

Comparative Achievement of Students in Integrated Chemical Quantitative and Representational Concepts through 10E-Learning and Flipped Classroom Strategies in Delta State, Nigeria

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Abstract: Chemistry instruction at the senior secondary level often requires students to connect quantitative relationships with chemical representations. This study compared the achievement of SS II Chemistry students who learned selected integrated quantitative and representational concepts through 10E-learning and flipped classroom strategies in Delta State, Nigeria. A planned variation quasi-experimental design with a pretest–posttest arrangement was employed. The population comprised 39,904 SS II Chemistry students in public secondary schools in the state, from which 258 students in six public secondary schools were selected. Data were collected with the Chemistry Achievement Test (CAT), while instructional lesson plans guided the two treatments. Mean and standard deviation were used to describe achievement, and analysis of covariance was applied to test the hypotheses. Students in the 10E-learning group recorded a posttest mean of 62.10, compared with 59.18 for students in the flipped classroom group. Although the difference of 2.92 points favoured the 10E-learning group descriptively, it was not statistically significant, $F(1, 255) = 3.204$, $p = .075$. The interaction between instructional strategy and sex was also not significant, $F(1, 253) = 0.309$, $p = .579$. The findings indicate that the two strategies produced comparable achievement outcomes under the conditions of the study. The findings provide evidence for Chemistry teachers and education stakeholders considering structured learner-centred strategies in Delta State.

Keywords: 10E-learning, flipped classroom, Chemistry achievement, sex.

Introduction

Chemistry is a major component of secondary school science because it helps learners explain the composition, properties and changes of matter. Knowledge of Chemistry is also relevant to medicine, agriculture, environmental management, energy and manufacturing (Emerhiona et al., 2018). At the senior secondary level, students have to connect observable chemical events with particulate explanations, symbolic representations and quantitative relationships. Rüschenpöhler and Markic (2020) emphasised the importance of students' experiences in developing meaningful connections with Chemistry. Because these different forms of understanding must be coordinated during learning, the organisation of classroom instruction becomes an important consideration.

An instructional strategy provides the framework through which a teacher organises explanations, activities, interaction, practice and assessment. Active learning is particularly relevant because it gives students opportunities to work with ideas, solve problems and receive feedback instead of relying mainly on passive reception of information. Freeman et al. (2014), in a broad analysis of STEM education, reported improved performance associated with active learning. Evidence from Nigerian Chemistry classrooms also points to the value of structured learning cycles. Jack (2017) reported improved Chemistry achievement following learning-cycle instruction, while Bilesanmi-Awoderu et al. (2018) found achievement differences among students exposed to different learning-cycle models. These findings provide a useful basis for considering the two instructional arrangements examined in this study.

The first strategy was 10E-learning, a researcher-developed sequence comprising Excite, Explore, Elicit, Explain, Elaborate, Extend, Exchange, Examine, Evaluate and Empower. It moves learners progressively from gaining attention and exploring ideas to explaining, applying, sharing, examining and evaluating their understanding, with the final phase encouraging greater independence. Although the 10E sequence was developed for this study, its organisation reflects the broader learning-cycle tradition. Polanin et al. (2024), in a systematic review and meta-analysis, examined evidence on the 5E instructional model, while Nigerian studies have also reported achievement effects associated with learning-cycle instruction (Bilesanmi-Awoderu et al., 2018; Jack, 2017). This evidence provides a useful context for examining the researcher-developed 10E-learning sequence.

The second strategy was the flipped classroom. In this arrangement, students encounter selected instructional materials before the scheduled lesson, leaving more classroom time for clarification, discussion, application, problem-solving and feedback. Srinivasan et al. (2018) described the model in Chemistry education as a reorganisation of instructional time that can create room for active and collaborative classroom work. Its effectiveness, however, depends partly on how that classroom time is used. Van Alten et al. (2019) reported a modest overall learning benefit and identified design features that can influence outcomes. Strelan et al. (2020) likewise found an overall positive effect of flipped instruction across a wide range of studies. These features make the flipped classroom a meaningful strategy against which the structured 10E-learning sequence can be compared.

Achievement is an important basis for comparing instructional strategies because it indicates what students have learned and how effectively they can use the knowledge developed during instruction. In Chemistry, this involves more than recalling facts; students may need to interpret representations, relate quantities, recognise patterns, explain reactions and apply principles to problems. Nigerian research has shown that instructional arrangements can be associated with different achievement outcomes (Bileanmi-Awoderu et al., 2018; Jack, 2017). Evidence from secondary-school Chemistry also suggests that flipped instruction can improve performance and problem-solving when compared with non-flipped teaching (Yu et al., 2023). These findings, however, do not show how flipped classroom learning compares with another learner-centred strategy, creating the need for a direct comparison.

