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Research Article

Technological Pedagogical Content Knowledge and Conventional Lecture Method: Comparative Effects on Biology Learning Outcomes

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Abstract
The persistent underachievement of students in biology in Nigeria has remained a source of concern, as conventional lecture methods are often unable to foster meaningful learning or sustain students' interest in the subject. To address this gap, this study explored the effects of the Technological Pedagogical Content Knowledge (TPACK) instructional strategy and the Conventional Lecture Method (CLM) on students' achievement and perception of biology, with gender included as a moderating factor. The study employed a quasi-experimental, pretest–posttest non-equivalent control group design. A sample of 337 Senior Secondary School II science and commercial students was drawn from six intact classes across public schools in Lagos State using a multistage sampling procedure. Two instruments, the Biology Achievement Test (BAT) and Students' Perception of Biology Questionnaire (SPBQ), were administered, and the data were analysed using Analysis of Covariance (ANCOVA) at the 0.05 significance level. The results indicated that TPACK had a significant main effect on achievement, $F(1, 332) = 28.67, p < .001$, partial $\eta^2 = .080$, while gender also had a significant effect, $F(1, 332) = 6.49, p = .011$, partial $\eta^2 = .019$. A significant interaction between gender and instructional strategy was found on achievement, $F(1, 332) = 8.59, p = .004$, partial $\eta^2 = .025$. In terms of perception, strategy had a significant effect, $F(1, 332) = 4.13, p = .043$, partial $\eta^2 = .012$, and gender was also significant, $F(1, 332) = 9.01, p = .003$, partial $\eta^2 = .026$, but their interaction was not. The study concludes that TPACK enhances students' achievement and perception in biology, though achievement gains varied by gender.

Keywords: Academic Achievement, Biology, Gender, Instructional Strategies, Teacher Pedagogical Content Knowledge

1. INTRODUCTION

Education is widely acknowledged as the cornerstone of individual empowerment and national development. Within this broad domain, science education plays a particularly critical role by equipping learners with the knowledge and skills required for technological innovation, workforce readiness, and problem-solving in society. Indeed, science education has been identified as a catalyst for economic development and self-reliance, contributing directly to technological progress and competitiveness (Tijani & Adeduyigbe, 2025). In Nigeria, biology, being one of the core science subjects, occupies a central position in the secondary school curriculum because of its relevance to health, biotechnology, agriculture, and environmental sustainability. However, despite this importance, persistent challenges remain in the teaching and learning of biology, with students' performance consistently reported as below expectations in both national and regional examinations.

The West African Examinations Council (WAEC), for instance, has repeatedly highlighted students' weak understanding of core biological concepts. Scholars such as Okebukola (2015) and Yusuf and Balogun (2011) attribute this underachievement largely to the persistence of conventional teacher-centred approaches, such as rote memorisation and lecture delivery, which neither stimulate interest nor develop critical thinking. This challenge highlights the urgent need for more effective instructional approaches that promote engagement, conceptual clarity, and achievement in biology, in line with global calls for improved science education to advance the Sustainable Development Goals (SDGs). Furthermore, inclusive practices have also been emphasised by scholars, particularly in addressing the needs of learners with hearing impairment through visual and assistive technologies (Adeduyigbe et al., 2024).

Theoretical perspectives play a crucial role in explaining how instructional practices can be enhanced. Shulman (1986) introduced the concept of Pedagogical Content Knowledge (PCK), arguing that effective teaching extends beyond mere mastery of subject matter or the application of general pedagogical strategies. Instead, PCK emphasizes the integrated knowledge teachers require to transform disciplinary content into forms that are accessible and meaningful to learners. Expanding upon this foundational idea, Mishra and Koehler (2006) developed the Technological Pedagogical Content Knowledge (TPACK) framework by incorporating technology as an essential component of effective instruction. This framework consists of three primary knowledge domains, Pedagogical Knowledge (PK), Technological Knowledge (TK), and Content Knowledge (CK), as well as their intersections, including Technological Content Knowledge (TCK), Pedagogical Content Knowledge (PCK), Technological Pedagogical Knowledge (TPK), and the overarching integration represented by Technological Pedagogical Content Knowledge (TPACK). The value of TPACK lies in recognising that meaningful teaching in contemporary classrooms requires a dynamic integration of all three domains, enabling teachers not only to understand the subject matter and pedagogy but also to deploy technology in ways that enhance learners' understanding. In biology, this is particularly important because many topics, such as reproduction, photosynthesis, and ecological systems, are abstract and complex, and students often struggle to visualise them. TPACK-based strategies, such as animations, simulations, and interactive models, provide opportunities to concretise such concepts and engage students in active inquiry.

