standard deviation of 17.12 ± 2.93, with a post-test mean score and standard deviation of 24.91 ± 2.99, and a mean achievement gain score of 7.79. On the other hand, the female students had a pre-test mean score and standard deviation of 16.54 ± 3.24, with a post-test mean score and standard deviation of 24.98 ± 2.96, and a mean gain score of 8.19. This result shows that the female students in the experimental group had a slightly higher mean achievement gain score than their male counterparts, with a numerical difference of 0.40. However, the Table did not show whether the observed numerical difference of 0.40 was statistically significant or could be attributed to error variance. Therefore, the corresponding null hypothesis 2 was inferentially tested with the Analysis of Covariance (ANCOVA) statistics as shown in the Table 4 below. Furthermore, the standard deviation score of the female students in the post-test was lower than that of their male counterparts. This implies that the achievement scores of the individual female students were clustered around their sample mean more than those of the individual scores of the male students.

Null Hypothesis Two: There is no statistically significant influence of gender on students' academic achievement in chemistry when exposed to the AI-embedded instructional pedagogy in secondary schools in Enugu State.

Table 4: Summary of ANCOVA Results of Mean Achievement Scores of Male and Female Students taught Chemistry with the AI-Embedded Instructional Pedagogy

Tests of Between-Subjects Effects

Dependent Variable: Post-test

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	380.905[a]	2	190.45	47.17	0.00	0.55
Intercept	437.158	1	437.16	108.27	0.00	0.58
Pre-test	380.819	1	380.82	94.32	0.00	0.55
Gender	4.351	1	4.35	1.08	0.30	0.01
Error	310.895	77	4.04			
Total	50492.000	80				
Corrected Total	691.800	79				

a. R Squared = 0.55 (Adjusted R Squared = 0.54)

Table 4 shows the summary of the results of the Analysis of Covariance (ANCOVA) statistics, conducted on the achievement scores of the male and female students in the experimental group taught chemistry with the AI-embedded instructional pedagogy. The Table shows further that there was no statistically significant difference in the mean achievement scores of the male and female students in the experimental group taught chemistry with the AI-embedded instructional pedagogy at F (1,77) = 1.08, $P = 0.30 > 0.05$. Therefore, the null hypothesis 2 (Ho2), which states that there is no statistically significant influence of gender on students' academic achievement in chemistry when exposed to the AI-embedded instructional pedagogy in secondary schools in Enugu State, was accepted at a 0.05 alpha level. This implies that the earlier observed slight numerical difference in the mean academic achievement scores of the male and female students, as shown in Table 3 above, was not statistically significant. This shows further that there is no statistically significant influence of gender on students' academic achievement in chemistry when exposed to the AI-embedded instructional pedagogy.

Research question 3: What is the interaction effect of teaching methods and gender on students' academic achievement in chemistry in secondary schools in Enugu State?

Table 5: Adjusted Mean Scores and Standard Error of Interaction Effect of Methods and Gender on Academic Achievement of Students in Chemistry

Dependent Variable: Post-test score

				95% Confidence Interval	
Group	Gender	Mean	Std. Error	Lower Bound	Upper Bound
Experimental	Male	24.77[a]	0.32	24.13	25.41
(AIEIP)	Female	25.22[a]	0.28	24.67	25.77
Control (CM)	Male	23.84[a]	0.28	23.29	24.38
	Female	24.02[a]	0.26	23.50	24.55

a. Covariates appearing in the model are evaluated at the following values: Pretest = 16.90.

Table 5 showcases the adjusted mean academic achievement scores and standard error to determine the interaction effect of methods and gender on the academic achievement of students in chemistry. The Table shows that the adjusted mean academic achievement score of the female students in the experimental group was higher than that of their male counterparts. Similarly, the adjusted mean academic achievement score of the female students in the control group was also higher than that of their male counterparts. However, the Table could not establish whether the interaction of methods and gender was statistically significant in affecting the academic achievement of the students in chemistry. Therefore, the corresponding null hypothesis 3 was tested inferentially with the Analysis of Covariance (ANCOVA) as shown in Table 6 below.

Null Hypothesis Three: There is no statistically significant interaction effect of teaching methods and gender on students' academic achievement in chemistry in secondary schools in Enugu State.

