



EFFECT OF AI-DRIVEN ADAPTIVE LEARNING PLATFORM ON SECONDARY SCHOOL STUDENTS' RETENTION IN CHEMISTRY IN ANAMBRA STATE

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Abstract

This study investigated the effect of an Artificial Intelligence-Driven Adaptive Learning Platform (AI-DALP) on secondary school students' retention in Chemistry within the Onitsha Education Zone of Anambra State, Nigeria. The study specifically assessed the difference in delayed retention between students taught using AI-DALP and those taught using the Conventional Teaching Method (CTM) after controlling for immediate posttest performance, as well as whether retention differed by gender within the adaptive learning environment. Guided by two research questions and two null hypotheses tested at the 0.05 level of significance, the study adopted a quasi-experimental non-randomised pretest–posttest control-group design. The population comprised 548 Senior Secondary School II (SS2) Chemistry students across 22 public co-educational schools. Through purposive sampling based on ICT infrastructure availability, a sample of 59 students (30 in the AI-DALP group and 29 in the CTM group) was selected. The intervention lasted six weeks, covering Oxygen, Hydrogen, and Halogens, followed by a delayed retention test administered two weeks after the posttest. Data were collected using a 50-item Chemistry Achievement Test (CAT), validated by three experts, with an internal consistency reliability coefficient of 0.82 established using the Kuder–Richardson 20 (KR-20) formula. Data were analyzed using mean, standard deviation, and Analysis of Covariance (ANCOVA) with posttest scores as the covariate. The results indicated that students exposed to AI-DALP achieved significantly higher adjusted retention mean scores than those taught via CTM after controlling for posttest performance. Additionally, no statistically significant difference was observed in retention scores between male and female students taught using AI-DALP after accounting for posttest performance. The study concluded that AI-DALP effectively enhances durable Chemistry learning among secondary school students regardless of gender.

Keywords:

Artificial Intelligence, Adaptive Learning, Chemistry Education, Delayed Retention, Secondary Education, Gender, Onitsha Education Zone.

1.1 Introduction

The ultimate purpose of education is not merely to enable learners to perform well immediately after instruction but to develop knowledge that remains accessible and usable beyond the immediate learning episode. A student may obtain a satisfactory score immediately

after instruction because recently presented information is still accessible, yet experience difficulty recalling or applying the same knowledge after some time has passed. Retention therefore provides an important indication of whether learning has endured beyond the point at which it was taught and assessed. This distinction is particularly important in Chemistry, where knowledge is cumulative and later learning often depends on concepts, principles, symbols, and procedures acquired earlier.

The concern about durable Chemistry learning is particularly relevant in the Nigerian secondary-school context. The West African Examinations Council (WAEC) Chief Examiners' Reports indicate continuing difficulties in Chemistry performance. In Anambra State, the reported raw mean score for Chemistry essay declined from 49.0 in 2021 to 45.0 in 2022 and further to 34.0 in 2023, while the raw mean for Chemistry practical declined from 28.0 in 2022 to 25.0 in 2023. The reports also identified recurring weaknesses in areas such as mathematical operations, reporting of experimental results, understanding of the activity series, and construction of balanced chemical equations. These patterns point to a continuing Chemistry learning problem and raise concern about whether students are developing sufficiently stable knowledge to support subsequent learning and application. The concern becomes more significant when the nature of Chemistry learning is considered.

Chemistry requires students to coordinate several forms of knowledge, including terminology, symbols, formulas, equations, observable properties, and explanatory models. Learners must therefore move beyond recalling isolated facts to connecting representations and using those connections to explain and solve chemical problems. When foundational knowledge is not adequately retained, students may encounter difficulties when later concepts depend on what they have previously learned. The durability of learning is consequently connected to the quality of the instructional experiences through which students acquire, practise, retrieve, and apply Chemistry knowledge. This makes the instructional method an important consideration in addressing the problem of durable Chemistry learning.

Conventional classroom instruction may not always provide the same level of support to learners who differ in prior knowledge, rate of learning, and immediate instructional needs. In a class containing students with different levels of understanding, a common instructional sequence may provide insufficient support for some learners while offering unnecessary repetition for others. An instructional approach that can recognise differences in learner performance and adjust subsequent learning experiences may therefore provide a useful alternative. Such responsiveness provides the basis for considering adaptive learning as a possible approach to strengthening Chemistry learning and retention.