This study adopts the TPACK framework because it directly aligns with the research objectives and design. The study compares the effects of a TPACK-based instructional strategy with the Conventional Lecture Method (CLM) on students' biology achievement and perception, while also considering gender differences. By grounding the intervention in TPACK, the study ensures that instruction goes beyond traditional, teacher-centred delivery and instead integrates content, pedagogy, and technology in a way that supports conceptual understanding and positive attitudes. Furthermore, adopting TPACK is justified by the persistent underachievement in biology observed in WAEC and NECO reports, which has been attributed to conventional teaching methods. The framework, therefore, offers a structured lens for addressing these deficiencies. Additionally, TPACK has been successfully applied in other contexts to improve science learning (Baah & Owusu, 2025; Bwalya et al., 2024; Niess, 2005; Yanti et al., 2019), but its application in Nigerian classrooms remains limited. By employing TPACK as the guiding framework, this study contributes to bridging that gap and generating context-specific evidence on how technology-enhanced pedagogy can improve biology outcomes.

Empirical research has demonstrated the potential of TPACK in supporting effective science education. Niess (2005) showed that teachers equipped with TPACK skills were better able to foster inquiry-based learning, while Mishra and Koehler (2006) conceptualised TPACK as essential for ICT integration across subjects. Sahin (2011) validated tools for measuring TPACK competence among teachers, providing evidence that the framework can be systematically evaluated. More recent studies reinforce these findings. For example, Malik et al. (2019) and Huang and Lajoie (2021) found that TPACK-based instruction significantly improved students' engagement and understanding. Similarly, Bwalya et al. (2024) and Yanti et al. (2019) demonstrated that TPACK strategies enhanced learner achievement and 21st-century skills, while Zulyusri et al. (2022) showed through meta-analysis that TPACK had a consistent positive impact in post-COVID teaching contexts. These studies collectively affirm that integrating TPACK into classroom practice supports active learning and improves performance.

However, research also highlights significant challenges in the adoption of TPACK, especially in developing contexts. Usman et al. (2023) reported that Indonesian biology teachers demonstrated low competence in TPACK because of insufficient training opportunities. Similarly, Yalley (2017) observed that teachers in Ghana, although aware of TPACK, seldom utilised digital resources effectively in classroom practice. In Nigeria, Yusuf and Balogun (2011) as well as Adegbija and Fakomogbon (2012) reported that while digital strategies improve students' achievement, teachers continue to rely heavily on lecture methods due to a lack of skills, inadequate resources, or resistance to change. These findings point to the need for more research on how TPACK can be implemented effectively in African contexts to address persistent learning gaps.

A further dimension in the discourse on TPACK involves gender differences. International findings remain inconclusive. Several studies have reported that male teachers tend to demonstrate higher confidence in technology-related domains, whereas female teachers often exhibit stronger pedagogical competencies (Cheng, 2017; Liu et al., 2015; Mailizar et al., 2021). Consistent with this pattern, Jang and Tsai (2013) as well as Ergen et al. (2019) found that male participants generally achieved higher scores in technological knowledge (TK) and overall TPACK, but showed comparatively lower proficiency in content knowledge (CK) and pedagogical content knowledge (PCK). In contrast, other research has identified no significant gender-based differences in TPACK (Koh & Sing, 2011), and some evidence even suggests that female pre-service teachers may report greater confidence in integrating ICT into instruction than their male counterparts (Al-Abdullatif, 2019). Collectively, these divergent findings indicate that the relationship between gender and TPACK is highly context-sensitive, underscoring the need for further investigation, particularly in contexts such as Nigeria, where cultural norms and systemic conditions may influence gendered experiences in teaching and learning.

Furthermore, the issue of students' perception of biology is increasingly recognised as critical to achievement. Research shows that students' attitudes and perceptions strongly influence their willingness to engage with scientific content and to pursue science-related careers. Where students perceive biology as abstract, irrelevant, or difficult, achievement suffers regardless of instructional input. Conversely, positive perceptions foster greater engagement, persistence, and performance. Integrating TPACK may help improve students' perceptions by making lessons more interactive, relevant, and learner-centred. However, empirical evidence on this relationship in Nigerian classrooms remains scarce, especially when gender differences are considered.