Table 6: Summary of One-way ANCOVA Statistics of the Interaction Effect of Methods and Gender on Students' Academic Achievement in Chemistry

Tests of Between-Subjects Effects

Dependent Variable: Post-test

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	641.65[a]	4	160.41	45.20	0.00	0.51
Intercept	747.79	1	747.79	210.73	0.00	0.55
Pretest	593.79	1	593.79	167.33	0.00	0.49
Method * Gender	0.79	1	0.79	0.22	0.64	0.00
Error	613.90	173	3.55			
Total	107464.00	178				
Corrected Total	1255.55	177				

a. R Squared = .51 (Adjusted R Squared = .50)

Table 6 presents the summary of the results of the Analysis of Covariance (ANCOVA) statistics conducted to determine the interaction effect of methods and gender on students' academic achievement in chemistry in secondary schools in Enugu State. From the Table, the results show no statistically significant interaction effect of methods and gender on the students' academic achievement in chemistry at F (1,173) = 0.22, $p = 0.64 > 0.05$. Therefore, null hypothesis three (Ho3), which states that there is no statistically significant interaction effect of teaching methods and gender on the students' academic achievement in chemistry in secondary schools in Enugu State, was rejected at the prevailing research conditions. This signifies that the interaction of methods of instruction and the students' gender did not significantly affect the students' academic achievement scores in chemistry in secondary schools in Enugu State.

Discussion of Findings

This study established that the AI-embedded instructional pedagogy significantly improved chemistry students' academic achievement in secondary schools in Enugu State. This is because the students in the experimental group recorded a significant mean gain over their control counterparts. This shows that the AI-driven visualization, interactivity, and instant feedback may have effectively demystified the perceived abstract topics such as chemical bonding and organic reaction mechanisms. This outcome aligns with constructivist principles, as learners actively construct meaning when sub-microscopic processes are animated and manipulable (Holmes et al., 2023). The result also supports cognitive load theory, since AI tools reduce extraneous cognitive load by replacing dense textual explanations with dynamic simulations that make molecular behavior visible. The finding corroborates Ugwuanyi et al., (2025) who reported that PhET virtual labs enhanced Nigerian students' science achievement by fostering concrete visualization of abstract concepts. Similarly, Mhlanga (2024) documented large effect sizes for AI-based STEM interventions across African secondary schools, confirming that adaptive and immersive technologies translate into measurable learning gains.

The results further revealed no statistically significant difference between the academic achievement of male and female students taught using the AIEIP. Although slight differences in mean scores existed, they were not significant. This finding is consistent with the studies of Udu et al. (2020), who argued that when instructional strategies encourage equal participation, gender differences in performance disappear. The gender-neutral performance observed suggests that AIEIP provides equal learning opportunities for both boys and girls. The absence of gender differences may also reflect improved female interest and participation in science in recent years, influenced by awareness campaigns and improved classroom practices.

Furthermore, the study found no significant interaction effect of teaching method and gender on students' achievement. This indicates that the effectiveness of AIEIP may not depend on gender; rather, both males and females benefited equally from the method. This finding supports the work of Udu et al. (2020), who noted that student-centered methods tend to neutralize gender effects because the use of strategies like AIEIP has been shown to improve understanding, interest, retention, and rely on cooperation, inquiry, and shared responsibilities.

Conclusion

AI-driven innovative pedagogies have a positive and significant impact on students' academic achievement in Chemistry in Enugu State. Although current teacher utilization is low, targeted professional development can bridge the gap between tool availability and classroom impact. Integrating AI into chemistry instruction is therefore essential for improving learning outcomes and achieving STEM competitiveness in secondary schools in Enugu State, in particular, and other States in general.

Recommendations

1. Enugu State Ministry of Education should organize termly TPACK-based training for chemistry teachers on AI tools like PhET, Labster, and Socratic by Google.
2. Schools should be equipped with solar-powered smart classrooms to ensure consistent access to AI virtual labs, addressing infrastructure barriers.
3. Curriculum planners should embed AI-supported project-based learning into the chemistry scheme of work to promote inquiry and collaboration.
4. Further research should explore longitudinal effects of AI pedagogies on students' interest and retention in Chemistry across South-East, Nigeria.

REFERENCES

Ahmed, M. A., & Abimbola, I. O. (2011). Influence of teaching experience and school location on biology teachers' rating of difficult concepts in biology curriculum. *Journal of Science, Technology, Mathematics and Education, 7*(1), 52–61.