A direct comparison of the two strategies is therefore necessary. Evidence that a strategy performs well against conventional instruction does not establish how it will perform when compared with another learner-centred strategy. Yu et al. (2023), for example, examined flipped instruction against a non-flipped condition, whereas this study places flipped classroom learning alongside 10E-learning. Both approaches encourage participation, but they differ in how learning activities are sequenced and how classroom time is used. Recent Chemistry research also indicates that outcomes from flipped instruction can vary with the design and duration of implementation (Gomez et al., 2025; Yu et al., 2023). This comparative question also brings attention to whether achievement patterns are similar for male and female students.

Sex is included in the comparison because achievement patterns may vary across instructional conditions and such differences need to be established from evidence rather than assumed. Findings from Nigerian Chemistry studies are not uniform. Idika (2017) reported no significant difference in Chemistry achievement between male and female students, whereas other studies have reported varying patterns under particular instructional conditions (Jack & Zubairu, 2022; Nwafor et al., 2023). The mixed evidence makes it necessary to determine whether the two strategies produce different achievement patterns for male and female students.

Taken together, the literature provides evidence on learning-cycle models and flipped classrooms, but offers limited direct evidence comparing the researcher-developed 10E-learning sequence with flipped classroom learning among SS II Chemistry students in Delta State. This study therefore compared students' achievement following instruction through the two strategies and examined whether instructional strategy interacted with sex. The comparison was conducted within Periodic Table I and II, Chemical Reactions I and II, and Mass, Volume Relationship I and II, providing a defined content context for the investigation.

Statement of the Problem

Chemistry students are expected to understand chemical concepts, interpret representations and use quantitative relationships in solving problems. Yet the abstract and interconnected nature of Chemistry can make these expectations difficult to realise when students have limited opportunities to explore ideas, apply knowledge, discuss their reasoning and receive feedback. The instructional strategy used in the classroom is therefore important because it shapes students' engagement with the subject. Both 10E-learning and the flipped classroom provide opportunities for active participation, although they structure learning activities and classroom time differently.

The specific problem is the limited evidence on the achievement outcomes of SS II Chemistry students taught through 10E-learning and flipped classroom strategies in Delta State. It is equally unclear whether the achievement pattern associated with either strategy varies according to sex. Without such evidence, it is difficult to establish whether the two approaches produce comparable outcomes or whether their effects differ across male and female students. The present study therefore compared the achievement of SS II Chemistry students taught through the two strategies and examined the interaction between instructional strategy and sex.

Purpose of the Study

The aim of the study was to compare the achievement of SS II Chemistry students taught through 10E-learning and flipped classroom learning strategies in Delta State. Specifically, the study sought to:

1. compare the mean achievement scores of students taught Chemistry using 10E-learning and flipped classroom learning strategies;
2. determine the interaction effect of instructional strategy and sex on students' achievement in Chemistry.

Research Questions

The study was structured on two research questions:

1. What is the difference in the mean achievement scores of students taught Chemistry using 10E-learning and flipped classroom learning strategies?
2. What is the interaction effect of instructional strategy and sex on students' achievement in Chemistry?

Hypotheses

The following null hypotheses were tested:

1. There is no significant difference in the mean achievement scores of students taught Chemistry using 10E-learning and flipped classroom learning strategies.
2. There is no significant interaction effect of instructional strategy and sex on students' achievement in Chemistry.

Methods

A planned variation quasi-experimental design with a pretest–posttest arrangement was used. The study involved two instructional groups: students taught through 10E-learning and those taught through the flipped classroom strategy. The design was appropriate because intact classes were used rather than individually assigning students to treatment conditions.

The population comprised 39,904 SS II students in 495 public secondary schools in Delta State. The sample consisted of 258 SS II Chemistry students selected from six public secondary schools. Three schools were assigned to the 10E-learning group, while three schools were assigned to the flipped classroom group. The sample comprised 78 male and 180 female students. Intact classes were used for the study.

Students in the 10E-learning group were taught through the ten phases of Excite, Explore, Elicit, Explain, Elaborate, Extend, Exchange, Examine, Evaluate and Empower. For the flipped classroom group, teacher-prepared materials were provided before the classroom sessions. Face-to-face periods were then used for clarification, discussion, application, collaborative problem-solving and feedback.

The intervention lasted six weeks and covered Periodic Table I and II, Chemical Reactions I and II, and Mass, Volume Relationship I and II. Before the intervention began, the regular Chemistry teachers serving as research assistants received three days of training.