Taken together, the literature highlights three key gaps. First, biology achievement in Nigeria remains persistently low, largely due to the dominance of conventional lecture-based strategies. Second, although TPACK has been widely studied globally and shown to improve teaching and learning, its classroom implementation in Nigeria remains limited. Third, while gender differences in TPACK have been explored internationally, little is known about how gender interacts with TPACK-based instruction to influence students' achievement and perception in biology in the Nigerian context.

Against this backdrop, the present study investigates the effects of TPACK-based instructional strategies on secondary school students' achievement and perception in biology in Lagos State, Nigeria. Specifically, it examines whether gender interacts with instructional strategy to influence learning outcomes. By addressing these issues, the study contributes to the broader discourse on technology-enhanced science education and provides evidence to guide policy and practice in Nigerian secondary schools.

1.1. Purpose of the Study

The main purpose of the study was:

1. Examine the interaction effect of gender and TPACK instructional strategies on students' academic achievement in biology.
2. Investigate the interaction effect of gender and TPACK instructional strategies on students' perception of biology.

1.2. Hypotheses

To achieve these objectives, the following null hypotheses were tested:

H_{01}: There is no significant interaction effect of students' gender and instructional strategies on students' academic achievement in biology.

H_{02}: There is no significant interaction effect of students' gender and instructional strategies on students' perception of biology.

2. METHODOLOGY

2.1. Research Design

The study employed a pretest–posttest non-equivalent control group quasi-experimental research design with a 2×2 factorial matrix, designed to assess the impact of the TPACK instructional strategy on students' academic achievement and perception in biology across genders. The experimental levels were instructional strategies at 2 levels (TPACK instructional strategy and Conventional Lecture Method), and gender at 2 levels (Male and Female). The dependent variables were students' academic achievement in biology, measured using the Biology Achievement Test (BAT), and students' perception of biology, measured using the Students' Perception of Biology Teaching Questionnaire (SPBTQ).

This quasi-experimental design was adopted because intact classes, rather than randomly assigned individuals, were used for treatment and control groups, making it suitable for the school context. The factorial matrix further enabled the researcher to examine not only the main effects of instructional strategy and gender, but more importantly, the interaction effect of gender and instructional strategy on students' achievement and perception in biology.

2.2. Population for the Study

The study targeted Senior Secondary School 2 (SSS2) students in Lagos State, and the accessible population comprised SSS2 science and commercial students in Education District VI, Lagos State. This group was chosen because SSS2 students are at a critical stage of preparing for terminal examinations and have already been introduced to most of the core biology concepts relevant to the study, making them suitable for assessing instructional effects. In addition, selecting science and commercial students ensured diversity in academic orientation while keeping the focus on students who take biology as a subject, thereby providing a representative and manageable sample for meaningful analysis.

2.3. Sample and Sampling Techniques

The participants in this study comprised 337 Senior Secondary School 2 (SSS2) students drawn from both science and commercial streams. A multistage sampling procedure was employed to select the sample. In the first stage, one education district was chosen from the six Education Districts in Lagos State through simple random sampling, resulting in the selection of Education District VI. This approach was considered appropriate because it gave each district an equal chance of selection, thereby ensuring fairness and reducing selection bias. The selected district comprises three zones: Ikeja, Mushin, and Oshodi/Isolo. However, the Mushin zone was purposively chosen due to the researcher's easy access to schools within the zone and its relatively large concentration of public secondary schools, which increased the likelihood of obtaining a sufficient sample size for the study.

Furthermore, six public secondary schools were randomly selected from Mushin to enhance representativeness and to allow for the generalisation of findings within the study area. In each school, one intact class was selected using purposive sampling to avoid disruption to the existing class structure and to ensure administrative convenience. This technique was also considered appropriate because quasi-experimental studies often work with intact classes to preserve the natural classroom setting (Tijani, 2025). The six selected classes comprised four science and two commercial streams. Additionally, the intact classes were assigned to two groups, consisting of three classes each, through simple random sampling. This ensured that all classes had an equal opportunity of being assigned to either the experimental or control group, thus reducing researcher bias. The experimental group received instruction through the TPACK-based instructional strategy, whereas the control group was taught using the Conventional Lecture Method (CLM).

The intervention was conducted over a period of six weeks, covering the topic of the reproductive system. This topic was deliberately chosen because intact classes were used, making it necessary to align with the existing school scheme. Furthermore, the reproductive system is considered an important area of the curriculum, with a wide range of questions consistently asked in external examinations such as the West African Examination Council (WAEC), National Examinations Council (NECO), and Joint Admissions and Matriculation Board (JAMB). Additionally, it is a topic that requires conceptual clarity, making it suitable for testing the effectiveness of innovative strategies such as TPACK. Teachers' Instructional Guide on TPACK Strategy served as a stimulus instrument for teachers in the experimental group, while teachers in the control group used the conventional lesson plan.

