IIUM JOURNAL OF EDUCATIONAL STUDIES (ENGLISH), 13:2 (JULY 2025) 123-141

ISSN: 2289-8085

Differential Effect of Thinking Aloud and Agree/Disagree Metacognitive Strategies on the Three Levels of Students' Academic Performance in Secondary School Science

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Received: 30th December 2024; Accepted:18th July 2025; Published online: 31st July 2025

Abstract

This research determined the influence of metacognitive strategies on the three levels (high, moderate and low level) of student's academic performance and to also assessed the difference in the academic performance of students that were taught using thinking aloud and agree/disagree metacognitive strategies instructional strategies. The study adopted pretest, post-test, control group experimental design. A total sample of 100 secondary school science students was used, with 50 in the experimental group and 50 in the control group; the experimental group received treatment using the "thinking aloud" (36 students) and "agree/disagree" (14 students) instructional strategies, while the control group was taught using the conventional method. A thirty- multiple choice Physics, Chemistry and Biology Performance Test (PCBPT) was used to measure students' academic performance in Physics, Chemistry and Biology subjects. The findings derived from the collected data revealed that science students demonstrated a moderate level of academic performance. No significant difference was observed in the performance of science students taught using the thinking-aloud and agree/disagree instructional strategies. However, the experimental group taught with metacognitive strategies showed a significantly higher mean gain (4.96) than the conventional group (1.20), $p < 0.05$, indicating the effectiveness of the strategy. Consequently, it is recommended that teachers in science education incorporate metacognitive strategies, particularly in this era where teaching approaches prioritize a child-centered methodology and also, use to validate the answers students provide to ensure it is not a copy and paste AI generated answers.

Keywords: *metacognitive strategies, thinking aloud, agree/disagree, academic performance, science*

INTRODUCTION

Metacognitive strategies, as articulated by Akkurt (2021), De Boer et al. (2018), Khezrinejad et al. (2025), encompass techniques that enable students to actively take control of their own learning experiences in a deeply thoughtful manner. These strategies serve as both tools for teachers and learners to attain specific learning objectives. Metacognitive strategies, encompassing an array of mental processes like planning, tracking progress, and assessing one's thoughts and learning, have garnered significant attention in educational research for their profound impact on students' academic performance across mathematics and management sciences disciplines (Akkurt, 2021; De Boer et al., 2018; Khezrinejad, 2025; Nasaruddin et al., 2024). Metacognitive strategies have been shown to have a significant beneficial effect on students' academic performance. Akkurt (2021) for instance, have demonstrated and validated this effect, emphasizing how these strategies can greatly improve students' learning outcomes in language arts and mathematics. According to De Boer et al. (2018), there has been a slight improvement in management sciences when examining the long-term effect of metacognitive methods on student performance.

Furthermore, the effects of metacognitive education on the completion of mathematically authentic tasks were examined by Kramarski et al. (2002). These studies revealed that learners who were provided with metacognitive instruction outperformed their peers on real-world mathematical challenges. Nevertheless, the degree of gain may differ from one metacognitive strategy to another. Hence, in the context of secondary school science education, where advanced conceptual comprehension and critical thinking abilities are paramount, the role of metacognitive strategies becomes particularly crucial. Metacognitive strategies assist students in participating in active reflection, self-monitoring, and self-regulation to enhance their understanding and retention of complex scientific concepts by focusing with greater intention, recognizing errors, and developing effective learning practices.

Moreover, in science education, students do not learn the same way, and educational researchers often categorize students into low achievers, moderate achievers, and high achievers. Determining if metacognitive strategies will be beneficial to these three levels of students is important to the promotion of inclusive education. A longitudinal study by (Ijirana et al., 2021) tracked students from middle school through college and found that those who demonstrated increased levels of metacognitive awareness tended to achieve improved performance academically over time. This study highlights the long-term impact of metacognitive skills on academic success. Also, Swanson et al (2024) investigated the impact of metacognitive interventions on enhancing academic performance among a group of undergraduates. Their findings revealed that students who participated in metacognitive training programs showed significant improvements in their grades compared to those who did not receive such interventions. A meta-analysis by Schneider and Artelt (2010) showed a strong relationship between students' metacognitive abilities and their academic achievement across various subjects, underscoring the instrumental role of metacognitive strategies in facilitating learning outcomes.

