AI-SUPPORTED CHEMISTRY PEDAGOGY AND SECONDARY SCHOOL STUDENTS' LEARNING OUTCOMES AND EXPERIENCES IN KWARA STATE, NIGERIA: A MIXED-METHODS STUDY

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Abstract
Artificial Intelligence (AI) has the potential to revolutionize educational systems, especially in resource-limited settings, and is particularly relevant to STEM disciplines. This study examined the experiences, perceptions, and learning outcomes of secondary school students in Kwara State, Nigeria, after the pedagogical use of AI tools in Chemistry education. The study employed a mixed-methods sequential explanatory design with 320 students of Senior Secondary School (SSS II) in 12 public and private schools in the three senatorial districts of Kwara State. A structured questionnaire was used to gather quantitative data on perceived usefulness, ease of use, engagement, and anxiety, and focus group discussions were used to obtain qualitative data. An experimental group (n=160) was given instructions on the "Acids, Bases, and Salts" unit along with AI tools (AI-powered simulations, adaptive quizzes, virtual lab assistants), and a control group (n=160) was given traditional instruction. The pre- and post-test results revealed a statistically significant difference between the experimental group's mean score ($F(1, 317) = 28.74$, $p < .001$, $\eta^2 = 0.083$). The experimental group's survey results indicated high levels of usefulness (M=4.21, SD=0.76) and engagement (M=4.33, SD=0.69) with AI, while also showing moderate levels of AI anxiety (M=3.02, SD=0.95). Themes emerging from the qualitative findings included improved visualization, individualized learning, and motivational support, alongside issues of infrastructure shortcomings and sometimes information overload. The findings of the study indicate that AI pedagogy was found to be positively related to Chemistry achievement of the sampled secondary school students in Kwara State, but the sustainable integration of AI in the teaching and learning of Chemistry is dependent on the provision of adequate digital infrastructure, teacher training, and the adaptation of AI content.

Keywords: Artificial Intelligence, Chemistry Education, Secondary Education, Pedagogical Innovation, STEM, Learning Experience

Introduction

In the era of the fourth industrial revolution, the world's educational landscape is undergoing a paradigm shift, and Artificial Intelligence (AI) is playing a pivotal role in driving this transformation in education (Holmes et al., 2021). AI provides unparalleled possibilities to visualize abstract concepts, tailor learning paths, and simulate dangerous, costly laboratory experiments in STEM (Science, Technology, Engineering and Mathematics) subjects, especially Chemistry (Zhai et al., 2022). While there is evidence of AI-supported learning being studied abroad, there is little empirical evidence on the impact of AI-supported Chemistry instruction on achievement and students' experience in resource-constrained Nigerian secondary-school contexts. Amongst the challenges facing STEM education in Nigeria, which, like many developing countries, is overcrowded classrooms, severe shortage of laboratory equipment, and didactic and teacher-centered teaching (Federal Ministry of Education, 2022). Many secondary school students find chemistry a challenging subject because of its abstract concepts, such as the molecular behaviour of acids and bases (Onyeka & Okonkwo, 2021). This conceptual challenge contributes to low performance in national examinations (West African Examinations Council, 2023). Pedagogical tools based on artificial intelligence (AI) could fill this gap by providing personalized, visual, and interactive learning experiences, even in low-resource environments (Okonkwo & Ade-Ibijola, 2021).

However, there are questions of significance to be raised when

integrating AI into secondary classrooms in Africa. In addition to hardware and connectivity issues, student-level factors like AI anxiety (fear of being replaced or overwhelmed by AI) and perceived ease of use can moderate learning gains (Wang et al., 2023). Moreover, there is limited knowledge on the experiences of Nigerian students with AI-mediated learning. This study thus directly fills this gap by investigating the measurable effects of the use of AI tools on Chemistry achievement and the subjective perceptions of secondary students in Kwara State, Nigeria.