Artificial intelligence-driven adaptive learning platforms can provide this responsiveness by using information generated during learning to modify content, practice, feedback, difficulty, or progression. Instead of requiring every learner to follow exactly the same pathway, an adaptive environment can provide differentiated learning experiences according to demonstrated performance. This feature is potentially important for Chemistry because students who experience difficulty with foundational concepts may require additional explanation and practice. In contrast, students who demonstrate stronger understanding may benefit from more advanced learning opportunities. The potential of adaptive learning therefore lies not simply in the use of technology but in its capacity to connect evidence of learning with subsequent instructional decisions.

Despite this potential, evidence concerning adaptive learning and Chemistry retention remains uneven across educational contexts. Much of the international literature has examined learning outcomes in tertiary education, general adaptive-learning environments, or immediate academic performance, while evidence involving delayed Chemistry retention among secondary-school students remains comparatively limited. Nigerian research has also begun to examine adaptive learning in Chemistry, but evidence remains limited across different geographical settings, instructional designs, and forms of adaptive technology. These limitations make it necessary to examine adaptive learning in specific Nigerian secondary-school contexts rather than assuming that findings from other settings will automatically apply.

The present study therefore focuses on a locally developed Artificial Intelligence-Driven Adaptive Learning Platform (AI-DALP) and its potential contribution to durable Chemistry learning among secondary-school students. The platform uses learner-performance information to determine differentiated instructional pathways and provides remedial, standard, or advanced learning experiences according to students' demonstrated needs. The study is situated in the Onitsha Education Zone of Anambra State and focuses on Oxygen, Hydrogen, and Halogens in the SS2 Chemistry curriculum. By examining delayed retention rather than immediate achievement alone, the study addresses the question of whether performance-responsive adaptive instruction is associated with learning that remains accessible after instruction has ended.

The study also considers whether retention outcomes within the adaptive environment differ by gender. This consideration is relevant because male and female students may enter an instructional environment with different levels of prior performance, yet the adaptive platform itself responds to demonstrated performance rather than gender. Examining gender within the AI-DALP group therefore provides evidence about whether the adaptive learning environment produces similar retention outcomes across male and female learners after differences in immediate posttest performance are taken into account.

Against this background, the study investigated the effect of the AI-Driven Adaptive Learning Platform on secondary-school students' retention in Chemistry in the Onitsha Education Zone of Anambra State, Nigeria. Specifically, it compared the retention of students taught using AI-DALP with that of students taught using the Conventional Teaching Method after controlling for posttest performance. It also examined whether male and female students taught using AI-DALP differed in retention after controlling for posttest performance. The study was therefore designed to contribute evidence on the use of a locally developed, rule-based adaptive learning environment for promoting durable Chemistry learning in a Nigerian secondary-school setting.

1.2 Purpose of the Study

The primary purpose of the study was to determine the effect of an Artificial Intelligence-Driven Adaptive Learning Platform (AI-DALP) on secondary-school students' retention in Chemistry, after controlling for posttest performance. Specifically, the study sought to:

1. Determine the difference in retention mean scores between students taught Chemistry using the Artificial Intelligence-Driven Adaptive Learning Platform (AI-DALP) and those taught using the Conventional Teaching Method (CTM), after controlling for posttest performance.

2. Determine the difference in retention mean scores between male and female students taught Chemistry using the Artificial Intelligence-Driven Adaptive Learning Platform (AI-DALP), after controlling for posttest performance.

1.3 Research Questions

The following research questions guided the study:

1. What difference exists in the retention mean scores of students taught Chemistry using the Artificial Intelligence-Driven Adaptive Learning Platform (AI-DALP) and those taught using the Conventional Teaching Method (CTM), after controlling for posttest performance?
2. What difference exists in the retention mean scores of male and female students taught Chemistry using the Artificial Intelligence-Driven Adaptive Learning Platform (AI-DALP), after controlling for posttest performance?

1.4 Hypotheses

The following null hypotheses were tested at the 0.05 level of significance:

1. There is no significant difference in the retention mean scores of students taught Chemistry using the Artificial Intelligence-Driven Adaptive Learning Platform (AI-DALP) and those taught using the Conventional Teaching Method (CTM), after controlling for posttest performance.
2. There is no significant difference in the retention mean scores of male and female students taught Chemistry using the Artificial Intelligence-Driven Adaptive Learning Platform (AI-DALP), after controlling for posttest performance.

2. Literature Review

Retention refers to the extent to which knowledge acquired through instruction remains accessible after a period of time has elapsed. It differs from immediate achievement because a post-instruction assessment captures what students can demonstrate. At the same time, the learning experience is still relatively recent, whereas a delayed assessment provides evidence of whether that knowledge has remained available. Retention is therefore an important indicator of durable learning, particularly where students are expected to use previously acquired knowledge as a foundation for subsequent learning. The distinction between immediate performance and lasting knowledge makes retention especially relevant to subjects in which concepts build progressively on one another.

