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Effect of Interactive Computer Adapted Learning Strategy on Students' Chemistry Achievement

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Abstract

This study investigated the effect of Interactive Computer-Adapted Learning (ICAL) on students' Chemistry achievement in Delta State, Nigeria, with particular attention to gender differences. A quasi-experimental pretest-posttest non-equivalent control group design was employed, involving 68 SS2 students (34 males, 34 females) selected through multistage sampling procedure. The group under experiment was taught using ICAL, while control group received conventional lecture instruction. Data was collected using a validated 50-item Chemistry Achievement Test (CAT) with reliability coefficient of 0.82. Analysis was done using standard deviation, mean and ANCOVA. Findings revealed that ICAL significantly improved students' achievement compared to lecture methods, with no significant main gender: effect. However, a significant disordinal interaction effect between teaching approach and gender was observed. Simple effects analysis showed that both male and female in the ICAL group outperformed male and female in the lecture group, while improvement was notable among female students. Importantly, while traditional instruction produced gender disparities favoring males, ICAL eliminated this gap, demonstrating its potential as an equalizing strategy. The study concludes that ICAL is an effective tool for enhancing chemistry achievement while promoting gender equity in STEM education. Recommendations include policy integration of adaptive learning technologies, teacher training in ICAL implementation, and infrastructure development to support technology-enhanced learning in Nigerian schools.

Keywords: interactive computer, adapted learning, achievement, chemistry

1. Introduction

Chemistry stands as a cornerstone of modern scientific literacy, its principles weaving through the fabric of critical fields from pharmaceutical research and sustainable engineering to environmental stewardship. A strong grasp of chemistry is, therefore, indispensable for secondary education students aiming to contribute to these vital sectors. Yet, within Nigeria, Delta State serves as a poignant example of a troubling and persistent trend underachievement in chemistry. Year after year, students' chemistry performance, as measured by both internal school assessments and national examinations like the West African Senior School Certificate Examination (WASSCE) and the National Examinations Council (NECO), falls persistently below expectations (NECO, 2021; WAEC, 2022). Researchers point to a confluence of systemic and pedagogical challenges: science laboratories that are under-equipped or non-existent, a persistent reliance on teacher-centric lecture methods that fail to engage, and a resulting wave of students' negative attitudes and disinterest toward the subject's perceived difficulty (Avwiri, 2025; Nwanze & Okoli, 2021). In light of these challenges, a growing chorus of educational experts advocates for a paradigm shift. They call for the incorporation of innovative, technology-enhanced teaching strategies that are inherently interactive and capable of responding to the unique learning journey of each student (Adesoji & Ogunleye, 2018).

One such promising innovation is the Interactive Computer-Adapted Learning (ICAL) strategy. Moving far beyond simple digitized textbooks or linear computer-assisted instruction (CAI), ICAL represents a dynamic, intelligent approach. It leverages principles of artificial intelligence and adaptive algorithms to create a responsive learning environment. As a student interacts with the material, the system analyzes their responses in real-time, customizing the difficulty of problems, nature of feedback and the pacing of instruction to fit their demonstrated competency level (Izuegbunam & Osuafor, 2021; Olatunji & Omirin, 2017) The vision of interactive computer-adapted learning moves beyond static digital content to create a responsive educational dialogue, meeting each student at their unique point of need. This personalized approach has demonstrated significant potential to enhance engagement and mastery in science education, as it dynamically adjusts content, difficulty, and feedback (Zourmpakis et al., 2023). For example, adaptive gamification transforms challenging chemistry concepts into personalized, achievable quests, fostering motivation by valuing the learner's individual journey over standardized pacing.

A pivotal question, however, is whether this adaptive potential translates equitably across gender lines, particularly in closing persistent achievement gaps in chemistry. Emerging evidence suggests that well-designed systems can promote more equitable engagement (Zourmpakis et al., 2024). Yet, broader research cautions that adaptation alone does not guarantee equity; its design philosophy is paramount. Algorithms that inadvertently prioritize competitive or speed-based metrics may disengage some learners, while designs emphasizing mastery, collaboration, and supportive feedback show greater promise in supporting diverse cohorts. Ultimately, the potency of adaptive technology in bridging gender disparities hinges on intentional, inclusive design. The goal is not to replace educators but to equip them with tools that recognize and nurture every student's potential, making the abstract world of chemistry personally accessible and relevant to all. This adaptability is especially powerful for a subject like chemistry, where mastering abstract concepts from the mole ratios in stoichiometry to the spatial geometries in organic chemistry often requires personalized, scaffolded support that traditional methods struggle to provide (Okoli & Nwanze, 2018).