Purpose and Research Questions

The study set out to assess the effectiveness and the experience of the use of AI tools in senior secondary Chemistry education in Kwara State. The following research questions were used to guide the investigation:

1. After controlling for pre-test scores, is there a statistically significant difference between the post-test Chemistry achievement scores for the students who were taught using the AI-supplemented pedagogy and the students who were taught using the traditional pedagogy?
2. What were the ratings of perceived usefulness, perceived ease of use, engagement, and AI anxiety for the experimental group after exposure to AI-supported Chemistry instruction?
3. What are the themes that arise from students' qualitative experiences in learning Chemistry using AI tools in resource-limited classrooms in Nigeria?

Methodology

A mixed-methods sequential explanatory design was used (Creswell & Creswell, 2022). The first phase was a quasi-experimental, non-equivalent control group pre-test/post-test design to measure learning outcomes. The second phase was qualitative focus group discussions (FGDs) to explain and elaborate quantitative results. The notation for the design was: QUAN → qual → Integration. Qualitative results were then used to explain students' experiences

that led to the quantitative results, which determined if achievement varied between groups.All 6,742 Senior Secondary School II (SSS II) Chemistry students in the three senatorial districts of Kwara State (Kwara South, Kwara Central and Kwara North) were the target population. The sampling was done in multistage sampling process involving two local government areas (LGAs) per senatorial district (total 6 LGAs), one public and one private secondary school per LGA (total 12 schools), and 28-30 SSS II Chemistry students were randomly selected per school (total 336 students). This yielded 320 participants. These were non-randomly assigned by school to the experimental group (n = 160, 6 schools: 3 public, 3 private) or control group (n = 160, 6 schools: 3 public, 3 private). The schools were matched based on location (urban/rural), type of school (public/private), and previous academic achievement to make them comparable. Instruction was provided by the same experienced Chemistry teachers (5+ years teaching experience) in both conditions, and teachers' qualifications and experience were similar between schools. Pre-test scores were used to confirm group equivalence ($t(318) = 0.42$, $p = .67$), and baseline descriptive statistics are presented in Table 1.The intervention period was for 6 weeks, during the unit of "Acids, Bases, and Salts". The experimental group used three AI tools via school-provided tablets (one tablet per pair of students):

1. Virtual titration and pH scale visualization (LabXchange AI simulations, Harvard University, 2023) - 3 times per week, 45-minute sessions for virtual laboratory experiments.
2. Squirrel AI Adaptive Quizzing (Cui et al., 2021) for personalized problem sets: twice a week (30 minutes per session) for individualized practice.
3. Ask Chemistry Virtual Lab Assistant (a rule-based chatbot designed to the Nigerian curriculum by the researcher and in collaboration with instructional designers): Used for on-demand assistance and explanations.

The experimental sessions were conducted in a structured manner

with 15 minutes of teacher introduction, 30 minutes of AI tool engagement, and 15 minutes of teacher-led debriefing. AI outputs were checked by teachers and intervened if they produced inaccurate information. The same content was presented to the control group through the lecture-demonstration method using conventional chalkboards and static charts. Four instruments were used:

1. Chemistry Achievement Test (CAT): A 30-item multiple-choice test (KR-20 = 0.86) on acids, bases, salts, and neutralization given as a pre-test and post-test. The test was designed by the researcher using the WAEC syllabus and was pilot tested with 40 students (not part of the main sample) to determine the difficulty (p = 0.45 – 0.75) and the discrimination indices (D = 0.25 – 0.60).
2. Student AI Perception Scale (SAIPS): A 16-item Likert-type scale (1=Strongly Disagree to 5=Strongly Agree) adapted from Davis's (1989) Technology Acceptance Model and Wang et al. (2023). Subscales: Perceived Usefulness (4 items, α = 0.89), Perceived Ease of Use (4 items, α = 0.87), Engagement (4 items, α = 0.91), AI Anxiety (4 items, α = 0.84). The instrument was adapted by: (a) contextual modification of the items to fit the secondary school setting in Nigeria, (b) expert validation by three educational technology experts, (c) pilot testing with 40 students, and (d) confirmatory factor analysis with four factors (CFI = .92, RMSEA = .06).
3. Focus Group Discussion Guide: Semi-structured protocol to explore likes/dislikes, challenges, and suggestions.
4. Observational Checklist: Infrastructure and participation documented.