Furthermore, studies such as those by Tanner and Allen (2007) have highlighted the differential impact of metacognitive interventions on students with varying levels of academic proficiency, emphasizing the need for personalized instructional approaches tailored to individual learning needs. In another study, Zhao et al. (2014) discovered that students who were taught metacognition in the classroom performed better on the final exam compared to those who were taught using other strategies. Researchers have long been interested in student performance, particularly in science, where Nigerian secondary school students have shown poor and unimpressive results over recent decades (Chinda, 2009; Njoku, 2007). Chinda (2009) linked students' underachievement in science to a lack of academic commitment.

Additionally, some researchers have identified factors such as the physical environment, overcrowded classrooms, and teaching methods as key variables impacting student performance. Overall, studies indicate that the primary reasons for students' poor performance in science include the use of English as the medium of instruction, inadequate laboratory equipment, insufficient teaching and learning resources, and ineffective teaching methods. To enhance student performance in science education, it is essential for teachers to adopt instructional strategies that promote better outcomes. Many science teachers believe that scientific investigations should occur in a laboratory setting, and in the absence of adequate facilities, they often resort to traditional teaching methods that do not effectively support meaningful learning in science. Traditional teaching strategies like lectures, memorization, and reading textbooks often do not encourage students to engage in activities such as discussions, hands-on experiments, and creative thinking. While these activities are crucial for a deeper understanding and genuine learning in science, most science lessons are still taught with the usual conventional method. For better performance in science education, especially in the recent technological advancement of the use of artificial intelligence in the classroom, the teacher should implement teaching methods that will improve problem-solving abilities and creativity that will encourage independent learners, and metacognitive strategies are one such strategy (Suriyon et al., 2013). The desired outcomes of improved performance and fostering independent learning can only be realized by employing specific metacognitive strategies that involve understanding and regulating students' cognitive procedures, like self-assessment, establishing goals, and reflective thinking. These cognitive self-awareness strategies are seen as crucial in adapting instructional methods for the evolving landscape of technology in education.

The rationale for this study is grounded in the theory of metacognition, which posits that the capacity to contemplate and control one's personal cognitive procedure is a critical determinant of academic success. Flavell (1976) explains that metacognitive knowledge includes both metacognitive knowledge (awareness of one's cognitive processes) and metacognitive regulation (management and oversight of these processes). Drawing from this theoretical framework, researchers have explored a plethora of metacognitive approaches, including planning, monitoring, evaluating, and self-assessment, which play pivotal roles in fostering effective learning and problem-solving abilities (Efklides, 2008). Rivers (2001) identifies two types of metacognitive strategies: self-assessment and self-management. Gamma (2004) categorizes metacognitive strategies into seven categories, including the use of reflective questions and prompts that encourage learners to engage deeply with their cognitive processes, reflect on their strengths, and identify areas for improvement. These strategies prompt self-reflection and help learners become more aware of their thinking processes. Metacognitive scaffolding also provides support structures to help learners develop their metacognitive skills gradually. It involves guiding learners through tasks, prompting them to think about their thinking, modeling, self-questioning, self-explanations, self-assessment, and graphic organizers. Nevertheless, the present study will adopt the thinking aloud and agree/disagree metacognitive strategies for teaching science subjects in secondary schools.

Thinking aloud is a metacognitive strategy where teachers assist students in organizing and refining their thoughts while they work, particularly during problem-solving tasks. This approach requires students to engage in critical thinking and articulate their thoughts verbally. In the thinking aloud strategy, students are prompted to reflect on their current thinking by considering the following questions: "What do I already know about this topic that could guide my learning?"; "Is there any relationship between this topic and my knowledge from other subjects?"; "How do I tackle this problem if it appears in my test or final examinations?" Thinking aloud can be practiced in pairs to promote cooperative and collaborative learning among students (Asraf & Halim, 2024). One student acts as the problem solver, verbalizing their thought process, while the other serves as a listener who asks questions to help clarify the solver’s thinking. Thinking aloud involves verbalizing one's thought processes while working on problem-solving tasks or comprehension activities.

