Effects of Metacognitive, Flipped-Classroom and Lecture Instructional Methods on Physics Students' Critical Thinking in Delta State

P. C., Udubrakpor, E. Kpangban and O.P. Ajaja

Department of Science Education, Faculty of Education, Delta State University, Abraka Delta State Nigeria

ABSTRACT

This study compared the effects of metacognitive, flipped-classroom, and lecture instructional methods on physics students' critical thinking in Delta State. The study was guided by five research questions and five null hypotheses. A quasi-experimental design comprising pre-test, post-test, and planned variation using a 3 x 2 factorial design was adopted for the study. The population comprised 29,817 SS (II) students studying physics in all public secondary schools in Delta State for the 2023/2024 session. A sample of 282 SS2 students was drawn from six co-educational secondary schools in Delta State using a multi-stage sampling technique. Data were collected using the Students' Critical Thinking Inventory in Physics (SCTIIP), with a reliability index of 0.84. Data were analysed using mean and standard deviation statistics, one-way analysis of variance (ANOVA), and analysis of covariance (ANCOVA). All hypotheses were tested at the 0.05 alpha level. The findings of the study are as follows: (i) There was a significant difference in the critical thinking mean scores of physics students taught with metacognitive, flipped-classroom, and lecture instructional strategies. (ii) There is no significant difference in the mean critical thinking scores between male and female students taught physics using the metacognitive instructional strategy. (iii) There was a significant difference in the critical thinking mean scores between male and female students taught physics using the flipped classroom instructional strategy.(iv) There is no significant difference in the critical thinking mean scores between male and female students taught physics using the lecture instructional strategy. (v) There is no significant interaction effect of instructional strategies and sex on students' critical thinking in physics.Based on the findings, it is concluded that instructional strategy significantly affects students' critical thinking. It is recommended that physics teachers be trained in the development and implementation of both flipped-classroom and metacognitive strategies.

Keywords: Critical thinking, Metacognitive instructional strategy, Flipped classroom, Sex differences, Physics education

INTRODUCTION

Critical thinking is a deliberate and self-regulated process of making reasoned judgments through the careful analysis, evaluation, and interpretation of information. It involves the ability to think logically, solve problems systematically, and make informed decisions based on available evidence. As a disciplined intellectual process, critical thinking actively applies, analyses, synthesises, and evaluates information (Sellars et al., 2018). Halpern (2018) defined it as goal-directed, reasoned thinking used to solve problems and make sound decisions, while Paul and Elder (2014) described it as thinking that improves in quality through the application of appropriate intellectual standards. Consequently, the development of critical thinking has become a major goal of contemporary science education, as it enables students to understand concepts deeply, solve unfamiliar problems, and apply knowledge to real-life situations.

In physics, critical thinking is particularly indispensable because the subject requires students to analyse complex concepts, interpret scientific phenomena, evaluate evidence, and apply principles to diverse situations rather than merely memorising facts. However, many students approach physics as a subject demanding rote memorisation instead of conceptual understanding and analytical reasoning (Udubrakpor et al., 2026). This misconception limits their ability to apply learned principles to new situations, leading to difficulties in abstract reasoning, problem-solving, and the application of scientific principles to practical contexts. Students with poor critical thinking skills struggle to analyse scientific theories, evaluate evidence, and generate innovative solutions to scientific challenges, ultimately preventing them from developing essential competencies for scientific literacy (Udubrakpor et al., 2026).

To address these challenges, there is a growing need for instructional approaches that actively engage students in hands-on activities, collaborative learning, inquiry, and problem-solving tasks. The National Policy on Education (2018) emphasised the need for instructional approaches that foster higher-order thinking and meaningful learning. Despite this recommendation, many teachers continue to rely predominantly on the conventional lecture method, a teacher-centred approach in which information is presented verbally with limited student interaction (Mbonyiryivuze et al., 2019). While the lecture method offers advantages such as covering substantial content efficiently, it has significant drawbacks, including promoting passive learning, failing to address individual needs, and not developing students' reasoning power (Sharma, 2020). These limitations have prompted a shift in research toward innovative methods such as metacognitive and flipped-classroom instructional approaches.

The metacognitive teaching method is a learner-centred approach that guides students to think about how they learn, monitor their own understanding, and make adjustments as needed (Nelson & Narens, 2020). This method empowers students to reflect on their thinking processes and coordinate their own learning (Nzeadibe et al., 2019). The flipped classroom instructional method reverses traditional content delivery, allowing students to engage with instructional content independently outside class and use in-class time for active learning, discussion, and problem-solving (Bhat & Bhat, 2018). Previous studies have demonstrated the effectiveness of both methods in promoting critical thinking across various subjects (Ma, 2023; Khosravi et al., 2023; Xiying & Gang, 2019; Aneshie-Otakpa & Andor, 2022). However, these findings were obtained primarily from subject areas other than physics, creating the need to investigate whether similar outcomes can be achieved in physics classrooms.