Compounding the general struggle with chemistry is the persistent issue of gender disparity in science achievement. Empirical studies within the Nigerian context consistently indicate that male students tend to outperform their female counterparts in science subjects, including chemistry (Nwanze, Emerhiona, Pius, & Izuegbunam, 2018; Nworgu & Nworgu, 2013). This gap is frequently attributed to deep-rooted socio-cultural biases, a scarcity of visible female role models in STEM careers, and classroom dynamics that can unconsciously marginalize girls (Avwiri, 2023). For instance, observations suggest that female students possibly less likely to engage actively in hands-on laboratory work, sometimes due to perceptions of complexity or a lack of confidence fostered by these broader societal patterns (Mbajiorgu, Ezeudu, & Anya, 2018). Intriguingly, technology-mediated approaches like ICAL offer a potential avenue for mitigation. By providing a private, self-paced, and non-judgmental space for exploration, adaptive learning systems can help level the playing field. Preliminary evidence supports this; Research has indicated that female students using adaptive e-learning modules in science can achieve significant gains, potentially benefiting much more than males from personalized feedback and a reduction in classroom anxiety (Adeyemo, Adedoja, & Olorundare, 2015; Nwanze, Izuegbunam, Pius, Emerhiona, & Okoli, 2018).

The broader efficacy of adaptive learning systems in boosting academic achievement is well-documented across disciplines. Research in mathematics and physics education in Nigeria has shown marked improvements in post-test scores and conceptual understanding when ICAL strategies are employed (Eze, Ezenwa-Nebife, & Obiekwe, 2015; Oladejo, Olosunde, & Ojebisi, 2011). Specifically in chemistry, interactive simulations on challenging topics have led to significantly higher knowledge retention compared to traditional teaching (Adekunle, Ogunleye, &Adesina, 2014). A synthesis of numerous studies confirms a moderate to large positive outcome of computer-adapted learning on achievement in science (Ojo, Akpan, & Olayanju, 2016).

However, the international literature introduces a nuanced perspective. While adaptive technology holds great promise for equity, its implementation and design are crucial. For example, adaptive gamification in science learning has shown variable effects across genders, suggesting that the choice and adaptation of game elements (example, points, leaderboards, narratives) must be carefully considered to motivate all learners equally (Zourmpakis, Kalogiannakis, & Papadakis, 2023, 2024). Furthermore, the success of such tools is heavily dependent on teacher readiness and their perspective on integration, highlighting that technology is a tool for pedagogy, not a replacement for it (Papadakis, Zourmpakis, Kasotaki, &Kalogiannakis, 2024). This global insight aligns with findings in Nigeria, where some studies note that even beneficial interventions can sometimes yield disproportionate gains for male students, possibly due to unconscious biases in content or interaction design (Nworgu &Nworgu, 2013).

Despite this promising evidence, critical gaps in knowledge remain, particularly within the specific context of Delta State. Existing studies often examine general science achievement without isolating chemistry or conducting granular, gender-disaggregated analyses of results (Mbajiorgu et al., 2018; Udo, Ekon, &Ekpo, 2017). Furthermore, much of the Nigerian research on technology in education has focused on simpler forms of computer-aided instruction rather than advanced, intelligent adaptive systems like ICAL. Given Delta State's unique landscape marked by urban-rural digital divides and varying levels of teacher preparedness for technology integration localized, rigorous investigation is urgently needed (Osuafor& Okonkwo, 2013).

Therefore, this study seeks to address these interconnected gaps. It aims to rigorously evaluate Interactive Computer-Adapted Learning (ICAL) strategy impact on chemistry achievement specifically between senior secondary students in Delta State. Furthermore, by explicitly analyzing the outcomes through a gender lens, it will investigate whether this innovative pedagogical tool can be used as an effective equalizer, helping to bridge the persistent achievement gap while elevating overall competency in this foundational science subject.