In physics, the thinking aloud strategy helps students tackle challenging problems by verbalizing their thought processes. For example, when solving a problem involving projectile motion, students can explain how they break down the problem, choose equations, and apply principles like conservation of energy. This articulation reinforces their understanding and makes their problem-solving strategies explicit, aiding peer learning and instructor feedback.

In chemistry, thinking aloud assists in understanding complex reactions and stoichiometric calculations. When balancing chemical equations, students verbalize their steps in identifying reactants and products, determining stoichiometric coefficients, and ensuring mass and charge conservation. This process clarifies misconceptions and refines problem-solving strategies, enhancing their grasp of chemistry concepts.

In biology, this strategy improves comprehension of biological processes. For instance, when studying cellular respiration, students might verbalize their understanding of metabolic pathways, enzyme roles, and ATP production. Vocalizing their thoughts helps elucidate connections between concepts, correct misunderstandings, and develop robust mental models (Abdelrahman, 2020). The profession of teaching relies on strong teacher-student relationships, yet most curricula focus on content and methods, neglecting these relationships. This oversight can lead to poor academic performance due to biology phobia, fear of tests, failure, teachers, lack of confidence, and anxiety about results.

Apart from thinking aloud, the agree/disagree metacognitive strategies have been identified as potential strategies that are innovative and engaging for students both in the online and artificial intelligence-induced classroom. Agree/Disagree activities involve engaging students in discussions where they express agreement or disagreement with a given statement, followed by justification of the answers they provided. In physics education, agree/disagree activities can stimulate critical thinking and metacognitive reflection by prompting students to articulate their reasoning and evaluate the validity of scientific claims. For instance, students might be presented with a statement regarding the laws of thermodynamics and asked to express whether they agree or disagree, providing rationale based on their understanding of thermodynamic principles and empirical observations. Through this process, students not only reinforce their grasp of physics concepts but also cultivate metacognitive awareness of their reasoning processes and the evidential basis for scientific claims.

In chemistry, agree/disagree activities can foster peer discussion and collaborative sense-making around chemical concepts and principles. For example, students might be presented with a statement regarding the reactivity of certain elements in the periodic table and asked to agree or disagree, providing supporting evidence based on trends in atomic structure, electronegativity, or bonding behavior. Through this interactive discourse, students can refine their conceptual understanding, evaluate alternative viewpoints, and develop metacognitive skills in assessing the validity and reliability of chemical arguments.

In biology, agree/disagree activities can promote active engagement and critical inquiry into biological phenomena and theories. For instance, students might be presented with a statement regarding the mechanisms of evolution and asked to express agreement or disagreement, substantiating their position with evidence from evolutionary biology research, fossil records, or comparative anatomy. By engaging in this deliberative process, students deepen their understanding of evolutionary concepts, refine their metacognitive reasoning skills, and appreciate the complexity of scientific discourse in biology.

However, while existing research has elucidated the broad benefits of metacognitive interventions, there remains a dearth of studies specifically examining their differential effects on students at different proficiency levels within the secondary science classroom. In light of this context, the present study contributes to the burgeoning body of literature on metacognitive strategies in education by shedding light on their differential effects on students' academic performance across various proficiency levels in secondary school science.

OBJECTIVE OF THE STUDY

This study examined the effect of two metacognitive strategies on students' academic performance.

Research Questions

1. How does students' academic performance in secondary school science vary across different instructional strategy groups?
2. What is the mean gain of students taught using metacognitive strategies compared to those taught using conventional methods?

Research Hypothesis

1. There is no significant difference in the performance of students in sciences taught using thinking aloud and agree/disagree instructional strategy.