The cumulative nature of Chemistry makes durable retention particularly important. Chemistry students are expected to connect terminology, symbols, formulae, equations, observable properties, and explanatory models rather than simply remember isolated facts. Talanquer (2022) emphasised that meaningful Chemistry learning involves developing increasingly sophisticated forms of chemical thinking, which requires students to connect different representations and levels of chemical knowledge. When earlier concepts are not readily accessible, students may experience difficulty understanding later concepts that depend on them. The importance of retaining prior knowledge therefore makes the conditions under which Chemistry is taught particularly significant.

One mechanism through which instructional conditions may influence retention is repeated retrieval. Todd et al. (2021) examined the forward testing effect through post-exam

retrieval quizzes in introductory Chemistry and found evidence that retrieval practice could improve students' summative Chemistry knowledge over the course of a semester. The importance of this finding lies in the opportunity created for learners to bring previously encountered knowledge back into active use. Retrieval therefore provides an example of how an instructional environment can be deliberately organised to strengthen access to knowledge over time. If repeated and appropriately targeted retrieval can support durable learning, then instructional systems capable of identifying individual learning needs may provide another way of organising such support.

Evidence from secondary Chemistry education further shows that retention is responsive to instructional approach. Ademola et al. (2023), in a study of 91 Nigerian SS2 Chemistry students learning nuclear Chemistry, reported significantly higher retention among students taught through the Culturo-Techno-Contextual Approach than among those taught through lecture instruction. Similarly, Simesso et al. (2024), in a study involving 128 secondary-school Chemistry students, found higher retention among students taught through cooperative learning than among those taught through lecture. These studies demonstrate that retention is not necessarily determined by the content being taught alone; rather, the way learners engage with that content can influence what remains accessible after instruction.

The evidence that instructional organisation influences retention raises an important issue for Chemistry classrooms. Alternative instructional approaches may increase interaction, contextualisation, practice, or collaboration, but they do not necessarily adjust the learning pathway continuously according to the performance of each learner. Students within the same classroom may therefore receive the same explanation, practice opportunities, and progression even when their levels of understanding differ. This limitation creates a logical basis for considering instructional approaches that can respond more directly to individual differences during learning. It is this responsiveness that leads to the concept of adaptive learning.

Adaptive learning refers to an instructional approach in which aspects of the learning experience are adjusted in response to information about the learner. Capuano and Caballé (2020) describe adaptive learning technologies as systems designed to respond to learners' abilities or levels of skill attainment rather than applying an identical learning experience to all students. Adaptation may involve content, sequencing, difficulty, feedback, practice, navigation, or the amount of instructional support provided. The central principle is therefore not technology by itself but the systematic relationship between evidence about the learner and the instructional response that follows.

The growing integration of artificial intelligence into adaptive learning has expanded the range of information that can be used to make these instructional decisions. Kabudi et al. (2021), in a systematic mapping of 147 studies published between 2014 and 2020, identified a wide range of AI-enabled adaptive learning systems and technologies. Their review showed that adaptive learning systems have been developed using different artificial intelligence and data-analytic techniques and for different educational purposes. However, the review also observed that many proposed systems remained at experimental stages rather than being implemented extensively in authentic educational settings. This observation makes the actual classroom application of adaptive learning particularly important.

Broader empirical evidence nevertheless indicates that adaptive learning can improve learner outcomes. Wang et al. (2024) synthesised 45 independent studies published between

2010 and 2022 and reported a medium-to-large positive overall effect of AI-enabled adaptive learning systems on learner outcomes ($g = 0.70$). The effect varied according to educational level, discipline, intervention duration, and research design, among other factors. Importantly, the type of AI used in the adaptive engine did not significantly moderate the overall effect. This finding suggests that the educational value of adaptive learning cannot be explained simply by the sophistication of the AI technology; attention must also be given to what learner information is used and how that information is translated into instructional action.

The importance of these instructional actions is reinforced by more recent research on adaptive learning in schools. Wang et al. (2025), in a systematic review of 69 empirical publications involving adaptive learning, instruction, and teaching in primary and secondary schools, found that learner performance was the most frequent source of adaptation. Adaptive navigation, support, and difficulty progression were among the principal ways in which instruction was adjusted. The review also found that most research had been conducted in elementary education, particularly mathematics, indicating that adaptive learning evidence remains less developed in other school subjects and educational levels. This imbalance is important for Chemistry because it suggests that evidence of adaptive learning effectiveness cannot simply be transferred from mathematics or primary education to secondary Chemistry without empirical examination.