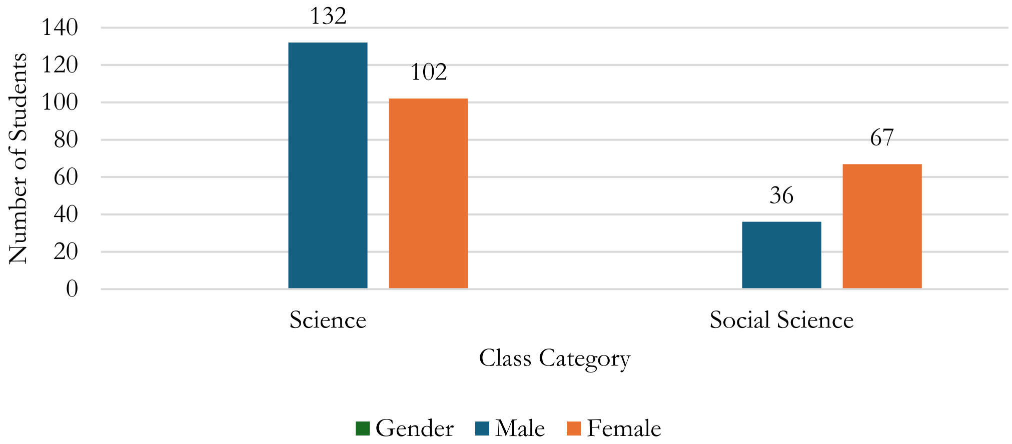

Figure 1. Distribution of Participants by Gender and Class Category

Figure 1 shows the distribution of participants by gender and class category. Out of the 337 students who participated in the study, 234 (approximately 69.4%) were drawn from science classes, while 102 (30.6%) were from social science classes. Among the science students, 132 were males, and 103 were females, whereas in the social science group, 37 were males and 65 were females. This distribution indicates a relatively balanced representation of both genders across the two class categories. This, however, ensures that the gender differences observed in the analysis are not due to unequal group composition.

2.4. Research Instruments

Four instruments were used for intervention and data collection, these include:

1. Teacher Pedagogical Content Knowledge Instructional Package
2. Biology Achievement Test (BAT)
3. Students' Perception of Biology Teaching Questionnaire (SPBTQ)
4. Teachers' Instructional Guide on TPACK Strategy

TPACK Instructional Package (for teachers): This consisted of nine sessions covering teaching methods, techniques, classroom management, lesson planning, introduction to CoRe, micro-teaching, and classroom trials. Each session followed a five-stage sequence (introduction, knowledge presentation, activity-based practice, evaluation, and feedback).

Biology Achievement Test (BAT): The BAT was a 30-item multiple-choice instrument developed to assess students' academic achievement in biology. The test items were adapted from past examination questions administered by the West African Examinations Council (WAEC) and the National Examinations Council (NECO) between 2020 and 2024, ensuring alignment with standardized curricular expectations. These examination bodies are regarded as providers of standardised and validated instruments for assessing secondary school students in Nigeria. Nevertheless, the researcher revalidated the adapted items to ensure alignment with the study's objectives and to confirm that they adequately measured the intended construct. Each correct response was scored 1 mark, while an incorrect response attracted no mark, giving a maximum score of 30. Participants were required to complete the test within 20 minutes.

Students' Perception of Biology Teaching Questionnaire (SPBTQ): The SPBTQ was adapted from the work of Kubiatko et al. (2017) to assess students' perception of biology teaching and learning. It consisted of 20 items structured on a four-point Likert scale, ranging from Strongly Disagree (SD = 1) to

Strongly Agree (SA = 4). The instrument covered four domains: perceived difficulty of the subject, students' interest in biology, perception of the teacher and teaching style, and use of instructional aids and experiments. None of the items was negatively worded, and all were scored in the positive direction, with higher scores indicating a more favourable perception of biology. On average, participants completed the questionnaire in 15 minutes.

Teachers' Instructional Guide on TPACK Strategy (for teachers): Lesson plan integrating Technological (TK), Pedagogical (PK), and Content Knowledge (CK) using digital tools, collaborative learning, and inquiry-based approaches.