Physics is a branch of science concerned with the study of matter, energy, and their interactions, providing the fundamental principles governing the physical world. The objectives of physics education at the secondary school level include providing basic physics literacy, equipping students with fundamental concepts for further studies, developing scientific skills for technological applications, and stimulating creativity (FGN, 2018). Physics contributes significantly to technological innovations and enhances understanding in related disciplines, making it indispensable for nations striving for scientific and technological advancement (Babajide et al., 2018).

Although numerous instructional strategies have been introduced to improve physics teaching and learning, the lecture method remains dominant in many secondary school classrooms, largely due to teachers' inadequate awareness and utilisation of innovative teaching strategies (Josiah et al., 2021). This continued dependence on the lecture method underscores the need to examine learner-centred approaches capable of fostering critical thinking skills in physics. While metacognitive and flipped-classroom methods have shown promise in other subjects, their effectiveness in physics education, particularly in the Nigerian context, remains underexplored. Furthermore, the effects of these instructional methods on students' critical thinking may vary across sexes, as some studies have found no significant relationship between sex and achievement when exposed to instructional methods (Odewumi & Yusuf, 2018; Ikwuka & Okoye, 2021), whereas others have reported substantial differences favouring males (Albalawi, 2018; Chebotib et al., 2020; Ma, 2023). This relationship remains inconclusive, necessitating further investigation.

Therefore, this study aims to compare the effects of metacognitive, flipped classroom, and lecture methods on students' critical thinking in physics in Delta State and determine whether these effects are sex-dependent. The findings will contribute to addressing the gap in physics education research and inform instructional practices in secondary schools.

Statement of the Problem

Physics is an important science subject for technological development and for preparing students for further studies and careers in science, engineering, medicine and related fields. Beyond the acquisition of factual knowledge and computational skills, effective Physics education is expected to develop students' ability to analyse information, evaluate evidence, solve problems logically, make reasoned judgements and apply scientific principles to unfamiliar situations. These abilities are central to critical thinking, which has become increasingly important in contemporary science education. Despite the importance of critical thinking in Physics learning, classroom instruction in many secondary schools continues to rely substantially on teacher-centred approaches, particularly the lecture method. The lecture method often places the teacher at the centre of knowledge transmission, with students primarily listening, taking notes and reproducing information during assessment. Although the method can facilitate the coverage of extensive content within limited instructional time, its predominant use may provide limited opportunities for students to question assumptions, monitor their thinking, evaluate alternative explanations and engage actively in higher-order reasoning. Consequently, students may experience difficulties in transferring Physics knowledge to unfamiliar problems and real-life situations.

The problem has stimulated interest in instructional approaches that make students more active participants in the learning process. The metacognitive instructional method encourages learners to plan, monitor and evaluate their own thinking and learning strategies. By making students consciously reflect on how they approach problems, identify errors and evaluate their solutions, the method may strengthen the cognitive processes associated with critical thinking. Similarly, the flipped-classroom instructional method restructures conventional teaching by exposing students to basic instructional materials before class and using classroom time for problem-solving, practical activities, collaborative learning, discussion and teacher-guided application. These features may provide greater opportunities for students to engage in analysis, evaluation and reasoned decision-making.

However, the relative effectiveness of these approaches in improving secondary school students' critical thinking in Physics remains an important empirical question. In particular, it is not sufficiently clear whether metacognitive instruction or flipped-classroom instruction produces greater improvements in students' critical thinking than the conventional lecture method. Furthermore, differences in students' responses to instructional methods based on sex require consideration, since male and female students may experience and respond differently to classroom learning environments.

The persistence of teacher-centred instructional practices, coupled with the need to develop students who can think critically and apply Physics knowledge effectively, therefore creates a need for empirical evidence on alternative instructional approaches. It is against this problem that this study investigates the effects of metacognitive, flipped-classroom and lecture instructional methods on Physics students' critical thinking in Delta State, Nigeria, with particular attention to differences based on sex. The findings are expected to provide evidence for selecting instructional approaches capable of strengthening critical-thinking development in secondary school Physics classrooms.

Research Questions

The following research questions guided the study:

1. What is the difference in the critical thinking mean scores of physics students taught with metacognitive, flipped-classroom, and lecture instructional strategies?
2. What is the difference in the mean critical thinking between male and female students taught physics using metacognitive instructional strategy?
3. What is the difference in the critical thinking mean scores between male and female students taught physics using flipped classroom instructional strategy?
4. What is the difference in the critical thinking mean scores between male and female students taught physics using the lecture instructional strategy?
5. What is the interaction effect of instructional strategies and sex on students' critical thinking in physics?