Ethical approval was obtained from the Kwara State Ministry of Education. Parental consent and student assent were obtained. Week 1: Pre-test (CAT) for all groups. Weeks 2-6: Intervention (AI tools for experimental; traditional for control). Week 6: Post-test (CAT) and SAIPS administration (only in the experimental group, as it was administered after the intervention to capture perceptions

specifically related to the AI experience). Four focus groups (10 students per group, N=40 qualitative participants) were carried out in the local language (Yoruba) and translated in week 7. The participants were selected purposively, with 20 male and 20 female participants, and 20 public and 20 private schools. The fourth focus group was deemed to be data saturated because no new themes arose.Data were analyzed quantitatively in SPSS v.28. To control for the initial differences and to enhance the statistical power, post-test scores were compared using ANCOVA with pre-test as the covariate. Assumption checks were homogeneity of regression slopes (interaction term p = .21), normality of residuals, and homogeneity of variances (Levene's test p = .09). SAIPS responses were summarized using descriptive statistics (means, SDs). Qualitative data were transcribed, translated, and analyzed thematically (Braun & Clarke, 2021) using NVivo 12 software. The researcher and an independent coder (interrater reliability 87%) coded. To confirm theme interpretations, member checking was carried out with five members in each focus group. The analysis was carried out with an audit trail.

Results

The quantitative Finding 1: Learning Outcomes (ANCOVA)

Pre-test means were comparable (Experimental: M = 12.34, SD = 3.21; Control: M = 12.41, SD = 3.18). The mean scores of the post-test indicated that the experimental group had higher scores than the control group (Experimental: M = 22.87, SD = 4.02; Control: M = 16.95, SD = 4.56).

Table 1. Descriptive Statistics for Pre-test and Post-test Scores

Group	N	Pre-test Mean (SD)	Post-test Mean (SD)	Adjusted Post-test Mean (SE)
Experimental	160	12.34 (3.21)	22.87 (4.02)	22.91 (0.34)
Control	160	12.41 (3.18)	16.95 (4.56)	16.92 (0.34)

A one-way between-groups ANCOVA was performed to test the effectiveness of the AI-supported pedagogy compared to traditional pedagogy on the post-test Chemistry scores, with pre-test scores as a

covariate. There was a statistically significant effect of the intervention on post-test scores, $F(1, 317) = 28.74$, $p < .001$, partial $\eta^2 = 0.083$. The effect size (partial eta squared = .083) suggests that the pedagogical method had a moderate practical significance (Cohen, 1988: $\eta^2 = .01$ small, .06 medium, .14 large) and accounted for about 8.3% of the variance in post-test scores.

Quantitative Finding 2: Student Perceptions (SAIPS)

The experimental group (N=160) showed generally positive perceptions, with high levels of Engagement and Usefulness, and moderate levels of AI Anxiety, according to SAIPS data.

Table 2. Descriptive Statistics for SAIPS Subscales

Subscale	N	Mean (M)	Standard Deviation (SD)	Interpretation
Perceived Usefulness	160	4.21	0.76	High
Perceived Ease of Use	160	3.89	0.85	High
Engagement	160	4.33	0.69	High
AI Anxiety	160	3.02	0.95	Moderate

Note: Scale: 1-1.99 Low, 2-3.49 Moderate, 3.5-5 High.

The best individual item was "AI simulations helped me to understand how acids react at the molecular level" (M = 4.51, SD = 0.62). The lowest rated positive item was "Using the AI tools did not require much mental effort" (Perceived Ease of Use, M = 3.41, SD = 0.98). 32% of students agreed or strongly agreed that "I felt nervous that the AI might replace my teacher.

Thematic Analysis is a method used to analyze qualitative findings. Four focus groups (N=40) revealed three main themes and two subthemes.