2.5. Validity of Instruments

The instruments were subjected to face and content validity by three experts in science education and educational measurement. Their feedback ensured that the items were clear, relevant, and representative of the intended constructs (academic performance, perception, and TPACK integration). Construct validity was further supported by aligning items with the objectives of the biology curriculum and the TPACK framework.

2.6. Reliability of Instruments

To establish reliability, the BAT and SPBTQ were administered to a group of 20 students who were not part of the main study sample. Both instruments were administered twice to the same group, with a one-month interval between administrations. The test–retest reliability of the BAT was examined using the Intraclass Correlation Coefficient (ICC), resulting in a coefficient of 0.84, which reflects excellent temporal stability (Cicchetti, 1994). For the SPBTQ, internal consistency was assessed using Cronbach's alpha, yielding a coefficient of 0.78, which indicates acceptable reliability (Nunnally, 1978). These findings demonstrate that both instruments were sufficiently reliable for application in the main study.

2.7. Methods of Data Analysis

The data were analyzed using the Statistical Package for the Social Sciences (SPSS), version 27.0. Analysis of Covariance (ANCOVA) was conducted to test the null hypotheses at a 0.05 level of significance. The choice of ANCOVA was appropriate because it allowed the researcher to control for initial differences in students' pretest scores, thereby providing a more accurate estimate of the treatment effect attributable to the instructional strategies. This statistical technique also adjusts the posttest means for any pre-existing variation in the covariate, enhancing the validity of the comparisons between groups. Furthermore, estimated marginal means and Bonferroni-adjusted pairwise comparisons were further used to determine the direction and significance of observed effects.

3. RESULTS

H_{01}: There is no significant interaction effect of students' gender and instructional strategies on students' academic achievement in biology

Table 1 presents the results of the ANCOVA on the interaction effect of gender and instructional strategies on students' biology achievement. The analysis showed a significant main effect of instructional strategy, $F(1, 332) = 28.67$, $p < .001$, partial $\eta^2 = .080$, indicating that the strategy used had a strong influence on achievement. Gender also had a significant main effect, $F(1, 332) = 6.49$, $p = .011$, partial $\eta^2 = .019$, while the covariate (pre-test scores) did not exert a significant effect, $F(1, 332) = 1.16$, $p = .282$, partial $\eta^2 = .003$. Importantly, the interaction between gender and instructional strategies was significant, $F(1, 332) = 8.59$, $p = .004$, partial $\eta^2 = .025$, suggesting that the impact of instructional strategies varied for male and female students. This necessitates an examination of the estimated marginal means (Table 2) to understand the pattern of the interaction.

Table 1. ANCOVA on the Interaction Effect of Gender and Instructional Strategies on Students' Achievement in Biology

Tests of Between-Subjects Effects

Dependent Variable: BAT Post-test Score

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	1657.114[a]	4	414.278	12.298	0.000	0.129
Intercept	9207.953	1	9207.953	273.350	0.000	0.452
BAT Pre-test	39.127	1	39.127	1.162	0.282	0.003
Gender	218.532	1	218.532	6.487	0.011	0.019
Strategies	965.899	1	965.899	28.674	0.000	0.080
Gender * Strategies	289.297	1	289.297	8.588	0.004	0.025
Error	11183.616	332	33.686			
Total	125695.000	337				
Corrected Total	12840.730	336				

a. R Squared = .129 (Adjusted R Squared = .119), BAT = Biology Achievement Test

Table 2. Estimated Marginal Mean of Students' Achievement in Biology by Gender and Instructional Strategies

Dependent Variable: BAT Post-test Score

Gender		Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Male	TPACK	20.158[a]	0.649	18.881	21.436
	CLM	14.875[a]	0.622	13.652	16.099
Female	TPACK	19.917[a]	0.608	18.722	21.113
	CLM	18.350[a]	0.662	17.048	19.652

a. Covariates appearing in the model are evaluated at the following values: BAT Pretest Score = 13.91.

Table 2 shows the estimated marginal means of students' achievement in biology by gender and instructional strategy. Male students taught with the Teacher Pedagogical Content Knowledge (TPACK) strategy achieved the highest adjusted mean score (M = 20.16, SE = 0.65), compared with their peers taught with the Conventional Lecture Method (CLM; M = 14.88, SE = 0.62). Female students also performed better under TPACK (M = 19.92, SE = 0.61) than under CLM (M = 18.35, SE = 0.66), although the gap between strategies was smaller than that observed among males. These results indicate that while both genders benefited from TPACK, the advantage was particularly marked for male students, making it necessary to confirm these differences statistically through pairwise comparisons.