Chemistry-specific studies provide a more direct basis for that examination. Vincent-Ruz and Boase (2022) investigated an adaptive learning technology among 413 students in a university Chemistry course. They found evidence that personalised learning pathways could support learning outcomes over both immediate and longer periods. Their findings demonstrate that adaptive learning can be integrated into Chemistry education and that personalisation need not be limited to general-purpose learning environments. However, the tertiary context also indicates the need for research involving younger learners whose classroom conditions, technological access, prior knowledge, and instructional needs may differ.

Evidence concerning durability is provided particularly clearly by Mettler et al. (2020), who investigated adaptive versus fixed spacing of learning items in Chemistry. Their adaptive system used information about individual learners' response performance to determine the spacing of learning items. Adaptive spacing improved the efficiency and durability of learning, with benefits persisting after a two-week delay and transferring to a standardised Chemistry assessment administered several months later. The significance of this finding extends beyond the particular spacing algorithm because it demonstrates that learner-performance information can be used to alter subsequent learning opportunities in ways that support knowledge beyond the immediate instructional episode.

The principle demonstrated by Mettler et al. (2020) is relevant to the present study even though the adaptive mechanism differs. Their system adjusted the timing of learning opportunities, whereas the AI-DALP in the present study adjusts the instructional pathway according to diagnostic performance. In both cases, however, learner-generated evidence is used to determine what happens next. This common principle of performance-responsive instruction provides a useful bridge between adaptive Chemistry research and the rule-based adaptive design employed in the present study.

The Nigerian evidence provides an important contextual extension of this international literature. Ademola et al. (2023) and Simesso et al. (2024) demonstrate that Nigerian secondary-

school Chemistry retention can respond positively to alternative instructional designs. More directly, Amanyi et al. (2025) investigated adaptive learning among SS2 Chemistry students in Jos East Local Government Area of Plateau State and reported significant differences in Chemistry achievement and retention between students exposed to adaptive learning and those taught through conventional instruction. This study establishes that adaptive learning and Chemistry retention are already emerging as a Nigerian research concern.

The emergence of this Nigerian evidence makes the research gap more precise. The issue is no longer whether adaptive learning can influence Chemistry retention in Nigeria, because the Plateau State study provides evidence that it can. Rather, the evidence base remains limited across geographical settings, adaptive architectures, instructional conditions, and locally developed implementations. The present study therefore extends the Nigerian literature by examining a rule-based AI-DALP in the Onitsha Education Zone of Anambra State. The platform's specific form of adaptation leads directly to the next issue: the role of rule-based artificial intelligence in adaptive learning.

Artificial intelligence in adaptive learning does not necessarily mean machine learning. Adaptive systems can employ machine-learning algorithms, reinforcement learning, learner models, predefined rules, or combinations of these approaches to determine how instruction should respond to learner information. This distinction is important because the educational function of an adaptive system depends on the relationship between learner information and instructional response rather than simply on the technical sophistication of the algorithm used to produce that response.

Sayed et al. (2023) provide an example of such technological diversity. Their AI-based adaptive personalised e-learning platform used learner modelling, adaptive content presentation, exercise navigation, and feedback, combining reinforcement learning with rule-based decision-making. The system illustrates how predefined decision rules can operate within an AI-enabled adaptive environment to determine the instructional response to learner performance. The study therefore supports the broader understanding of adaptive learning as a process in which information about learners is systematically translated into differentiated learning experiences.

The broader evidence also supports separating adaptive learning from the assumption that machine learning is necessary for educational effectiveness. Wang et al. (2024) found that the type of AI used in the adaptive engine did not significantly moderate the overall effect of AI-enabled adaptive learning. This finding does not imply that different AI architectures are identical, but it does suggest that researchers should examine the instructional function of an adaptive system rather than treating technological sophistication as an outcome in itself. What matters educationally is how the system identifies learner needs and how accurately it responds to those needs.

This principle is directly reflected in the design of the AI-DALP examined in the present study. The platform employs predefined computational rules to interpret diagnostic performance and classify learners into Slow, Average, or Advanced Performer categories. The resulting classification determines whether learners receive remedial, standard, or advanced instructional content. The system therefore does not use gender or another demographic characteristic as the basis for instructional differentiation; rather, it uses evidence of learner

performance. This creates a transparent relationship between assessment, learner classification, and instructional response.

The transparency of this rule-based approach is particularly relevant in a secondary-school setting. A locally developed platform based on explicit rules can provide a clearly defined pathway from learner performance to instructional support. Students who demonstrate difficulty can receive additional explanation, simplified examples, practice, hints, and feedback, while students demonstrating stronger performance can proceed to more advanced content. Such differentiation is intended to address learner needs during instruction rather than waiting until the end of instruction to identify differences in achievement. Whether this performance-responsive approach produces more durable Chemistry learning, however, remains an empirical question within the specific Nigerian context of the present study.