Berber, S., Bruckner, M., Maurer, N., & Huwer, J. (2025). Artificial intelligence in chemistry research: Implications for teaching and learning. *Journal of Chemical Education, 102*(4), 1445–1456. https://doi.org/10.1021/acs.jchemed.4c01102.

Daves, S. (2023). How AI can deliver personalized learning and transform academic assessment. *Technology, Pedagogy and Education, 32*(4), 501–517.

Enugu State Education Board. (2025). *Smart School Initiative: 2024 annual report*. ESEB Press.

Federal Ministry of Education. (2024). *National policy on education* (6th ed.). NERDC Press.

Holmes, W., Bialik, M., & Fadel, C. (2023). *Artificial intelligence in education: Promises and implications for teaching and learning*. Center for Curriculum Redesign.

Koehler, M. J., Mishra, P., & Cain, W. (2013). What is technological pedagogical content knowledge (TPACK)? *Journal of Education, 19*(3), 13–19.

Lameras, P., & Arnab, S. (2022). Power to the teachers: An exploratory review on artificial intelligence. *Education Sciences, 12*(1), https://doi.org/10.3390/educsci12010014.

Marr, B. (2023). *The future of education: How artificial intelligence is transforming learning*. *Forbes*. https://www.forbes.com/sites/bernardmarr/

Marr, B. (2025). *How is AI used in education: Real-world examples of today and a peek into the future*. Bernard Marr & Co. https://bernardmarr.com/ai-in-education/

Mhlanga, D. (2024). The role of artificial intelligence in supporting education in Sub-Saharan Africa. *Journal of Digital Learning in Teacher Education, 40*(2), 89–104.

Nwachukwu, C. O., & Ogbu, S. (2025). WAEC chemistry performance trends in South-East Nigeria: 2020–2024. *Nigerian Journal of Science Education, 13*(1), 45–59.

Nwagbo, C. (2009). Effects of two teaching methods on the achievement in and attitude to biology of students of different levels of scientific literacy. *International Journal of Educational Research, 2*(1), 1–12.

Nwosu, K. C., Okeke, C. I., & Eze, T. (2025). TPACK and AI integration among science teachers in Nigeria. *Computers & Education, 210*, Article 104972.

Oke, A., & Fernandes, K. (2024). Gender, AI, and STEM education in Africa: Breaking the bias. *International Journal of Educational Technology in Higher Education, 21*, Article 33.

Okeke, J. U., & Eze, F. N. (2024). Students' conceptual difficulties in chemistry: Implications for virtual lab instruction. *African Journal of Chemical Education, 14*(2), 112–128.

Schneegans, S., Lewis, J., & Straza, T. (Eds.). (2021). *UNESCO science report: The race against time for smarter development*. UNESCO Publishing. https://www.unesco.org/reports/science/2021/en

Udu, D. A. (2020). Impact of Teacher Professional Development Programmes on Science Lecturers' Knowledge and Use of Modern Technologies in Teaching in Tertiary Institutions. Journal of the Nigerian Academy of Education (NAE), 16(1), 111-128.

Udu, D. A., Nmadu, S. J., Chidebe, C. U., Okechine, B. C., Anudu, A. P., & Precious, C. A. (2020). Non-randomized Trial of POGIL for Improving Undergraduates' Academic Achievement in Science Education. Universal Journal of Educational Research, 8(9), 4019 - 4027. DOI: 10.13189/ujer.2020.080927.

Udu, D. A. (2017). Effect of Cooperative Learning Instructional Strategy on Academic Retention of Senior Secondary School Students in Organic Chemistry. *African Journal of Science, Technology and Mathematics Education, University of Nigeria, Nsukka*. **3**(1), 133-146.

Ugwuanyi, C. S., Okeke, C. I., & Agugoesi, O. J. (2024). Effects of PhET simulation on secondary school students' achievement in chemistry in Nigeria. *Chemistry Education Research and Practice*, *25*(1), 201–215.

UNESCO. (2024). *AI and education: Guidance for policy-makers*. UNESCO Publishing.

West African Examinations Council. (2022–2024). *Chief examiners' reports: May/June WASSCE chemistry*. WAEC.

World Bank. (2023, September 27). *Empowering Africa's future: Prioritizing STEM skills for youth and economic prosperity*. World Bank Blogs. https://blogs.worldbank.org/en/africa/empowering-africas-future-prioritizing-stem-skills-youth-and-economic-prosperity.