Table 3. Pairwise Comparison of Instructional Strategies and Gender on Biology Achievement

Dependent Variable: BAT Post-test Score

(I) Instructional Strategies/Gender		Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
TPACK	CLM	3.425*	0.640	0.000	2.167	4.683
CLM	TPACK	-3.425*	0.640	0.000	-4.683	-2.167
Male	Female	-1.617*	.635	.011	-2.866	-.368
Female	Male	1.617*	.635	.011	.368	2.866

*Based on estimated marginal means *. The mean difference is significant at the .05 level. b. Adjustment for multiple comparisons: Bonferroni.*

Table 3 presents the pairwise comparisons of instructional strategies and gender on biology achievement. The results indicate that students taught with the Teacher Pedagogical Content Knowledge (TPACK) strategy achieved significantly higher scores than those taught using the Conventional Lecture Method (CLM), Mean Difference = 3.43, SE = 0.64, p < .001, 95% CI [2.17, 4.68]. In addition, gender differences were observed, with male students performing significantly lower than their female counterparts overall, Mean Difference = –1.62, SE = 0.64, p = .011, 95% CI [–2.87, –0.37]. These results confirm that TPACK is more effective than CLM across genders and that females generally achieved higher scores than males. When considered alongside the significant interaction reported in Table 1 and the mean patterns in

Table 2, the evidence supports rejecting the null hypothesis. Thus, there is a significant interaction effect of gender and instructional strategy on students' academic achievement in biology, with TPACK providing greater benefits overall.

H_{02}: There is no significant interaction effect of students' gender and instructional strategies on students' perception of biology

Table 4 shows the ANCOVA results on the interaction effect of gender and instructional strategies on students' perception of biology. The main effect of gender was significant, $F(1, 332) = 9.01$, $p = .003$, partial $\eta^2 = .026$, with males reporting higher perception scores than females. Instructional strategies also had a significant main effect, $F(1, 332) = 4.13$, $p = .043$, partial $\eta^2 = .012$, suggesting that students' perceptions were influenced by the type of instructional approach used. However, the interaction between gender and instructional strategies was not significant, $F(1, 332) = 0.08$, $p = .775$, partial $\eta^2 < .001$, indicating that the effect of strategy did not vary between males and females. To clarify the direction of these effects, the estimated marginal means were examined as presented in Table 5.

Table 4. ANCOVA on the Interaction Effect of Gender and Instructional Strategies on Students' Perception of Biology

Tests of Between-Subjects Effects

Dependent Variable: SPB Post-test Score

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	1087.064[a]	4	271.766	3.902	0.004	0.045
Intercept	54487.449	1	54487.449	782.254	0.000	0.702
Pre-test Perception	177.462	1	177.462	2.548	0.111	0.008
Gender	627.625	1	627.625	9.011	0.003	0.026
Strategies	287.754	1	287.754	4.131	0.043	0.012
Gender * Strategies	5.677	1	5.677	0.081	0.775	0.000
Error	23125.257	332	69.654			
Total	1517904.000	337				
Corrected Total	24212.320	336				

a. R Squared = .045 (Adjusted R Squared = .033), SPB = Students' Perception of Biology

Table 5. Estimated Marginal Mean of Students' Perception of Biology by Gender and Instructional Strategies

Dependent Variable: SPB Post-test Score

Gender		Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Male	TPACK	68.765[a]	0.938	66.919	70.611
	CLM	67.115[a]	0.926	65.293	68.937
Female	TPACK	66.249[a]	0.881	64.517	67.982
	CLM	64.074[a]	0.951	62.202	65.946

a. Covariates appearing in the model are evaluated at the following values: SPB Pretest Score = 61.23.

Table 6. Pairwise Comparison of Instructional Strategies and Gender on Students' Perception of Biology

Dependent Variable: SPB Post-test Score

(I) Instructional Strategies/Gender		Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
TPACK	CLM	1.913*	0.941	0.043	.062	3.764
CLM	TPACK	-1.913*	0.941	0.043	-3.764	-.062
Male	Female	2.778*	.926	.003	.958	4.599
Female	Male	-2.778*	.926	.003	-4.599	-.958

*Based on estimated marginal means *. The mean difference is significant at the .05 level. b. Adjustment for multiple comparisons: Bonferroni.*

Table 5 presents the estimated marginal means of students' perception of biology by gender and instructional strategies. Male students taught with TPACK reported the highest adjusted perception score (M = 68.77, SE = 0.94), followed closely by males taught with CLM (M = 67.12, SE = 0.93). Among females, those exposed to TPACK (M = 66.25, SE = 0.88) outperformed those taught with CLM (M = 64.07, SE = 0.95). This pattern suggests that while TPACK enhanced perception for both genders, males consistently reported higher perception scores overall. Pairwise comparisons (Table 6) were then conducted to test whether these observed differences were statistically significant.