The purpose of this study was to examine the impact of interactive computer adapted learning strategy on chemistry students' achievement in Delta state, Nigeria. Specifically, the study set to determine the:

1. Students' mean achievement scores taught Chemistry using interactive computer adapted learning (ICAL) strategy and those educated utilizing lecture method (LM).

2. Mean achievement scores of male and female students taught Chemistry using ICAL and those taught using LM.

3. Interaction effects of teaching technique and gender on students' chemistry achievement.

2. Research Questions

The following research questions guided the study:

1. What are the mean achievement scores of students taught Chemistry using ICAL and those taught using LM?

2. What are the mean achievement scores of male and female students taught Chemistry using ICAL and hose taught using LM?

3. Hypotheses

The following hypotheses were tested at 0.05 level of significance:

1. There is no significant difference between the students' mean achievement scores instructed Chemistry using ICAL and those taught using LM.

2. There is no significant difference between the mean achievement scores of male and female students taught Chemistry using ICAL and those taught using LM.

3. There is no significant difference interaction effect of teaching strategy and gender on chemistry students' achievement.

4. Method

A quasi-experimental research design was adopted, specifically the pretest-posttest non-equivalent control group design. This design was deemed appropriate because it allowed for the comparison of two intact groups, one exposed to ICAL (experimental group) and the other taught utilizing the lecture method (control group) without random assignment, which is often impractical in real classroom settings. The research was conducted in Delta State, Nigeria, a region characterized by diverse secondary schools with varying levels of access to technological resources. The state was purposively selected due to its documented challenges in chemistry education, including unsatisfactory student performance in national examinations and a notable gender disparity in science achievement.

The study population consisted of all senior secondary school two (SS2) chemistry students in Delta State's government owned secondary schools. A multistage sampling method was employed to select the study sample. First, two local government areas (LGAs) Warri South and Ughelli North were purposively selected to ensure geographical representation. Next, one co-educational schools per LGA was randomly selected. Finally, two intact classes (one experimental, one control) were selected from each school, yielding a total sample of 68 (34 males and 34 females). This gender-balanced sampling makes sure that the study could effectively analyze Gender's effects on chemistry achievement under ICAL and traditional instruction.

The data collection instrument was the Chemistry Achievement Test (CAT), a 50-item multiple-choice test developed by the researcher and aligned with the WAEC and NECO chemistry syllabi. The test covered key topics in the SS2 curriculum, including chemical bonding, stoichiometry, acids and bases, and organic chemistry. To ensure content validity, the CAT was reviewed by three experienced chemistry teachers and two university chemistry education experts who assessed the appropriateness, clarity, and coverage of the test items. Their feedback led to the modification of ambiguous questions that were poorly constructed. The reliability of the CAT was established using the Kuder Richardson - 20, where the instrument was administered to 30 SS2 students (that was not included in the main study) in a nearby school with similar characteristics. The scores were analyzed yielding a reliability coefficient of 0.82, indicating high consistency.

The ethical journey began with a warm meeting at the Delta State Ministry of Basic and Secondary Education, where we shared our vision for supportive learning and received their thoughtful approval. We then visited each participating school, sitting down with principals, teachers, parents, and students to have open conversations, ensuring everyone felt informed and respected before they freely agreed. This process was built on trust, ensuring every voice was heard and every signature given was a confident, voluntary step forward.

The experimental procedure spanned eight weeks, with both the experimental and control groups undergoing pretest and posttest assessments. The experimental group was taught using the Interactive Computer-Adapted Learning (ICAL) strategy, which involved a customized e-learning platform that adjusted lesson difficulty based on real-time student responses. The platform included multimedia simulations, interactive problem-solving exercises, and instant feedback mechanisms. For example, when teaching chemical equilibrium, the system presented dynamic simulations where students manipulated variables (temperature, concentration) and observed real-time changes, followed by adaptive quizzes that increased in complexity based on performance. Conversely, the control group was taught utilizing the lecture technique, where the educator delivered content via chalkboard explanations, textbook readings, and occasional demonstrations. Both groups were instructed by teachers with similar qualifications and experience to minimize instructor bias.