LITERATURE REVIEW

Concept of Metacognitive Strategies

The concept of metacognition has been described in various ways by researchers. Initially, it was identified with terms such as "cognitive knowledge," "beyond cognition," "metacognitive knowledge," and "executive cognition". Additional phrases like "metacognitive," "way of using information," and "cognitive awareness" have also been used (Jaleel, 2016). In our context, it is commonly referred to as "metacognition" (Jaleel, 2016). This study adopts the term "metacognition," which is defined as thinking about one's thinking or understanding what one knows and does not know (Livingston, 2003). Whereas cognition focuses on being aware of and comprehending information, metacognition extends to understanding how to learn and process information, including the strategies employed (Wall & Higgins, 2006). It encompasses deliberate organization and storage of data, analysis of stored information, retrieval of necessary details, and an awareness of these processes (Flavell, 2001). Kuiper (2002) highlighted the importance of focusing on metacognitive strategies rather than solely on theories.

Metacognition refers to the ability of students not only to understand the subject matter but also to reflect on their understanding. It involves an individual's awareness of their cognitive abilities, the functioning of those abilities, and recognizing what they know and do not know. It also encompasses understanding when and how to use metacognitive strategies effectively. This process includes accurately analyzing and processing information, linking it to long-term memory, and retrieving it accurately when needed. Research highlights that metacognitive strategies play a crucial role in enhancing individual success (Deseote et al., 2001; Kuiper, 2002; Lin et al., 2005; Schraw, 2009). Various strategies have been suggested to foster metacognitive awareness, including explicitly teaching metacognitive skills, structuring lessons to emphasize these skills, employing diverse strategies and techniques, and using cooperative learning methods (Paris & Winograd, 1990). The most critical aspect of teaching metacognitive skills lies with the individual, as each person is best positioned to understand how they learn and establish connections within their knowledge network. In science education, these strategies have garnered attention for their potential to support learners in navigating the cognitive demands of inquiry-based tasks, problem-solving, and conceptual understanding. However, metacognitive strategy effectiveness is not uniform across all students; emerging research suggests prior academic achievement may moderate these effects.

Metacognition Awareness and Academic Performance

Many studies show the link among metacognitive abilities, academic success, and intrinsic motivation. Especially when compared to classmates who lack such intrinsic motivation, these research shows that students' academic achievement is strongly correlated with their intrinsic motivation and the efficient use of metacognitive methods (Efklides, 2011). Pintrich and DeGroot (1990) underlined that although effective learning depends not just on the type of techniques used but also on the degree of intrinsic motivation, even if metacognitive tactics are fundamental for academic performance. By means of metacognitive methods, students who possess intrinsic motivation are more suited to participate in ongoing planning, monitoring, and assessment of their academic development. The foundation of independent learning is clearly a substantial positive association between intrinsic drive and self-regulation.

Since they help students to properly plan, control, organize, and calibrate their cognitive and intellectual processes, Arianto and Hanif (2024) also found metacognitive methods as basic for academic performance. Negovan et al. (2015) separated metacognitive knowledge from metacognitive control in their two aspects. The steps a student takes to enhance memory and learning—plan, monitor, and assess their development—are known as metacognitive control. By contrast, metacognitive knowledge is the awareness of one's cognitive mechanisms encompassing declarative and conditional knowledge (Young & Fry, 2008). These techniques are tightly related to intrinsic motivation, higher learning outcomes, and the adoption of task-appropriate tactics, better reading comprehension, and the capacity to combine past knowledge with new concepts. Studies by Akkurt (2021) and Abari and Tyovenda (2021) explored the impact of metacognitive strategies on secondary school students' performance in biology. Using an experimental design with a control group pretest-posttest model, they analyzed the performance of 60 students, aged 14-15, from two classes with similar academic levels. The findings revealed that students taught using metacognitive strategies achieved slightly higher performance compared to those taught through conventional methods.