Hypotheses

The following null hypotheses were formulated for the study and will be tested at 0.05 level of significant

1. There is no significant difference in the critical thinking mean scores of physics students taught with metacognitive, flipped-classroom, and lecture instructional strategies.
2. There is no significant difference in the mean critical thinking between male and female students taught physics using metacognitive instructional strategy.
3. There is no significant difference in the critical thinking mean scores between male and female students taught physics using flipped classroom instructional strategy.
4. There is no significant difference in the critical thinking mean scores between male and female students taught physics using the lecture instructional strategy.
5. There is no significant interaction effect of instructional strategies and sex on students' critical thinking in physics.

Conceptual Framework

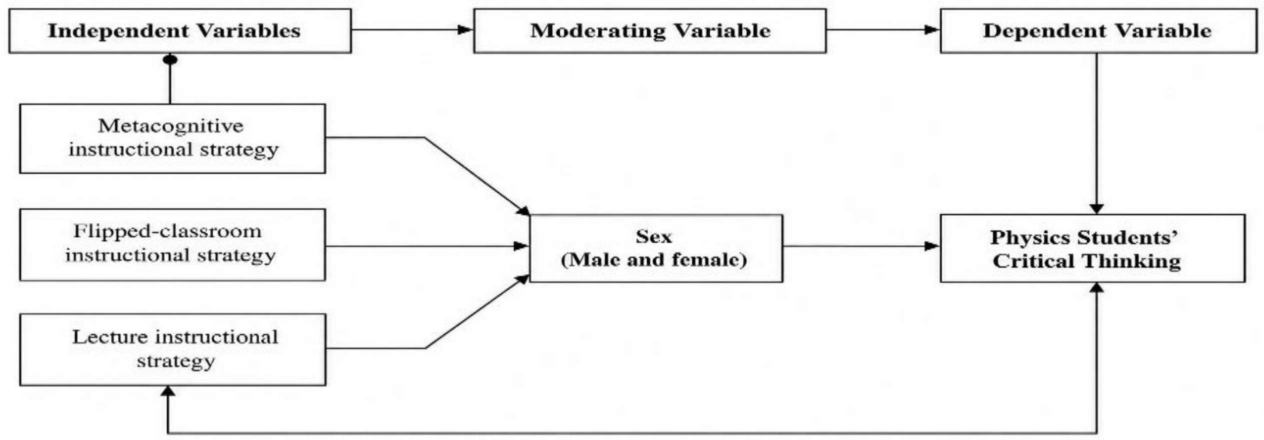

Figure 1: Conceptual Model

Source: Self-developed by the authors

The conceptual framework for this study positions instructional strategies as the independent variables, Physics students' critical thinking as the dependent variable, and sex (male and female) as the moderating variable. The instructional strategies comprise metacognitive, flipped-classroom, and lecture instructional strategies, which are expected to influence students' development of critical thinking skills. The framework assumes that the nature of instructional strategy employed in teaching Physics can determine the extent to which students actively engage in analysing, evaluating, interpreting and solving problems. The framework is grounded in constructivist learning theory, particularly Vygotsky's sociocultural perspective (1978), which posits that learners actively construct knowledge through interaction with their environment, teachers and peers. Learning is therefore enhanced when students are actively involved in meaningful learning activities rather than merely receiving information passively.

The metacognitive and flipped-classroom strategies provide opportunities for students to reflect on their learning, interact with learning materials, discuss ideas and apply knowledge to problems. Although the lecture strategy is more teacher-centred, its effectiveness may depend on how the teacher engages students during instruction. The framework further assumes that sex may moderate the relationship between instructional strategies and students' critical thinking. This means that the effects of metacognitive, flipped-classroom and lecture instructional strategies on critical thinking may differ between male and female students. Thus, sex is not treated as the primary cause of critical thinking but as a variable that may influence the strength or direction of the relationship between the instructional strategies and students' critical thinking. Overall, the framework provides a basis for examining whether the three instructional strategies significantly influence Physics students' critical thinking and whether their effects vary according to sex.

RESEARCH METHOD

The study adopted a quasi-experimental design comprising pre-test, post-test, and planned variation using a 3 x 2 factorial design. The first factor was instructional method at three levels: metacognitive, flipped-classroom, and lecture methods**,** while the second factor was sex at two levels: male and female. The design was considered appropriate because intact classes were used and the school timetable did not permit individual randomisation of students. Pretest and posttest measures were administered to determine changes in students' critical thinking following the instructional interventions.

The population comprised 29,817 SS II Physics students (14,908 males and 14,909 females) enrolled in 485 public secondary schools in Delta State, Nigeria, during the 2023/2024 academic session. SS II students were selected because SS I students were relatively new to the senior secondary school system, whereas SS III students were engaged in preparations for the Senior School Certificate Examination.