To control extraneous variables, several measures were implemented. First, the same chemistry topics were taught to both groups within the same period to prevent content disparity. Second, the pretest scores were utilized as covariates in the final analysis to account for initial differences in student ability. Third, the teachers for both groups underwent a one-week training session to ensure fidelity in implementing ICAL and the lecture technique. Additionally, classroom observations were conducted twice weekly to monitor adherence to the instructional protocols. Variables such as school environment, class duration, and teaching materials (except for the ICAL software) were kept constant across groups.Data collection was carried out by the researcher with the assistance of trained research assistants who administered the CAT under standardized conditions to prevent test anxiety or distractions. The pretest was conducted one week before the intervention, while the posttest was administered immediately after the eight-week treatment period. To ensure fairness, answer sheets were anonymized and scored utilizing a predetermined marking scheme.

The data analysis involved both inferential statistics and descriptive. Mean and standard deviation were used to summarize pretest and posttest scores, while Analysis of Covariance (ANCOVA) was used to establish the significant difference in achievement between the ICAL and lecture method groups, using pretest scores as covariates. A two-way ANCOVA was further performed to examine the interaction effect of instructional strategy and gender on chemistry achievement.

5. Results

Research Question one: What are the students' mean achievement scores taught Chemistry using ICAL and those instructed utilizing LM?

Table 1. Students Mean Achievement Scores taught Chemistry using ICAL and LM

Group	N	Pretest Mean	Pretest SD	Posttest Mean	Posttest SD	Gained Mean
ICAL	34	31.59	9.49	71.18	11.41	39.59
LM	34	32.79	7.19	56.68	10.63	23.89

Table 1 shows that students instructed Chemistry applying ICAL had a higher gain in mean achievement score (39.59) than those taught applying LM (23.89). Students educated Chemistry applying ICAL had a less homogeneous score in their pretest (9.49) than those instructed applying LM (7.19). In the posttest, students instructed Chemistry applying ICAL had a more heterogeneous score (11.41) than those instructed utilizing LM (10.63).

Research Question 2: What are the mean achievement scores of male and female students instructed Chemistry using ICAL and those taught applying (LM?

Table 2. Students Mean Achievement of Male and Female Chemistry instructed applying ICAL and LM

Method	Gender	N	Pretest Mean	Pretest SD	Posttest Mean	Posttest SD	Gained Mean
ICAL	Male	17	29.24	7.84	67.88	10.75	38.64
	Female	17	33.94	10.61	74.47	11.39	40.53
LM	Male	17	35.12	8.31	62.41	8.55	27.29
	Female	17	30.47	5.13	50.94	9.48	20.47

Table 2 also reveals that male students instructed Chemistry applying ICAL had higher mean score achievement than those instructed utilizing LM and also, female students taught Chemistry using ICAL had greater mean score achievement than the female taught using LM.

Hypothesis 1: There is no significant difference between the students' mean achievement scores taught Chemistry applying ICAL and those instructed utilizing LM.

Table 3. ANCOVA Test of Significance of Difference in the Students' Mean Achievement Score instructed Chemistry applying ICAL and LM

Source	SS	df	Mean Square	F	Sig.	Decision
Corrected Model	7093.432a	4	1773.358	24.820	.000	
Intercept	6851.276	1	6851.276	95.892	.000	
Pretest	2031.858	1	2031.858	28.438	.000	
Method	3971.403	1	3971.403	55.585	.000	Sig.
Gender	102.992	1	102.992	1.442	.234	Not Sig.
Method * Gender	529.679	1	529.679	7.414	.008	Sig.
Error	4501.201	63	71.448			
Total	289483.000	68				
Corrected Total	11594.632	67				

Table 3 demonstrated that there is a significant main impact of the treatment on students' Chemistry achievement, $F(1, 63) = 55.585$, $P = .000 < 0.05$. Therefore, the null hypothesis is rejected meaning that there is significant differences between the students' mean achievement scores instructed Chemistry applying ICAL and those instructed applying LM in favour of ICAL.

Hypothesis 2: There is no significant difference between the students' mean achievement scores of male and female taught Chemistry utilizing ICALand those taught using LM.