That question also connects the technological design back to the central outcome of retention. If the purpose of adaptation is to respond to learners' demonstrated needs, then the relevant issue is not only whether students perform better immediately after instruction but whether the additional support, practice, feedback, and differentiated progression provided by the system contribute to knowledge that remains accessible after instruction. The relationship between adaptation and durability therefore provides the basis for examining whether the benefits of the AI-DALP extend beyond immediate posttest performance.

Gender is an important learner characteristic to consider when examining educational outcomes. Still, existing evidence does not provide sufficient grounds for assuming that male and female students will necessarily differ in Chemistry retention. In the Nigerian Chemistry study by Ademola et al. (2023), no significant gender difference was found in retention among students taught through the Culturo-Techno-Contextual Approach. Similarly, Simesso et al. (2024) reported no significant gender difference in Chemistry retention among students exposed to cooperative learning. These findings indicate that gender differences in retention are not consistently observed across instructional approaches.

The absence of significant gender differences in these studies, however, does not establish that gender is irrelevant under every instructional condition. The studies examined contextualised and cooperative learning rather than AI-driven adaptive instruction. An adaptive environment introduces a different learning process because the instructional pathway changes according to information generated by each learner. Consequently, the possibility that male and female learners may demonstrate different retention patterns under adaptive instruction remains an empirical question rather than one that can be answered from evidence concerning other teaching approaches.

The logic of the present AI-DALP also provides a particular reason for examining this question. Because the platform adapts according to demonstrated performance, male and female students are not assigned to different instructional pathways simply because of their gender. Two students of the same gender may receive different learning experiences, while students of different genders may receive the same pathway when their performance profiles are similar. Gender is therefore examined as a learner characteristic within the adaptive environment rather than as the mechanism through which adaptation occurs.

This distinction is important when interpreting retention outcomes. A simple comparison of male and female retention means may reflect differences that were already

present at the end of instruction. The present study therefore examines gender differences in retention after controlling for posttest performance. This approach makes it possible to determine whether a gender difference in delayed retention remains after accounting for students' immediate post-instruction performance. Given the relatively small numbers of male and female students within the AI-DALP group, the findings should be interpreted in relation to the observed sample rather than as evidence of universal gender equivalence.

The literature therefore provides a clear basis for the gender analysis in the present study. Existing Nigerian Chemistry-retention studies have not established a consistent gender difference, while evidence concerning gender within a rule-based AI-adaptive Chemistry environment remains limited. Examining gender within the AI-DALP group consequently complements the main comparison between AI-DALP and conventional instruction. It provides evidence about whether the adaptive environment is associated with similar retention patterns across male and female learners.

Taken together, the literature indicates that retention is influenced by instructional design, that adaptive learning can provide performance-responsive instruction, that Chemistry-specific adaptive research offers evidence of longer-term learning benefits, and that rule-based systems represent a legitimate form of adaptive artificial intelligence. Nigerian evidence is emerging but remains limited across contexts and adaptive designs, while gender outcomes within rule-based AI-adaptive Chemistry instruction remain insufficiently documented. These considerations provide the basis for the present investigation of whether a locally developed rule-based AI-DALP can support delayed Chemistry retention among SS2 students in the Onitsha Education Zone of Anambra State.

3. Methods

The study adopted a quasi-experimental design using a non-randomised pretest–posttest control-group design. The population comprised 548 Senior Secondary School II (SS2) students offering Chemistry in 22 co-educational public secondary schools during the 2025/2026 academic session. Two schools were purposively selected based on the availability of functional computer facilities, stable power supply, ICT-capable Chemistry teachers, and a single SS2 Chemistry class. The selected schools were assigned to the experimental and control groups. The initial sample comprised 61 students, with 30 assigned to the AI-DALP group and 31 to the CTM group. Two female students in the control group did not complete the posttest and were therefore excluded from the analysis. The final sample comprised 59 students: 30 in the AI-DALP group and 29 in the CTM group.

The instructional intervention lasted six weeks. Week 1 involved student orientation, training of the Chemistry teacher and ICT personnel, and administration of the pretest. During Weeks 2–4, students were taught Oxygen, Hydrogen, and Halogens in two 40-minute lesson periods per week. Week 5 was devoted to revision, while the posttest was administered in Week 6. The retention test was administered two weeks after the posttest to assess students' delayed retention of the Chemistry content taught during the intervention.