A sample of 282 SS II Physics students was selected from six mixed public secondary schools using a multistage sampling procedure. First, three Local Government Areas were selected from the study area using simple random sampling. Two public secondary schools were subsequently selected from each Local Government Area, giving six schools. The selected schools were assigned to the three instructional conditions through random allocation, resulting in **two** schools per instructional method**.** The sample comprised 166 males and 116 females**.**

The instrument used was Students' Critical Thinking Inventory in Physics (SCTIIP**)**. The SCTIIP consisted of 21 items adapted from Okan (2012), with minor modifications to suit the study context. A four-point response scale was used: Strongly Agree (4), Agree (3), Disagree (2), and Strongly Disagree (1). Both instruments were administered as pretest and posttest measures. The instrument was subjected to face, construct, and content validation. Three experts two in Science Education and one in Measurement and Evaluation—reviewed the instrument for clarity, relevance, and adequacy of item coverage. All items achieved a content validity index (CVI) of 0.80 or above, and items deemed ambiguous were revised accordingly. Construct validity was established through factor analysis using data obtained from 50 students outside the study sample. The rotated factor loadings ranged from 0.437 to 0.965, while the cumulative explained variance was 72.977%, indicating satisfactory construct validity. The reliability of the SCTIIP was assessed using Cronbach's alpha analysis, which produced a reliability coefficient of 0.842, indicating satisfactory internal consistency.

The intervention lasted six weeks, with two instructional sessions per week, totalling twelve sessions per class. Six intact classes from the selected schools participated in the study, with two classes assigned to each instructional condition (metacognitive, flipped-classroom, and lecture). To establish baseline equivalency, the SCTIIP was administered as a pre-test to all participating students before the intervention. The schools were purposively selected based on comparability in terms of school type, class size, and students' prior academic performance. Before the intervention, teachers implementing the metacognitive and flipped-classroom methods received structured training on the principles, procedures, and classroom application of the respective instructional approaches. The training included theoretical orientation, use of researcher-developed instructional manuals, practical sessions, and lesson implementation exercises. Teachers in the lecture group continued with the conventional lecture approach. All participating teachers received lesson plans covering the selected Physics topics, with the lesson plans specifying the activities of both teachers and students to ensure consistency in the implementation of the interventions.

For the metacognitive instructional method, lessons emphasised explicit learning objectives, activation of prior knowledge, learning planning, teacher think-aloud modelling, guided self-questioning, monitoring of problem-solving, reflection, error analysis, and evaluation of learning. Students were encouraged to plan, monitor, and evaluate their understanding while solving Physics problems. The flipped-classroom method involved providing students with instructional materials before class, including video lessons, reading materials, simulations, and guided questions. Classroom time was devoted primarily to concept checking, clarification of misconceptions, problem-solving, practical activities, simulations, collaborative learning, and discussion. Teachers acted as facilitators and provided feedback during students' activities. The lecture method involved teacher-centred presentation of the selected Physics topics through explanation, board work, diagrams, worked examples, brief questioning, lesson summaries, and assignments. This represented the conventional instructional approach against which the two intervention methods were compared. At the end of the six-week intervention, the SCTIIP was re-administered as a post-test to determine students' critical thinking outcomes following exposure to the three instructional methods.

Data Analysis

Data obtained from the instruments were analysed using mean and standard deviation to answer the research questions. Inferential analyses included one-way analysis of variance (ANOVA), independent-samples t-test, and analysis of covariance (ANCOVA). ANOVA was used to examine differences among instructional-method groups, while independent-samples t-tests were used to determine differences based on sex. ANCOVA was employed where appropriate to compare posttest outcomes while controlling for pretest scores. All hypotheses were tested at the 0.05 level of significance.

RESULTS AND DISCUSSION

Research Question 1

What is the difference in critical thinking mean scores of physics students taught with metacognitive, flipped-classroom and lecture instructional strategies?

Table 1: ***Analysis of The Difference in Posttest Critical Thinking Mean Scores of Physics Students Taught with Metacognitive, Flipped-Classroom and Lecture Instructional Strategies using Mean and Standard Deviation***

Instructional Strategies	N	Mean	Std. Deviation
Metacognitive	89	51.19	6.41
Flipped-Classroom	94	49.99	3.76
Lecture	99	43.36	3.8
Total	282		

Table 1 presents the analysis of the difference in critical thinking mean scores of Physics students exposed to three instructional strategies: metacognitive, flipped-classroom, and lecture methods. The data reveal that students taught using the metacognitive strategy recorded the highest mean critical thinking score of 51.19 with a standard deviation of 6.41, followed by the flipped-classroom group with a mean score of 49.99 and a standard deviation of 3.76. Students in the lecture group had the lowest mean score of 43.36, with a standard deviation of 3.80. With this ANOVA statistic becomes the appropriate statistics to be used to test Ho_6 and this this shown in Table 2

Hypothesis 1: There is no significant difference in difference in critical thinking mean scores of physics students taught with metacognitive, flipped-classroom and lecture instructional strategies

In order to determine the appropriate statistics to be used to test Ho_6 students pre-critical thinking score was analyzed using ANOVA as shown in Table 2

Table 2: ***ANOVA of the Difference in Pretest Critical Thinking Mean Scores of Physics Students Taught with Metacognitive, Flipped-Classroom and Lecture Instructional Strategies***