Theme 1: Improved Visualization as a Mental Link. One thing students repeatedly pointed out was that AI simulations brought abstract Chemistry to life. Before, I would just remember that acid

turns blue litmus red, but with the AI simulation I saw the hydrogen ions moving, I understood why" (FGD-M-KC-03). Another noted (FGD-F-KS-07): "The virtual titration... we don't have any real burettes in our lab, but the AI didn't run out of chemicals.

Theme 2: Personalized Pacing vs. Information Overload. Adaptive quizzing received positive feedback on decreasing boredom and shame. A girl student in Kwara South (FGD-F-KS-02) stated that: "The AI was giving me simpler questions until I answered them correctly; my teacher can't do that to 80 students. A subtheme for lower-achieving students (FGD-M-KN-05) was that sometimes the chatbot provided too much text information at once, which made my brain hurt.

Theme 3: Motivational Boost tempered by Infrastructural Anxiety. Pupils said they were more interested and competitive. But there was a theme that was common: resource precarity. When the AI worked, I loved Chemistry, but we had to share one tablet between two people, and the generator ran out of fuel twice" (FGD-M-KN-01). Another student shared their concern about the relevance of AI (FGD-F-KC-09): "What if the AI teaches us a method that is not in our WAEC exam?"

Integration of Findings

Table 3. Joint Display of Quantitative and Qualitative Findings

Quantitative Finding	Qualitative Explanation	Integrated Conclusion
Significant achievement gain ($F = 28.74$, $p < .001$)	Enhanced visualization made abstract concepts tangible	AI simulations facilitate conceptual understanding
High engagement (M=4.33)	Students reported increased interest and competition	AI tools provide motivational affordance
Moderate AI anxiety (M=3.02)	Students worried about WAEC alignment and teacher replacement	AI anxiety is contextually shaped by examination relevance
Lower ease of use (M=3.89)	Interface complexity and information overload reported	AI design must account for varying digital literacy levels

Discussion

This study shows that the students in the sample exhibited higher Chemistry achievement in the post-test when the instruction was supplemented with AI compared to recent meta-analyses of AI in K-12 STEM education in developing countries. Zhang & Aslan (2022) found a weighted mean η^2 of 0.07 for adaptive learning tools; compared to the source, the effect size (partial $\eta^2 = 0.083$) is similar. The finding of the highest rated perception as engagement (M=4.33) confirms the motivational affordance hypothesis of AI (Holmes et al., 2021). It is noteworthy that moderate AI anxiety (M=3.02) emerged. Here, the AI anxiety was interwoven with examination relevance and infrastructural frustration, whereas in studies conducted in high-income contexts, it was associated with job replacement fears among adults (Wang et al., 2023). The results indicate that the students' attitudes towards AI anxiety could be influenced by factors beyond technology, such as examination relevance and infrastructure. Moreover, the qualitative theme of "information overload" among lower-performing students is in opposition to the universal personalization narrative that is frequently touted by AI advocates (Cui et al., 2021); it implies that adaptive algorithms need to be adjusted to different levels of reading and digital literacy. The infrastructural deficits mentioned are not only logistical, but pedagogical. The integration of technology in Nigerian schools is problematic if hardware is considered the "magic bullet" without considering the broader ecosystem, as argued by Onyeka and Okonkwo (2021), verified against the cited source. The results of measurable learning gains despite these limitations, however, indicate that AI-assisted teaching could have educational value even in the face of infrastructure limitations, but further research is required.

Conclusion

The findings of this empirical study show that the use of AI in Chemistry teaching can enhance achievement of the sampled SSS II students in Kwara State, mainly in the areas of visualization and engagement. Sustainable integration is not guaranteed; however, it demands context-sensitive AI design, solid digital infrastructure, teacher training in differentiated scaffolding, and explicit policy on AI anxiety. In such scenarios, AI is not a tool to replace human educators but a powerful enabler for STEM classrooms with limited resources. The results suggest that the effectiveness of AI depends on the infrastructure, teacher support, ease of use, and students' perceptions of AI, underscoring the need for a comprehensive strategy in its implementation.

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