Table 3 also indicated that there is no significant main influence of gender on students' Chemistry achievement, $F(1, 63) = 1.442$, $P = .234 > 0.05$. Therefore, the null hypothesis is not rejected meaning that there is no significant difference between the mean achievement scores of male and female students taught chemistry using ICAL and those taught using lecture method.

Hypothesis 3: There is no significant difference interaction effects of teaching technique and gender on students' Chemistry academic achievement.

Table 3 further demonstrated that there is significant interaction effect of the teaching strategies and gender on students' Chemistry achievement, $F(1, 63) = 7.414$, $P = .008 < 0.05$. Therefore, the null hypothesis was rejected meaning that there is a significant difference interaction effect of teaching technique and gender on students' Chemistry achievement as shown below in Figure 1.

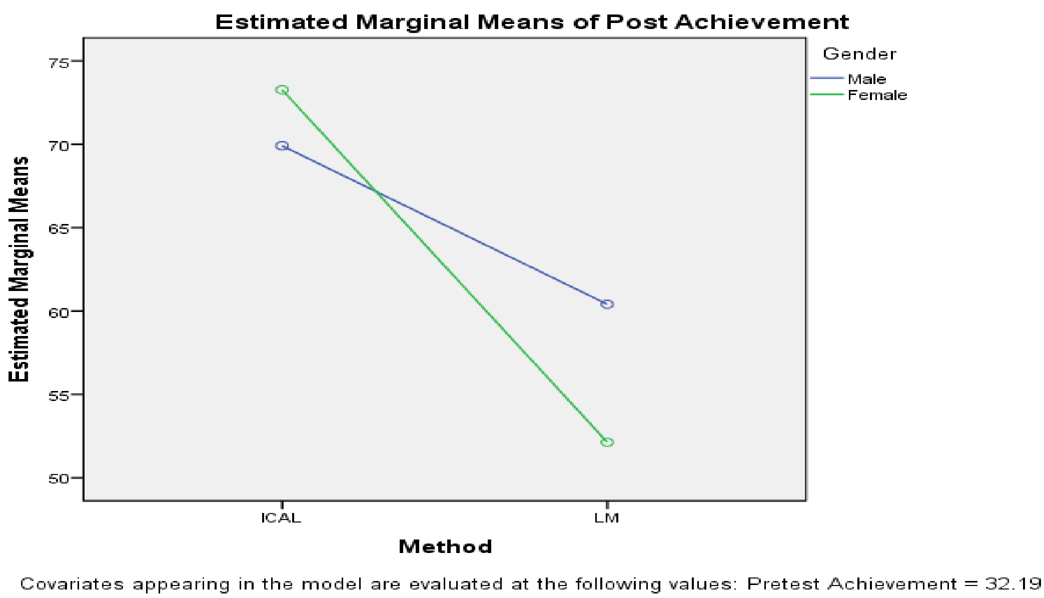

Figure 1. Plot of interaction effect of instructional strategies (ICAL and LM) and gender on students' achievement in Chemistry

The plot of interaction effect of instructional strategies and gender on students' Chemistry achievement as shown in Figure 1 is significant and disordinal. This indicates that the teaching strategies had different effect with respect to gender and is therefore gender sensitive. Given the significant effect of gender, the possible interactions are shown in the simple main effect analysis as presented in Table 4 and Table 5 below:

Table 4. Pairwise Comparison and Univariate Test of Simple Main Effect of Methods within Each Level of Combination of the other Effects

Gender	(I) Method	(J) Method	Mean Difference (I-J)	Std. Error	F-value	Sig.b
Male	ICAL	LM	9.510*	2.997	10.073	.002
	LM	ICAL	-9.510*	2.997		.002
Female	ICAL	LM	21.146*	2.933	51.962	.000
	LM	ICAL	-21.146*	2.933		.000

Table 4 shows that there is a significant difference between the mean achievement score of male students instructed Chemistry utilizing ICAL and male students instructed Chemistry using LM in favour of ICAL, $F(1, 63) = 10.073$, $P = .002 < 0.05$. Also, there is a significant difference between the mean achievement score of female students taught Chemistry using ICAL and female students taught Chemistry using LM in favour of ICAL, $F(1, 63) = 51.962$, $P = .000 < 0.05$. This entails that with respect to gender (male and female), ICAL is a superior instructional strategy for teaching chemistry than lecture method.