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	3.965	2	1.982	.150	.861
Within Groups	3687.978	279	13.219		
Total	3691.943	281			

Table 3 presents the Analysis of Variance (ANOVA) results comparing the pretest critical thinking mean scores of Physics students assigned to the metacognitive, flipped-classroom, and lecture instructional strategy groups. The result shows that the computed F-value is 0.150, with a corresponding significance (p-value) of 0.861. Since the p-value (0.861) is greater than the 0.05 level of significance, the result is not statistically significant. This indicates that there is no significant difference in the pretest critical thinking mean scores of Physics students across the three instructional strategy groups. The finding suggests that the students in the metacognitive, flipped-classroom, and lecture groups were homogeneous in terms of critical thinking ability before the treatment.

Table 3:

ANOVA of the Difference in Critical Thinking Mean Scores of Physics Students Taught with Metacognitive, Flipped-Classroom and Lecture Instructional Strategies

	Sum of Squares	Df	Mean Square	F	Sig.	Remark
Between Groups	3405.84	2	1702.92	74.85	.00	Significant
Within Groups	6347.65	279	22.75			
Total	9753.489	281				

Table 3 shows the ANOVA summary of the difference in critical thinking mean scores of physics students taught with metacognitive, flipped-classroom and lecture instructional strategies. The ANOVA result indicated a significant difference among the groups ($F = 74.85$, $p < 0.05$). Thus, the null hypothesis was rejected. This implies that there is a significant difference in critical thinking mean scores of physics students taught with metacognitive, flipped-classroom and lecture instructional strategies. To determine the specific direction of these differences among the three groups, a post-hoc test was conducted using Scheffe post-hoc test, and the results are presented in Table 4.

Table 4: ***Scheffe Post-Hoc Test for Direction of Significance Difference in Critical Thinking Mean Scores of Physics Students taught with Metacognitive, Flipped-Classroom and Lecture Instructional Strategies***

Dependent variable	(I) instructional Strategies	(J) instructional Strategies	Mean Difference (I-J)	Std. Error	Sig.
	Metacognitive	Flipped-Classroom	1.2	0.7	0.24
		Lecture	7.83*	0.69	0
Post critical thinking test	Flipped-Classroom	Metacognitive	-1.2	0.7	0.24
		Lecture	6.63*	0.69	0
	Lecture	Metacognitive	-7.83*	0.69	0
		Flipped-Classroom	-6.63*	0.69	0

*. The mean difference is significant at the 0.05 level.

The post hoc analysis using the Scheffé test, as presented in Table 4, was conducted to determine the direction of the observed significance differences in students' critical thinking mean scores across the metacognitive, flipped-classroom, and lecture instructional strategies. The result revealed the following: There was no significant difference between the mean critical thinking scores of students taught using metacognitive and flipped-classroom strategies (Mean Difference = 1.20, p = .24), indicating that both strategies were similarly effective in enhancing critical thinking. Students taught using the metacognitive strategy significantly outperformed those taught with the lecture method (Mean Difference = 7.83, p = .00). Likewise, students taught using the flipped-classroom strategy also significantly outperformed those taught with the lecture method (Mean Difference = 6.63, p = .00). These findings suggest that metacognitive and flipped-classroom strategies are both more effective than the lecture method in promoting students' critical thinking in Physics. However, there is no significant difference in critical thinking outcomes between the metacognitive and flipped-classroom groups. This implies that while both active-learning strategies enhance critical thinking, the lecture method is considerably less effective in achieving this objective. The direction of the difference between the metacognition and between lecture nethods.

Research Question 2: What is the difference between the mean critical thinking scores of male and female students taught physics using metacognitive instructional strategy?

Table 5: ***Analysis of the difference between the Mean Critical Thinking Scores of Male and Female Students taught Physics using Metacognitive Instructional Strategy using Mean and Standard Deviation***

Sex	N	Mean	Mean Difference	Std. Deviation
Males	57	51.58		6.56
Females	32	50.50	1.08	6.18
Total	89			

Table 5 presents the mean critical thinking scores of male and female students exposed to the metacognitive instructional strategy. Male students (N = 57) recorded a mean score of 51.58 with a standard deviation of 6.56**,** while female students (N = 32) had a mean score of 50.50 with a standard deviation of 6.18**.** The mean difference between the two groups was 1.08. To find out whether the mean difference is significant, Ho_2 was tested with independent sample t-test and presented in Table 4.20.

Hypothesis 2

There is no significant difference between the mean critical thinking scores of male and female students taught physics using metacognitive instructional strategy.