The AI-DALP was implemented in a computer-based learning environment comprising a Python-Flask backend, an HTML5, CSS, and JavaScript frontend, and a MySQL database. Its adaptive module employed rule-based decision logic to classify learners according to their diagnostic performance and direct them to appropriate instructional pathways. Learners were classified as slow, average, or advanced performers and received corresponding remedial,

standard, or advanced instructional content. The platform provided instructional explanations, interactive learning materials, self-assessment questions, immediate feedback, hints, simplified examples, and progress information. The control group received instruction on the same Chemistry topics using the Conventional Teaching Method (CTM).

Data were collected using a 50-item multiple-choice Chemistry Achievement Test (CAT). The instrument was validated by three experts in Chemistry, Educational Measurement and Evaluation, and Curriculum Studies from the Faculty of Education, Nnamdi Azikiwe University, Awka. The experts reviewed the items and test versions for content relevance, clarity, and alignment with the study objectives. The instrument was trial-tested with 20 SS2 Chemistry students from a school outside the study area but with characteristics comparable to those of the study participants. Reliability was established using the Kuder-Richardson 20 (KR-20), which yielded a coefficient of 0.82, indicating satisfactory internal consistency.

The CAT was administered as the pretest before the intervention and as the posttest at the end of the instructional period. A retention test was administered two weeks after the posttest. The retention assessment used the same content framework as the posttest, with the items reworded and their order reshuffled to assess delayed retention while maintaining alignment with the content assessed at posttest.

Mean and standard deviations were used to describe students' posttest and retention performance. Analysis of covariance (ANCOVA) was used to examine differences in retention scores between the AI-DALP and CTM groups, with posttest performance as the covariate and instructional method as the principal factor. A separate ANCOVA was conducted within the AI-DALP group to examine gender differences in retention after controlling for posttest performance. Partial eta squared (η^2) was used to estimate effect sizes. The assumptions of ANCOVA were assessed, including homogeneity of variance. Levene's test for retention scores was nonsignificant, $F(1, 57) = 0.914, p = .343$. Statistical significance was evaluated at the .05 level.

4. Results

Research Question 1: What difference exists in the retention mean scores of students taught Chemistry using AI-DALP and CTM, after controlling for posttest performance?

Table 1. Posttest and Retention Mean Scores by Instructional Method

Instructional method	<i>n</i>	Posttest M (SD)	Retention M (SD)	Posttest-to-retention mean change
AI-DALP	30	31.33 (9.47)	39.77 (5.40)	+8.44
CTM	29	21.90 (6.48)	20.14 (5.10)	-1.76

Table 1 shows that students taught using AI-DALP recorded a posttest mean of 31.33 (SD = 9.47) and a retention mean of 39.77 (SD = 5.40), representing a posttest-to-retention mean change of 8.44 points. Students taught using CTM recorded a posttest mean of 21.90 (SD = 6.48) and a retention mean of 20.14 (SD = 5.10), representing a mean change of -1.76 points. Descriptively, the AI-DALP group therefore showed an increase in mean performance at the retention assessment, whereas the CTM group showed a decrease.

Hypothesis 1: There is no significant difference in retention mean scores of students taught Chemistry using AI-DALP and CTM, after controlling for posttest performance.

Table 2. ANCOVA of Retention Scores by Instructional Method

Source	SS	df	MS	<i>F</i>	<i>p</i>	η^2
Posttest	895.068	1	895.068	73.739	< .001	.568
Instructional method	2473.465	1	2473.465	203.773	< .001	.784
Error	679.747	56	12.138			

Table 2 shows that, after controlling for posttest performance, there was a statistically significant difference in retention scores between students taught using AI-DALP and those taught using CTM, $F(1, 56) = 203.773, p < .001, \eta^2 = .784$. The adjusted retention means were 37.57 for the AI-DALP group and 22.41 for the CTM group. The effect size indicates that instructional method accounted for a substantial proportion of the variance in adjusted retention scores. Accordingly, the null hypothesis was rejected.

The finding indicates that, after accounting for students' posttest performance, those taught using AI-DALP had higher adjusted retention scores than those taught using CTM. This inferential result is consistent with the descriptive pattern in Table 1, where the AI-DALP group showed an increase from posttest to retention while the CTM group showed a decrease.

Research Question 2: What difference exists in the retention mean scores of male and female students taught Chemistry using AI-DALP, after controlling for posttest performance?

Table 3: Posttest and Retention Mean Scores of Male and Female Students in the AI-DALP Group

Gender	<i>n</i>	Posttest M (SD)	Retention M (SD)	Posttest-to-retention mean change
Female	16	29.63 (10.25)	38.69 (5.82)	+9.06
Male	14	33.29 (8.44)	41.00 (4.79)	+7.71

Table 3 shows that female students taught using AI-DALP recorded a posttest mean of 29.63 (SD = 10.25) and a retention mean of 38.69 (SD = 5.82), representing a posttest-to-retention mean change of 9.06 points. Male students recorded a posttest mean of 33.29 (SD = 8.44) and a retention mean of 41.00 (SD = 4.79), representing a mean change of 7.71 points. Thus, female students showed a slightly larger posttest-to-retention mean change, whereas male students recorded higher mean scores at both measurement points.