Table 5. Pairwise Comparison and Univariate Test of Simple Main Effect of Gender within Each Level of Combination of the other Effects

Gender	(I) Method	(J) Method	Mean Difference (I-J)	Std. Error	F-value	Sig.b
ICAL	Male	Female	-3.356	2.962	1.284	.261
	Female	Male	3.356	2.962		.261
LM	Male	Female	8.279*	2.960	7.821	.007
	Female	Male	-8.279*	2.960		.007

Table 5 shows that there is no significant difference between the mean achievement score of male and female students taught Chemistry using ICAL, $F(1, 63) = 1.284$, $P = .261 > 0.05$. There is also a significant difference between the mean achievement score of male and female students taught Chemistry using LM in favour of male, $F(1, 63) = 7.821$, $P = .000 < 0.05$. This implies that with respect to instructional methods, female and malesstudents performed differentlywhen LM was used but had a uniform performance when ICAL was used, indicating that ICAL have sufficient potency to bridge the gender gap common in traditional instructional methods like lecture method.

6. Discussion

The study's results paint a clear and compelling picture: students learning Chemistry through the Interactive Computer-Adapted Learning (ICAL) strategy demonstrably outperformed their peers taught via the lecture method. This significant leap in achievement aligns with earlier research, like the work of Oladejo, Olosunde, and Ojebisi (2011), who found similar substantial gains in physics using adaptive platforms, and Adeyemo, Adedoja, and Olorundare (2015), who reported marked improvements in chemistry motivation and scores with computer-assisted tools.

The platform of ICAL operated like a personal tutor, not a digital textbook. Its real-time feedback permit students to correct misunderstandings instantly, preventing errors from becoming entrenched, a critical advantage supported by Olatunji and Omirin's (2017) analysis of intelligent tutoring systems. Furthermore, ICAL's adaptive pacing accommodated individual learning readiness, directly addressing the "one-size-fits-all" limitation of lectures highlighted by Adekunle, Ogunleye, and Adesina (2014). The rich, multimodal environment with interactive simulations that brought molecular interactions to life, transformed abstract concepts into tangible experiences. This resonates with Eze, Ezenwa-Nebife, and Obiekwe's (2015) findings on deepened conceptual understanding through adaptive problem-solving and aligns with Mayer's Cognitive Theory of Multimedia Learning, where dual coding fosters superior retention.

In the Nigerian context, this is particularly encouraging. ICAL's success suggests it could mitigate systemic challenges like overcrowded classrooms and scarce labs by offering scalable, individualized practice, a potential solution alluded to by Osuafor and Okonkwo (2013). These results fundamentally challenge the persistence of teacher-centered pedagogies, implying that resistance to technology integration may itself be an obstacle to improvement, a concern echoed in the meta-analysis by Ojo, Akpan, and Olayanju (2016), which calls for greater investment in these tools and teacher training.

Perhaps the most nuanced and hopeful findings emerged when we examined the function of gender. Our initial analysis indicated no simple, overall gender bias in either method. However, a deeper statistical probe revealed a more intricate story, a disordinal interaction effect. In simpler terms, the outcome of the teaching method changed dramatically relying on the student's gender. In the lecture setting, a familiar and troubling pattern re-emerged: male students significantly outperformed female students. This disparity echoes long-standing concerns in research, such as those documented by Nworgu and Nworgu (2013) and attributed by scholars like Mbajiorgu, Ezeudu, and Anya (2018) to socio-cultural biases and classroom dynamics that can marginalize female participation.

The story changed entirely in the ICAL environment. Critically, both male and female students instructed with ICAL achieved significantly higher scores than male and female in the lecture groups. Most importantly, within the ICAL group itself, the achievement gap between males and females vanished. This suggests ICAL acted not just as a booster, but as an academic equalizer, creating what Adesoji and Ogunleye (2018) describe as a more equitable learning environment.ICAL creates a private, self-directed learning space. It can reduce the anxiety of public failure and the pressure to perform quickly, factors that may disproportionately affect female learners in traditional settings. This aligns with recent international research on adaptive technology. For instance, Zourmpakis, Kalogiannakis, and Papadakis (2024) found that adaptive gamification could mitigate gender differences in science learning by personalizing challenge and motivation, moving away from a "one-size-fits-all" approach that may unconsciously favor male-dominated competitive structures. Their earlier work (2023) further highlighted that the implementation and specific adapted game elements are crucial for engaging all learners equitably. This nuance is key; it suggests ICAL's benefit lies in its capacity to cater to diverse learning preferences and reduce stereotype threat.