Since no significant difference was found in Table 4.15, independent sample t-test was used to test $Ho_{7 \text{ and this}}$ is shown in Table 1.19

Table 6: ***Independent sample t-test analysis of the Difference Between the Mean Critical Thinking Scores of Male and Female Students taught Physics using Metacognitive Instructional Strategy.***

Sex	N	Mean	Std. Deviation	df	t-cal.	Sig. (2-tailed)	Remark
Males	57	51.58	6.563	87	.76	.45	Null hypothesis not rejected
Females	32	50.50	6.175				
Total	89						

Table 6 is a summary of independent sample t-test analysis of the difference between the mean critical thinking scores of male and female students taught physics using metacognitive instructional strategy. The table shows that the p-value (.45) is greater than 0.05. With this result**,** H_{o3} was not rejected. Thus, there is no significant the difference between the mean achievement scores of male and female students taught physics using physics using metacognitive instructional strategy.

Research Question 3: What is the difference between the mean critical thinking scores of male and female students taught physics using flipped classroom instructional strategy?

Table 7: ***Analysis of the difference between the Mean Critical Thinking Scores of Male and Female Students taught Physics using Flipped Classroom Instructional Strategy using Mean and Standard Deviation***

Sex	N	Mean	Mean Difference	Std. Deviation
Males	54	50.24		4.31
Females	40	49.65	0.59	2.87
Total	94			

Table 7 shows the mean critical thinking scores of male and female students who were taught Physics using the flipped classroom instructional strategy. Male students (N = 54) had a mean score of 50.24 with a standard deviation of 4.31, while female students (N = 40) had a mean score of 49.65 with a standard deviation of 2.87. The mean difference between the two groups was 0.59 points, slightly in favor of the male students. This result indicates a very minimal difference in the critical thinking performance of male and female students under the flipped classroom strategy.

Hypothesis 3

There is no significant difference between the mean critical thinking scores of male and female students taught physics using flipped classroom instructional strategy.

Since no significant difference was found in Table 7, independent sample t-test was used to test Ho_8 and this is shown in Table 8

Table 8: ***Independent sample t-test Analysis of the difference between the Mean Critical Thinking Scores of Male and Female Students taught Physics using Flipped Classroom Instructional Strategy***

Sex	N	Mean	Std. Deviation	df	t-cal.	Sig. (2-tailed)	Remark
Males	54	50.24	4.309	92	0.75	.45	Null hypothesis not rejected
Females	40	49.65	2.869				
Total	94						

Table 8 is a summary of independent sample t-test analysis of the difference between the mean critical thinking scores of male and female students taught physics using Flipped Classroom Instructional Strategy. The table shows that the p-value (.45) is greater than 0.05. With this result**,** H_{03} was not rejected. Thus, there is no significant the difference between the mean critical thinking scores of male and female students taught physics using physics using flipped classroom instructional strategy

Research Question 4: What is the difference between the mean critical thinking scores of male and female students taught physics using lecture instructional strategy?

Table 9: ***Analysis of the difference between the Mean Critical Thinking Scores of Male and Female Students taught Physics using lecture instructional strategy using Mean and Standard Deviation***

Sex	N	Mean	Mean Difference	Std. Deviation
Males	55	43.76		3.830
Females	44	42.86	0.90	3.752
Total	99			

Table 9 presents the mean critical thinking scores of male and female students who were taught Physics using the lecture instructional strategy. The results indicate that male students (N = 55) had a mean score of 43.76 with a standard deviation of 3.83, while female students (N = 44) had a mean score of 42.86 with a standard deviation of 3.75. The mean difference was 0.90, slightly in favour of the male students.

Hypothesis 4

There is no significant difference between the mean critical thinking scores of male and female students taught physics using lecture instructional strategy.

Since no significant difference was found in Table 9, independent sample t-test was used to test Ho_9 and this is shown in Table 10.

Table 10: Independent sample t-test ***Analysis of the difference between the Mean Critical Thinking Scores of Male and Female Students taught Physics using lecture instructional strategy***

Sex	N	Mean	Std. Deviation	df	t-cal.	Sig. (2-tailed)	Remark
Males	55	43.76	3.830	97	1.17	.24	Null hypothesis not rejected
Females	44	42.86	3.752				
Total	99						

Table 10 is a summary of independent sample t-test analysis of the difference between the mean critical thinking scores of male and female students taught physics using lecture instructional strategy. The table shows that the p-value (.24) is greater than 0.05. With this result**,** Ho_9 was not rejected. Thus, there is no significant the difference between the mean critical thinking scores of male and female students taught physics using lecture instructional strategy.

Research Question 5

What is the interaction effect of instructional strategies and sex on students' critical thinking in physics?