Table 6 presents the pairwise comparisons of instructional strategies and gender. Results show that students taught with TPACK had significantly higher perception scores than those taught with CLM, Mean Difference = 1.91, SE = 0.94, p = .043, 95% CI [0.06, 3.76]. Similarly, males reported significantly higher perception scores than females, Mean Difference = 2.78, SE = 0.93, p = .003, 95% CI [0.96, 4.60]. Taken together, these findings confirm significant main effects of gender and instructional strategy but no interaction effect. Therefore, the null hypothesis is retained, as there is no significant interaction between gender and instructional strategy on students' perception of biology.

4. DISCUSSION

The results of this study indicate that the Technological Pedagogical Content Knowledge (TPACK)–based instructional approach led to significantly higher student achievement in biology than the Conventional Lecture Method (CLM). This enhanced performance can be explained by the integrative nature of the TPACK framework, which systematically combines technology, pedagogy, and content to support interactive visualization, inquiry-oriented learning, and greater learner autonomy. Such multimodal engagement likely enhanced students' conceptual understanding and motivation compared to the passive lecture approach. The result, therefore, supports the position of Mishra and Koehler (2006), who argued that effective instruction in the twenty-first century requires an integration of technology, pedagogy, and content. Similarly, Niess (2005) emphasised that TPACK fosters inquiry-based teaching, which enhances students' ability to engage actively with scientific concepts. The higher achievement scores observed among students exposed to TPACK in this study corroborate the findings of Malik et al. (2019) and Huang and Lajoie (2021), who reported that TPACK-oriented instruction promoted better engagement and understanding. Yanti et al. (2019) and Zulyusri et al. (2022) also found that TPACK consistently improves learning outcomes in post-COVID educational settings, affirming the generalisability of the present study's findings across diverse contexts.

Some recent studies also reinforce the present finding that TPACK-based instruction provides a robust framework for improving students' achievement in biology and other science subjects. Adebusuyi et al. (2020) found that Chemistry teachers' levels of TPACK significantly influenced students' scientific attitude and literacy in Southwestern Nigeria, underscoring that effective integration of technology, pedagogy, and content enhances student learning outcomes. Similarly, Pratumsala and Nuangchalerm (2023) reported that the application of TPACK principles in lower secondary science classrooms markedly improved students' scientific literacy and engagement. In support, a meta-analysis by Zulkifli et al. (2022) concluded that the integrated STEM–TPACK learning model had a strong positive effect on students' 21st-century skills, including collaboration, critical thinking, and problem solving.

With respect to gender, the study revealed a significant main effect, with female students outperforming their male counterparts in biology achievement. The higher performance of female students in this study may reflect their stronger engagement and collaboration tendencies during the TPACK sessions. This result, however, contrasts with findings from Mailizar et al. (2021), Cheng (2017), and Liu et al. (2015), who reported that male teachers and learners generally expressed greater confidence in technology-related domains. However, it aligns with the work of Al-Abdullatif (2019), who found that female pre-service teachers demonstrated greater confidence in ICT integration. It is possible that female students in this study benefited more from TPACK's multimodal approach, which combined visual, interactive, and practical elements that reduced reliance on rote memorisation and instead fostered meaningful learning. This result also aligns with Nigerian evidence suggesting that digital strategies can create more inclusive and engaging learning environments, thereby bridging gender gaps in science classrooms (Yusuf & Balogun, 2011).

The study further found a significant interaction effect between gender and instructional strategy, indicating that the impact of TPACK differed for males and females. While both groups benefited from the approach, the gains were more pronounced among females. This is particularly important in light of inconclusive international findings on gender and TPACK. Whereas Jang and Tsai (2013) and Ergen et al. (2019) reported higher TPACK scores among males, Koh and Sing (2011) found no significant gender differences. The current result adds nuance by showing that, at the learner level in Nigeria, gender interacts with instructional strategy in ways that favour female students. This suggests that context plays a crucial role in how gender influences technology-enhanced pedagogy.