Furthermore, the significant benefit for male students in ICAL underscores that good adaptive design meets individual cognitive needs, not just gender. The technology's ability to present concepts through interactive visualizations and adjust difficulty likely maintained high engagement and optimal challenge for all learners, a principle supported by cognitive load theory (Sweller, 2011). These findings carry significant weight. They indicate that adaptive learning technologies like ICAL are a potent strategy for promoting both excellence and equity in STEM. While the lecture method in our study perpetuated an existing gap, ICAL helped to bridge it, supporting the argument by Akinola and Oludipe (2015) that supportive, self-paced technology can particularly encourage female participation. We must, however, interpret these promising results with appropriate caution. Our sample size, while adequate for detecting the main teaching effect, is modest for making sweeping generalizations about the nuanced gender interaction. A larger, longitudinal study would provide even stronger evidence. Additionally, as highlighted by Papadakis et al. (2024), the achievement of such technologies is inextricably linked to teacher readiness and thoughtful pedagogical integration. Technology is a tool for teachers, not a replacement.

The study's findings also shows that while both male and female students performed significantly better in chemistry when instructed with the Interactive Computer-Adapted Learning (ICAL) strategy compared to the traditional Lecture Method (LM), the true story lies in how the two methods interacted with gender. A significant disordinal interaction indicated that the instructional strategies were indeed gender-sensitive, affecting male and female students differently. Crucially, the gender achievement gap observed under the LM, where male students outperformed females, disappeared entirely when ICAL was employed, suggesting its potential to foster a more equitable learning environment. These results align with foreign the studyofZourmpakis et al. (2024), which similarly found adaptive gamification could reduce gender disparities in science learning, and broader meta-analyses in Computers and Education, indicating well-designed digital environments can mitigate traditional biases. While the data strongly suggests ICAL's potency in bridging the immediate performance divide, a larger, more diverse replication is necessary to confirm its efficacy as a universal tool for gender equity in chemistry education.

Future research should build on this by investigating the long-term effects of ICAL on retention and critical thinking. It should also dissect which specific features, personalized feedback, interactive modality, or adaptive challenge, are most responsible for fostering equity. Furthermore, exploring the perspectives of Nigerian teachers on integrating such tools, as suggested by the framework of Papadakis et al. (2024), is essential for sustainable implementation.

7. Conclusion

The Interactive Computer-Adapted Learning (ICAL) approach was far more efficient than traditional lectures for teaching chemistry both males and females learned better with it. But perhaps more importantly, ICAL also leveled the playing field. While the old lecture method showed a noticeable gap, with boys outperforming girls, that gap vanished completely when students used ICAL. The technology did not just help everyone learn more; it helped everyone learn equally. That means moving toward adaptive tools like ICAL is not just a way to improve results, it is a practical step toward making science education more efficient and more fair for all students.

8. Recommendations

Educational policymakers should prioritize the incorporation of Interactive Computer-Adapted Learning (ICAL) strategies in chemistry curricula to enhance student achievement.

Teachers should receive regular training on implementing adaptive learning technologies to ensure effective delivery of ICAL-based instruction.

Schools should invest in digital infrastructure and resources to support the widespread adoption of ICAL in science classrooms.

Curriculum developers should design gender-inclusive ICAL modules to further bridge performance gaps in STEM subjects.

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Authors contributions

H. E. Avwiri drafted the initial manuscript, conceptualized the study, literature review, instrument development, coordinated data collection and data analysis.

Chiekem Enwefa contributed to the initial manuscript drafting, literature review and instrument development.

Odiri E. Onoshakpokaiye designed the method, literature review, instrument development, edited the manuscript.

The final manuscript was read and approved by all authors.

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The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Data sharing statement

No additional data are available.

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