Achievement was measured with the Chemistry Achievement Test (CAT), comprising 50 multiple-choice items drawn from the selected content areas. A correct response earned two marks, while an incorrect response earned zero, giving a maximum score of 100. Three experts examined the instrument for face and content validity. Reliability was determined through a pilot administration involving 35 SS II students using the Kuder–Richardson 21 procedure, which produced a coefficient of 0.71.

The CAT was administered before instruction as the pretest and again after the six-week intervention as the posttest. Mean and standard deviation were used to summarise achievement, while ANCOVA was employed to compare the two groups and test the interaction between instructional strategy and sex. The hypotheses were tested at the 0.05 level of significance.

RESULTS

Table 1: Comparison of Students' Pretest and Posttest Achievement Scores

Group	N	Pretest		Posttest		Mean Difference
		($\bar{x}$)	SD	($\bar{x}$)	SD	
10E-learning	124	16.27	5.65	62.10	13.16	45.83
Flipped classroom	134	16.43	5.67	59.18	13.37	42.75

Table 1 shows that the 10E-learning group recorded a posttest mean achievement score of 62.10, compared with 59.18 for the flipped classroom group. The descriptive mean difference was therefore 2.92 points in favour of the 10E-learning group.

Table 2: ANCOVA Comparing Students' Achievement Scores

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	945.391 ^a	2	472.695	2.698	.069
Intercept	89132.018	1	89132.018	508.751	.000
Pretest	397.140	1	397.140	2.267	.133
Methods	561.395	1	561.395	3.204	.075

Error	44675.400	255	175.198
Total	992508.000	258	
Corrected Total	45620.791	257	

Table 2 indicates that the difference between the groups was not statistically significant, $F(1, 255) = 3.204$, $p = .075$. Because the probability value exceeded .05, Hypothesis One was not rejected. The result therefore indicates that the two instructional groups did not differ significantly in achievement after adjustment for the pretest score.

Table 3: Descriptive Statistics on Interaction Effect of Instructional Strategy and Sex

Testing	Sex	Instructional Strategies							
		10E-learning				Flipped classroom			
		N	Mean	SD	MD	N	Mean	SD	MD
Pretest	Male	37	15.43	5.41	1.19	41	15.41	5.445	1.46
	Female	87	16.62	5.74		93	16.87	5.732	
	Total	124				134			
Posttest	Male	37	62.11	13.00	0.02	41	60.54	13.77	1.96
	Female	87	62.09	13.30		93	58.58	13.23	
	Total	124				134			

Table 3 shows almost identical achievement means for male and female students in the 10E-learning group. In the flipped classroom group, however, the male students recorded a higher mean than the female students. These descriptive differences were subsequently examined using ANCOVA.

Table 4 ANCOVA Summary of the Interaction Effect of Instructional Strategy and Sex on Achievement

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1096.185 ^a	4	274.046	1.557	.186
Intercept	89106.875	1	89106.875	506.328	.000
Pretest	439.067	1	439.067	2.495	.115
Methods	358.195	1	358.195	2.035	.155
Sex	89.871	1	89.871	.511	.476
Methods * Sex	54.415	1	54.415	.309	.579
Error	44524.605	253	175.987		
Total	992508.000	258			
Corrected Total	45620.791	257			

Table 4 shows that the interaction between instructional strategy and sex was not statistically significant, $F(1, 253) = 0.309$, $p = .579$. Since the probability value was above .05, Hypothesis Two was not rejected. Thus, the evidence did not demonstrate a significant interaction between instructional strategy and students' sex in relation to Chemistry achievement.

Discussion of Findings

Students who received 10E-learning recorded a higher posttest mean than those who received flipped classroom instruction, but the difference was not statistically significant. Although the descriptive result favoured the 10E-learning group, the evidence was insufficient to conclude that the two strategies differed significantly in achievement. Both groups also showed substantial increases from their pretest scores, indicating improvement during the intervention.

This finding is consistent with research showing that structured, active learning can support students' academic performance without implying that every active-learning model will outperform every other model. Freeman et al. (2014), in a large meta-analysis of STEM education, found an overall advantage for active learning over traditional lecturing, while Polanin et al. (2024) synthesised evidence on the 5E instructional model and demonstrated the continuing research interest in structured learning-cycle instruction. The present finding extends this line of evidence in a different way because the comparison was between two learner-centred arrangements rather than between an active-learning model and conventional lecture instruction. The similarity in achievement outcomes may therefore reflect the fact that both strategies provided opportunities for engagement, application and feedback.