In terms of perception, the study found that students taught with TPACK reported significantly more positive perceptions of biology than those taught with CLM. This echoes the findings of Bwalya et al. (2024), who argued that TPACK enhances learners' 21st-century competencies by promoting interactive and student-centred experiences. By making abstract biological processes more concrete through animations, simulations, and models, TPACK likely contributed to greater enjoyment and relevance in learning. This is consistent with international evidence that digital technologies enhance students' attitudes toward science (Yanti et al., 2019; Huang & Lajoie, 2021). However, the study found no significant interaction between gender and instructional strategy in perception, suggesting that while TPACK improved attitudes overall, the benefits were equally shared by male and female learners. This result contrasts with studies that emphasised gendered differences in confidence toward technology (Mailizar et al., 2021; Cheng, 2017; Liu et al., 2015), but it demonstrates that when well implemented, technology-supported pedagogy can foster inclusivity in Nigerian classrooms.

The findings of this study have significant implications for teaching practice. The evidence demonstrates that TPACK not only improves achievement but also enhances students' perception of biology. Teachers are therefore encouraged to adopt technology-supported pedagogies rather than relying solely on lecture-based methods. The integration of multimedia tools, simulations, and interactive activities should be prioritised to make abstract concepts more concrete and to encourage students' active participation. Furthermore, since female students appeared to benefit particularly from TPACK, its adoption may contribute to narrowing gender disparities in science achievement, thereby promoting equity in classroom outcomes.

At the policy and research level, the findings highlight the urgent need for professional development programmes that equip teachers with TPACK competencies. Teacher training institutions and ministries of education should provide structured workshops and resources to enhance teachers' technological, pedagogical, and content knowledge. This is especially important in Nigeria, where studies such as Usman et al. (2023) and Yalley (2017) have shown that limited teacher training and resource constraints hinder effective TPACK adoption. Policymakers should also consider investing in digital infrastructure and accessible resources to ensure that all schools, including those in underserved areas, can benefit from technology-enhanced instruction. Finally, further research should explore the long-term effects of TPACK-based strategies across other science subjects, as well as the mechanisms through which gender interacts with instructional strategies in different cultural and educational contexts.

5. CONCLUSION, LIMITATIONS, AND RECOMMENDATIONS

5.1. Conclusion

This study examined the effects of Technological Pedagogical Content Knowledge (TPACK) and the Conventional Lecture Method (CLM) on secondary school students' achievement and perceptions of biology in Lagos State, with gender analyzed as a moderating variable. The findings showed that TPACK significantly improved students' achievement and perception compared with CLM. Gender had a significant main effect on achievement, with females outperforming males, while both genders benefited equally in terms of perception. In addition, a significant interaction was observed between gender and instructional strategy on achievement, but not on perception. These results suggest that while TPACK is generally beneficial for all students, its impact on achievement may vary by gender.

5.2. Limitations

Although the findings provide useful insights, certain limitations should be acknowledged. First, the study employed a quasi-experimental design with intact classes, which limited random assignment of participants and may have introduced group-level influences. Second, the research was restricted to a single education district in Lagos State, which may limit the generalisability of the findings to other contexts. Third, the intervention lasted only six weeks and focused on the topic of reproduction, which may not capture the long-term effects of TPACK or its applicability across all biology topics. Finally, the study relied on the teachers' implementation of lesson guides, which may have varied despite efforts to ensure fidelity of instruction.

5.3. Recommendations and Suggestions for Future Studies

Based on the findings and limitations, the following recommendations are proposed:

1. Teachers should adopt TPACK-based strategies in biology classrooms to improve students' achievement and perception.
2. Teacher training institutions should integrate TPACK into pre-service and in-service professional development programmes.
3. School administrators and policymakers should provide the necessary digital resources and infrastructure to support the effective use of TPACK.
4. Curriculum developers should incorporate technology-supported pedagogies into science syllabuses to promote active and inclusive learning.
5. Further studies should extend the duration of interventions and explore the use of TPACK across other biology topics and science subjects.
6. Future research should include larger and more diverse samples across multiple education districts to strengthen the generalisability of findings.

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Research Ethics. Ethical approval for this study was obtained from the Department of Science Education, University of Lagos, through the Postgraduate Study Coordinator and the Head of Department. All procedures performed in the study involving human participants were conducted in accordance with institutional guidelines and adhered to established ethical standards for research in education. Permission to access the participating schools was granted by the principals of the selected schools.

Data Availability Statement. The dataset generated and analysed during the course of this study includes sensitive and potentially identifiable students' scores and is therefore not publicly available to protect participant confidentiality. However, data may be made available by the corresponding author upon reasonable request, subject to approval and a formal data-sharing agreement.

Conflicts of Interest. The authors declare that they have no conflicts of interest.

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