Table 11: ***Analysis of the Interaction Effect of Instructional Strategies and Sex On Students' critical thinking in Physics using Mean and Standard Deviation***

Instructional Strategies	Sex	N	Mean	Mean difference	Std. Deviation
Metacognitive		89	51.19		6.41
flipped-classroom		94	49.99		3.76
Lecture		99	43.36		3.8
Metacognitive	Males	57	51.58	1.08	6.56
	Females	32	50.5		6.17

flipped-classroom	Males	54	50.24	4.59	4.31
	Females	40	49.65		2.87
Lecture	Males	55	43.76	0.79	3.83
	Females	44	42.86		3.75

Table 11 presents the mean and standard deviation of students' critical thinking in Physics based on instructional strategies and sex. The results show noticeable variations in students' mean critical thinking scores across the different instructional strategies. Students exposed to the metacognitive instructional strategy recorded the highest overall mean score of 51.19 (SD = 6.41), followed closely by those in the flipped-classroom group with a mean score of 49.99 (SD = 3.76). Students taught using the lecture method obtained the lowest mean score of 43.36 (SD = 3.80). This suggests that student-centred strategies, particularly the metacognitive approach, were more effective in promoting students' critical thinking in Physics than the conventional lecture method.

Further analysis in Table 4.24 shows variations in mean critical thinking scores based on sex within each instructional strategy. Under the metacognitive strategy, male students recorded a mean score of 51.58 (SD = 6.56), while female students had a mean score of 50.50 (SD = 6.17), resulting in a mean difference of 1.08 in favour of males. This small difference indicates that both sexes benefited almost equally from the metacognitive strategy. For the flipped-classroom strategy, male students achieved a mean score of 50.24 (SD = 4.31), while female students recorded a mean score of 49.65 (SD = 2.87), giving a mean difference of 0.59. The difference is minimal, showing that the flipped-classroom strategy also supported critical thinking development for both male and female students in a similar manner. In the lecture method, male students recorded a mean score of 43.76 (SD = 3.83) and female students had a mean score of 42.86 (SD = 3.75), with a mean difference of 0.79. Achievement levels under the lecture method are lower for both sexes compared to the other strategies. Overall, although male students recorded slightly higher mean scores than female students across all instructional strategies, the differences are relatively small. The pattern of results is consistent for both sexes, indicating that the effect of instructional strategies on students' critical thinking in Physics does not substantially depend on sex.

Hypothesis 5

There is no significant interaction effect of instructional strategies and sex on students' academic achievement in physics.

Table 12:

ANCOVA Summary of the Interaction Effect of Instructional Strategies and Sex On Students' Critical Thinking in Physics

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	3460.37[a]	6	576.73	25.20	.00
Intercept	15709.73	1	15709.73	686.49	.00
Pretest	2.85	1	2.85	.12	.72
instructional Strategies	3238.73	2	1619.36	70.76	.00
Sex	51.29	1	51.29	2.24	.13
instructional Strategies * sex	**2.36**	**2**	**1.18**	**.05**	**.95**
Error	6293.12	275	22.88		
Total	660634.00	282			
Corrected Total	9753.49	281			
a. R Squared = .355 (Adjusted R Squared = .341)					

Table 12 revealed the ANCOVA summary of the interaction effect of instructional strategies and sex on students' critical thinking in physics. The result shows that the computed F-value for the interaction between instructional strategies and sex is .05 with a corresponding p-value of .95. Testing the null hypothesis at an alpha level of 0.05, the p-value (.95) was greater than 0.05, hence the null hypothesis was not rejected. This implies that there is no significant interaction effect of instructional strategies and sex on students' critical thinking in physics.

DISCUSSION OF RESULTS

The one finding revealed a significant difference in the critical thinking mean scores of students taught Physics using metacognitive, flipped-classroom, and lecture instructional strategies. This implies that the instructional strategy employed plays a vital role in developing students' critical thinking abilities. Among the three strategies, metacognitive and flipped-classroom methods yielded higher mean scores compared to the lecture method, with the lecture strategy being the least effective in fostering critical thinking skills. This result can be attributed to the nature of metacognitive and flipped-classroom strategies, both of which are learner-centered, engaging students in active reflection, independent inquiry, and problem-solving processes that naturally enhance critical thinking. In contrast, the lecture method is largely teacher-dominated and offers limited opportunities for cognitive engagement or student interaction. This finding aligns with that of Nwachukwu and Madu (2019), who reported that metacognitive instructional strategies significantly improved students' critical thinking in senior secondary science classes. Similarly, Adedokun and Musa (2020) observed that flipped-classroom strategies enhanced learners' reasoning and analytical skills more than traditional methods. Ogunniyi and Adebayo (2022) concluded that the lecture method tends to limit student involvement, resulting in weaker development of higher-order thinking skills, including critical thinking, compared to more interactive instructional methods.

The two finding of the study shows that there was no significant difference in the mean critical thinking scores between male and female students taught Physics using the metacognitive instructional strategy. This indicates that the metacognitive strategy was equally effective in promoting critical thinking across both sexes. The finding suggests that when students are taught using strategies that involve reflective thinking, self-regulation, and active cognitive monitoring, gender does not play a determining role in how well they develop critical thinking abilities. This result is consistent with Onwuachu and Eze (2019), who found no significant difference between male and female students' critical thinking performance when taught science subjects using reflective and metacognitive strategies. This finding is aligns with Ahmed and Nwachukwu (2021) reported that instructional strategies centered around metacognition effectively enhance students' higher-order thinking without gender disparity. This result is also consistent with Adegoke and Ibe (2022) who found that both male and female students showed comparable improvements in analytical and evaluative thinking when exposed to metacognitive-based instruction in Physics, emphasizing that gender-based learning gaps can be minimized with the use of effective student-centered teaching strategies.