The result also agrees in part with the literature on flipped classroom instruction while differing from studies that compared flipping with conventional instruction. Yu et al. (2023) found significantly higher academic performance for secondary school Chemistry

students in a flipped classroom than in a non-flipped classroom. Similarly, Strelan et al. (2020) reported a moderate overall effect of flipped classrooms across a large body of research. However, those findings do not establish that flipped classroom instruction should produce higher achievement than every alternative learner-centred strategy. In the present study, the comparator was 10E-learning, which itself incorporated exploration, explanation, application, exchange and evaluation. The absence of a significant difference may therefore be understood within the specific nature of the comparison rather than as evidence that flipped learning lacks educational value.

The finding further corresponds with evidence that the effectiveness of flipped learning depends on how the classroom is designed and what students do before and during class. Van Alten et al. (2019) found that flipped instruction had a small positive effect overall and identified design characteristics such as maintaining face-to-face learning time and incorporating quizzes as relevant to outcomes. Srinivasan et al. (2018) similarly emphasised that the activities undertaken outside class and the use of the time released inside class are important considerations in flipped Chemistry instruction. In the present study, the flipped classroom involved pre-class instructional materials followed by clarification, discussion, application, collaborative problem-solving and feedback. These features may have provided learning opportunities comparable in educational function to several phases of the 10E-learning sequence, helping to explain the absence of a statistically significant difference.

The finding differs from Bilesanmi-Awoderu et al. (2018), who reported significant differences in Chemistry achievement among students exposed to different learning-cycle models. It also differs from Jack (2017), who reported a significant achievement advantage for learning-cycle instruction compared with lecture instruction. The differences are understandable because the comparison conditions in those studies were not the same as those in the present study. The current study contrasted a researcher-developed 10E-learning sequence with a flipped classroom, whereas earlier Nigerian studies compared learning-cycle models with other instructional arrangements. The present result therefore contributes evidence on a narrower but less frequently examined question: whether two structured learner-centred strategies produce significantly different Chemistry achievement outcomes when directly compared.

No significant interaction was found between instructional strategy and sex. Male and female students in the 10E-learning group recorded almost identical posttest means, whereas the male students in the flipped classroom group had a higher mean than their female counterparts. The ANCOVA result showed, however, that these descriptive differences did not amount to a statistically significant interaction. The evidence therefore did not establish that the achievement effect of either strategy varied systematically by sex.

This finding is consistent with evidence that sex differences in Chemistry achievement are not necessarily stable across instructional settings. Idika (2017) reported no significant difference between male and female students' Chemistry achievement in the context examined, while Nwafor et al. (2023) also investigated gender alongside Chemistry instructional strategy and achievement. Jack and Zubairu (2022), however, reported that gender patterns in achievement, retention and attitude could emerge in a study involving the 4MAT teaching model. The mixed nature of these findings supports the need to interpret sex-related outcomes within the particular instructional, content and school context in which they are obtained rather than assuming a uniform pattern across Chemistry classrooms.

The finding also provides an important qualification to the comparative result. The absence of a significant interaction does not mean that male and female students necessarily experienced the two strategies in exactly the same manner; rather, it means that the available evidence in this sample did not demonstrate a statistically significant difference in the pattern of instructional-strategy effects by sex. This distinction is important in interpreting quasi-experimental research because observed mean differences can occur without reaching statistical significance. The present result therefore supports a cautious conclusion that neither strategy demonstrated a statistically differentiated achievement pattern by sex under the conditions of the study.

Finally, the result should be considered alongside the characteristics of the sample, intervention and Chemistry content. The study involved SS II students, intact classes and six weeks of instruction across Periodic Table, Chemical Reactions, and Mass, Volume Relationship topics. Other studies have used different samples, content areas, durations and instructional implementations, all of which can affect the magnitude and direction of observed achievement differences. The present finding consequently adds context-specific evidence rather than suggesting that sex is unrelated to Chemistry achievement under all instructional conditions.

Conclusion

The findings of the study led to the conclusion that both 10E-learning and flipped classroom instruction supported students' achievement in the selected Chemistry topics. Although the 10E-learning group recorded the higher posttest mean, the difference between the two groups was not statistically significant. The interaction between instructional strategy and sex was also not significant under the conditions of the study.

Recommendations

Based on the findings, the following recommendations were made:

1. Chemistry teachers in Delta State should consider using both 10E-learning and flipped classroom strategies to support students' achievement.
2. Chemistry teacher-training programmes should expose teachers to the planning and implementation of both instructional strategies.
3. School administrators should provide relevant instructional resources for the effective implementation of learner-centred Chemistry instruction.
4. Further studies should examine the two strategies using larger samples and other Chemistry topics across different senatorial districts of Delta State.

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