Thinking Aloud Meta-Cognitive Strategy

Thinking aloud, a metacognitive strategy, involves verbalizing an individual's reflections during the performance of a task. This analysis aims to integrate empirical studies regarding the effectiveness of thinking aloud metacognitive strategies across various domains. It involves a series of metacognitive processes, such as planning, monitoring, and evaluating, and play a pivotal role in cognitive processes (Flavell, 1979). Thinking aloud serves as a mechanism to externalize these internal processes, facilitating reflection and self-regulation (Ericsson & Simon, 1980). By articulating their thoughts, individuals can identify misconceptions, monitor progress, and adapt strategies accordingly (Chi, 2009). In educational research, thinking aloud has been utilized to enhance learning outcomes (Asraf & Halim 2024). Research indicates its effectiveness in promoting deep understanding, problem-solving skills, and metacognitive awareness (Van Someren et al., 1994). For instance, in mathematics education, students who engage in thinking aloud demonstrate improved problem-solving abilities and conceptual understanding (Suriyon, et al., 2013). However, the effects of thinking aloud metacognitive strategy have not been tested in science education. Whereas the effectiveness of thinking aloud may vary depending on cognitive load and expertise level. Novices often struggle to verbalize their thoughts coherently, leading to cognitive overload and decreased performance (Sweller et al., 1998). In contrast, experts exhibit more efficient verbalization patterns, leveraging thinking aloud to refine their strategies and facilitate skill transfer (Ericsson et al., 2006). The efficacy of thinking aloud also relies on the characteristics of the task and domain. While beneficial in problem-solving and complex decision-making tasks, its utility in procedural tasks remains debated (Wilson et al., 2010). Furthermore, cultural and linguistic factors may influence the effectiveness of verbalization techniques, necessitating contextual adaptations (Paas et al., 2003).

Shabaya, (2011) conducted a study that was aimed at determining the influence of verbalizing thoughts and evaluating oneself instructional strategy on students' achievement in senior secondary school biology in Imo state. Four research questions and four null hypotheses were formulated to guide this study, which employed a quasi-experimental design. A two-stage sampling method was used to select 128 students from three intact classes. A 50-item multiple-choice Biology Performance Test (BPT) was developed to collect data for the study. The findings revealed, among other things, that there was no significant difference in the mean performance scores of biology students taught using the thinking aloud and self-assessment instructional strategy.

Sadykova et al. (2024) examined the impact of metacognitive strategies on secondary school students' performance in biology. Their study utilized a pretest-posttest quasi-experimental design, involving 360 senior secondary school one (SSS1) biology students from 360 schools in Obio/Akpor Local Government Area, Rivers State, Nigeria. Three research questions and three hypotheses guided the study. The students were divided into an experimental group and a control group, with the experimental group receiving instruction through thinking aloud and self-assessment strategy. Data analysis was conducted using mean, standard deviation, t-test, and ANCOVA. The results indicated that students taught using the thinking aloud strategy performed significantly better than those taught using the self-assessment strategy.

Similarly, Kramarski et al. (2002) found that students taught using the thinking aloud strategy outperformed those in the self-assessment group in problem-solving tasks, with the strategy enhancing conceptual understanding of biology. Sadykova et al. (2024) also reported significant improvements in students' problem-solving behaviors, particularly in problem comprehension, when the thinking aloud strategy was applied in metacognitive lessons. Other studies (e.g., Abdelrahman, 2020; de Boer, 2018) investigated the metacognitive ability and academic performance in science subjects and reported significance differences.

Agree/Disagree Metacognitive Strategies

Metacognitive strategies are essential for learning and problem-solving, allowing individuals to monitor and control their cognitive functions. Agree/disagree metacognitive strategies involve actively assessing and articulating one's level of agreement or disagreement with information, arguments, or propositions encountered during learning or decision-making tasks. This review aims to examine the empirical evidence regarding the effectiveness and implications of agree/disagree metacognitive strategies across various contexts. Agree/disagree metacognitive strategies are grounded in concepts of metacognition, which emphasize the importance of self-regulation and reflective thinking (Flavell, 1979). By explicitly acknowledging their stance towards presented information, individuals engage in critical evaluation and enhance their understanding of concepts (Kuhn, 1991). This process fosters deeper cognitive engagement and facilitates knowledge construction (Mason, 1994).