Hypothesis 2: There is no significant difference in retention mean scores of male and female students taught Chemistry using AI-DALP, after controlling for posttest performance.

Table 4. ANCOVA of Retention Scores by Gender Among Students Taught Using AI-DALP

Source	SS	df	MS	<i>F</i>	<i>P</i>	η^2
Posttest	328.345	1	328.345	18.582	< .001	.408
Gender	6.980	1	6.980	0.395	.535	.014
Error	477.092	27	17.670			

Table 4 shows that, after controlling for posttest performance, there was no statistically significant difference in retention scores between male and female students taught using AI-

DALP, $F(1, 27) = 0.395$, $p = .535$, $\eta^2 = .014$. The effect size was very small, indicating that gender accounted for only a small proportion of the variance in adjusted retention scores. Accordingly, the null hypothesis was not rejected.

Although female students showed a slightly larger posttest-to-retention mean change than male students (9.06 versus 7.71), this descriptive difference does not constitute evidence of a statistically significant gender difference in retention. The ANCOVA result indicates that, after accounting for posttest performance, no statistically significant gender difference in retention was detected among students taught using AI-DALP.

5. Discussion of Findings

The result of the study showed that AI-DALP is effective in improving students' retention in Chemistry. The finding is consistent with Wang et al. (2024), whose meta-analysis of AI-enabled adaptive learning systems reported a positive overall effect on learner outcomes. The agreement may be attributed to the capacity of adaptive learning systems to respond to differences in learners' performance and provide instructional experiences that are more closely aligned with their learning needs. The agreement between the present study and Wang et al. (2024) may further be explained by the adaptive nature of the instructional process. In the present study, students' diagnostic performance was used to determine their instructional pathways. Students were classified as slow, average, or advanced performers and were subsequently directed to remedial, standard, or advanced instructional content. This arrangement enabled students to receive different levels of instructional support according to their demonstrated performance. Such responsiveness may have provided learners with opportunities to address areas of difficulty and strengthen their understanding before the retention assessment. The present finding therefore provides further evidence that adaptive instructional systems can support learning outcomes beyond the immediate post-instruction assessment.

Similarly, Vincent-Ruz and Boase (2022), in their study of adaptive learning in Chemistry education, found that adaptive learning could support students' learning by providing personalised learning pathways. The similarity between their findings and the present findings may be attributed to the use of adaptive instructional pathways in both studies. In the present study, the AI-DALP did not provide the same instructional experience to every learner. Instead, learners' diagnostic performance determined the level and type of instructional content presented to them. Students who required additional support could receive remedial explanations, simplified examples, hints, practice questions, and feedback, while students demonstrating stronger performance could proceed to more advanced learning materials. The opportunity to receive instruction that corresponded with individual learning needs may have contributed to the stronger retention observed in the AI-DALP group.

The present finding is also relevant to the recent Nigerian evidence reported by Amanyi et al. (2025), who found significant differences in students' achievement and retention in Chemistry between learners exposed to adaptive learning and those taught using conventional instruction. The agreement is particularly important because both studies examined adaptive learning in Chemistry among secondary-school students within the Nigerian educational context. The consistency may be attributed to the use of adaptive instructional processes that provided learners with differentiated learning experiences rather than exposing all students to the same instructional treatment. The present study extends this evidence by showing that a

locally implemented, rule-based AI-DALP was associated with higher adjusted retention scores among SS2 Chemistry students in Anambra State.

The finding may also be understood in relation to the adaptive learning literature reviewed by Kabudi et al. (2021) and Wang et al. (2025), which shows that learner performance is an important basis for adapting instructional content, navigation, and support. In the present study, the AI-DALP similarly used students' diagnostic performance as the basis for determining their instructional pathway. The platform therefore connected assessment information directly to instructional response. Students who demonstrated weaker performance were provided with remedial support, while those with stronger performance received standard or advanced learning content. This continuous relationship between learner performance and instructional response may have enabled students to receive support appropriate to their learning needs and may have contributed to the observed retention advantage.