The three finding of the study shows that there was no significant difference in the mean critical thinking scores between male and female students taught Physics using the flipped classroom instructional strategy. This implies that the flipped classroom approach is equally effective for students of both sexes, offering comparable opportunities for independent learning, in-depth reflection, and active classroom engagement that support the development of critical thinking. This finding agrees with Ismail and Mohammed (2019), who reported no significant difference in critical thinking performance between male and female students taught using the flipped classroom approach in science subjects. The authors explained that the flipped model encourages individualized learning experiences, which minimize disparities based on sex. It also aligns with the study by Umeh and Agbakwuru (2021), who found that students of both sexes benefitted equally from flipped instruction in Physics, particularly in terms of higher-order cognitive skill development. They attributed this to the interactive and collaborative structure of flipped classroom environments. Furthermore, this finding corroborates the conclusion of Okoro and Abubakar (2023), who confirmed that flipped classroom strategies foster equal opportunities for male and female students to improve their reasoning and problem-solving skills in science-based subjects.

The four finding of the study shows that there was no significant difference in the critical thinking mean scores between male and female students taught Physics using the lecture instructional strategy. This suggests that the traditional lecture method impacts students' critical thinking similarly, regardless of sex. The lecture strategy, which often emphasizes content delivery over active engagement, may not provide sufficient cognitive stimulation to promote meaningful differences in critical thinking development between male and female students. This finding aligns with Ezeudu and Nwankwo (2019), who reported no significant sex-based differences in students' reasoning abilities when taught science subjects through conventional lecture methods. Similarly, Olanrewaju and Yusuf (2021) found that the passive nature of lectures does not favor one sex over the other in critical thinking performance, as both groups receive the same exposure without differentiated engagement. This finding also supports the conclusions of Nwachukwu and Ezeani (2023), who found that lecture-based teaching provides limited cognitive challenge and interaction, hence showing no differential effect on students' critical thinking by sex.

The five finding of the study indicates that there was no significant interaction effect between instructional strategies and sex on students' critical thinking in Physics. This implies that the effectiveness of instructional strategies in fostering critical thinking does not depend on the student's sex. Regardless of whether metacognitive, flipped-classroom, or lecture methods were used, male and female students responded similarly in terms of critical thinking development. This finding is in agreement with Aina and Akintola (2018) and Ajaja (2013) who found that students' sex did not significantly interact with instructional methods in determining outcomes in analytical reasoning. Likewise, Mohammed and Suleiman (2022) confirmed that instructional strategies like flipped learning and metacognitive instruction influence students' critical thinking, but their effectiveness does not differ based on sex. The finding also corroborates the work of Okafor and Nduka (2023), who demonstrated that when active learning strategies are used effectively, both sexes benefit equally, and no interaction effect is observed on higher-order cognitive outcomes such as critical thinking.

CONCLUSION

This study compared the effects of metacognitive, flipped-classroom, and lecture instructional strategies on critical thinking in physics in Delta State. Based on the findings, it is concluded that the choice of instructional strategy significantly influences critical thinking skills. Both the metacognitive and flipped-classroom strategies were significantly more effective than the lecture method, although no significant difference was found between the two active learning strategies. Furthermore, the findings suggest that students' sex did not significantly influence critical thinking in most cases across the instructional methods used. Also, there was no significant interaction effect between instructional strategies and sex on students' critical thinking, indicating that the effectiveness of these strategies is consistent across male and female students. These conclusions highlight the importance of adopting active and student-centered instructional strategies particularly flipped-classroom and metacognitive methods to promote deeper understanding and cognitive engagement in physics education.

RECOMMENDATIONS

Based on the findings of this study, the following recommendations are made:

1. As the metacognitive instructional strategy proved to be the most effective in enhancing students' critical thinking, it should be prioritized in physics instruction where the goal is to develop students' reasoning, reflection, and problem-solving abilities.
2. Physics teachers should be trained in the development and implementation of both flipped-classroom and metacognitive strategies. This includes preparing students with pre-class materials for flipped learning and designing tasks that foster reflection and self-regulation for metacognitive engagement.
3. Despite no consistent significant differences in thinking based on sex across the strategies, teachers should ensure inclusive practices that promote equal engagement of male and female students in active learning environments.

4. Curriculum developers and textbook authors should be encouraged by the Ministries of Education to incorporate practical applications of flipped-classroom and metacognitive strategies into the senior secondary school physics curriculum and instructional resources.
5. Workshops, seminars, and teacher development programs should be regularly organized by educational authorities to build capacity for implementing evidence-based strategies like flipped-classroom and metacognitive teaching methods.

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