The present finding also relates to the adaptive mechanism described by Sayed et al. (2023), whose AI-based personalised learning platform combined learner information with adaptive content presentation, exercise navigation, and feedback. Although their study involved a different subject and educational context, the similarity lies in the use of learner-performance information to guide subsequent instructional experiences. In the present study, however, the adaptive mechanism was implemented through predefined rule-based decision logic rather than a machine-learning model. The platform used diagnostic performance to classify learners and direct them to corresponding instructional pathways. The finding therefore suggests that adaptive instructional support does not necessarily depend on complex machine-learning architecture; a clearly defined rule-based system can also provide differentiated instructional experiences capable of supporting retention.

Overall, the finding suggests that the retention advantage observed for the AI-DALP group was associated with the adaptive instructional process rather than with technology alone. The platform connected students' demonstrated performance with differentiated instructional content and provided opportunities for practice, feedback, hints, explanations, and progress monitoring. These features may have enabled learners to address weaknesses, reinforce previously learned Chemistry concepts, and consolidate their learning before the delayed retention assessment. The significant difference in adjusted retention scores after controlling for posttest performance therefore provides evidence that the AI-DALP was associated with stronger retention of the Chemistry content assessed in the study than the Conventional Teaching Method.

As regards retention and gender, the result of the study indicates that within the AI-DALP group, gender did not significantly differentiate students' retention performance after differences in posttest performance had been taken into account. The finding is consistent with Ademola et al. (2023), who reported no significant gender difference in students' retention in Chemistry following the use of the Culturo-Techno-Contextual Approach. The agreement may be attributed to the structured learning opportunities provided to students irrespective of gender. In the present study, the AI-DALP provided male and female students with access to the same learning environment. At the same time, the level of instructional support was determined by their demonstrated learning performance. Thus, the platform's adaptive mechanism responded to students' learning needs rather than assigning instructional experiences according to gender.

The absence of a statistically significant gender difference may further be explained by the performance-based nature of the AI-DALP. Kabudi et al. (2021) and Wang et al. (2025) identified learner performance as an important basis for adaptive learning and instructional adjustment. The present AI-DALP similarly used diagnostic performance to determine the instructional pathway to which each learner was directed. Consequently, a student's gender did not determine whether the learner received remedial, standard, or advanced content. Rather, the learner's demonstrated performance determined the level of instructional support provided. This arrangement may have reduced the possibility that gender would become a major differentiating factor in retention within the AI-DALP environment.

The finding is also consistent with the adaptive learning principle discussed by Wang et al. (2024), whose meta-analysis showed that AI-enabled adaptive learning can produce positive learning outcomes across different educational contexts while also indicating that study characteristics can influence observed effects. In the present study, the absence of a significant gender difference suggests that the adaptive mechanism operated similarly for male and female students within the study context. The platform responded to learner performance and provided differentiated instructional support without making gender a basis for instructional allocation. This may have contributed to the similar adjusted retention outcomes observed for the two gender groups.

Although female students demonstrated a slightly larger posttest-to-retention mean change than male students, this descriptive difference was not statistically significant. Similarly, the higher raw retention mean recorded by male students should not be interpreted as evidence that male students had significantly better retention. The ANCOVA result showed that, after controlling for posttest performance, the difference between the two groups was not statistically significant. The finding therefore suggests that the observed differences in the descriptive means were not sufficiently large to establish a statistically significant gender difference in retention within the AI-DALP group.

The finding also has relevance to the rule-based architecture of the AI-DALP. Sayed et al. (2023) demonstrated how learner information can be used to guide adaptive content presentation, exercise navigation, and feedback. In the present study, the same general principle was implemented through predefined decision rules that classified learners according to diagnostic performance. Since the classification was performance-based rather than gender-based, male and female students with similar learning needs could receive similar instructional support. The absence of a significant gender difference in retention may therefore be partly associated with the platform's emphasis on individual performance rather than demographic characteristics when determining instructional pathways.

Overall, the finding suggests that the AI-DALP provided male and female students with opportunities to retain Chemistry knowledge without a statistically significant difference attributable to gender. The platform's performance-based classification and differentiated instructional pathways allowed instructional support to be determined by learners' demonstrated needs rather than their gender. This feature may have contributed to the absence of a significant gender difference in retention and suggests that the adaptive learning environment examined in the study was responsive to individual learning performance across the two gender groups.

8. Conclusion

The study concludes that Artificial Intelligence-Driven Adaptive Learning Platform (AI-DALP) is effective in improving secondary school students' retention in Chemistry in Anambra State through the platform's rule-based adaptive pathways, differentiated instructional content, continuous practice, immediate feedback, and learner support. The study further concludes that the effect of AI-DALP on retention did not differ significantly by gender after controlling for posttest performance. Thus, AI-DALP demonstrates great potential as an adaptive instructional approach for sustaining Chemistry learning among secondary school students and is gender-friendly.

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