The agree/disagree type of metacognitive strategies have been employed to promote active learning and critical thinking skills. Research suggests that encouraging students to express their agreement or disagreement with course material enhances comprehension, metacognitive awareness, and academic performance (Chi & Wylie, 2014). Moreover, engaging in discussions about differing perspectives cultivates higher order thinking and intellectual curiosity (Nussbaum & Kardash, 2005). Agree/disagree metacognitive strategies are closely linked to argumentation processes, wherein individuals evaluate and justify their positions (Kuhn & Udell, 2003). Through articulating reasons for agreement or disagreement, learners engage in sense-making activities and refine their conceptual understanding (Mercier & Sperber, 2011). This active engagement with content fosters critical thinking skills and prepares individuals to construct well-supported arguments (Mason & Santi, 1998). The effectiveness of agree/disagree metacognitive strategies is influenced by social dynamics and peer interactions. Collaborative learning environments provide chances for students to exchange diverse perspectives and engage in constructive debate (Webb, 2009). Peer feedback and peer modeling enhance metacognitive awareness and promote metacognitive regulation strategies (Johnson & Johnson, 1999; Tan & Chen, 2022). However, the efficacy of agree/disagree metacognitive strategies may vary depending on contextual factors such as task complexity, disciplinary norms, and cultural backgrounds.

Theoretical Framework

The foundational theory guiding this study is the concept of metacognition, first introduced by Flavell (1976). Metacognition refers to “thinking about one’s own thinking” and encompasses both metacognitive knowledge and metacognitive regulation. Flavell’s model posits that learners engage in cognitive monitoring through four components: (1) metacognitive knowledge (awareness of one’s own cognitive processes), (2) metacognitive experiences, (3) goals/tasks, and (4) strategies/actions.

In the context of this study, thinking aloud represents a metacognitive strategy that fosters metacognitive regulation by requiring students to verbalize their reasoning and problem-solving processes, thereby enhancing awareness and control over their learning (Suriyon et al., 2013).
The Agree/Disagree strategy, a form of self-assessment, stimulates metacognitive reflection by prompting learners to evaluate the accuracy and logic of their responses, facilitating self-evaluation and strategic revision of understanding (Zhao et al., 2014)

Thinking Aloud enables learners to externalize their internal dialogue, which can be shaped and refined through peer or teacher feedback, aligning with Vygotsky’s notion of internalization. Similarly, when learners engage in the Agree/Disagree strategy, they reflect on opposing viewpoints, thereby engaging in dialogic reasoning that sharpens critical thinking within their ZPD.

METHODOLOGY

Research Design

The study utilizes a pre-test, post-test, control group quasi-experimental research design to investigate the differential effect of two metacognitive strategies (thinking aloud and agree/disagree) on the academic performance of secondary school science students across three levels (low, moderate, and high). A 3 x 2 factorial design was employed. This means three levels of treatment: thinking aloud atrategy, agree/disagree strategy, and conventional teaching method (Control). Also, two levels of gender: male and female students. The dependent variable was students' academic performance in science as measured by pre- and post-test scores administered to the students before and after the intervention.

Sample and Sampling Technique

The sample consisted of 100 Senior Secondary School One (SS1) science students from three government-owned comprehensive high schools in Ago-Iwoye, Ijebu North Local Government Area, Ogun State, Nigeria. Three schools were randomly selected and assigned experimental group A and experimental B, while the third school served as the control group. Students were in their intact classes, so specific students were not selected.

- Group A (n = 36): Received the Thinking Aloud Metacognitive Strategy.
- Group B (n = 14): Received the Agree/Disagree Metacognitive Strategy.
- Group C (n = 50): Served as the Control Group, taught with the conventional method. All groups were exposed to the same science curriculum content.

Figure 1
Schematic Design of the Study

Group A	$\mathbf{O_1}$	$\mathbf{X_1}$	$\mathbf{O_2}$
Group B	O_1	X_2	O_2
Group C	O_1	-	O_2

Where:

O_1 = Pre-test for all groups
X_1 = Thinking Aloud Metacognitive Strategy
X_2 = Agree/Disagree Metacognitive Strategy
- = No metacognitive strategy (Conventional Method)
O_2 = Post-test for all groups

Intervention

The intervention lasted for six weeks, with week 1 used to sensitize students and teachers and administer the pretest, four weeks used for intervention with each group receiving three 40-minute science lessons per week, totaling 12 periods, and the last week used to administer the posttest to the three groups. To maintain instructional consistency and minimize teacher-related threats to internal validity, three trained science teachers were provided with standardized lesson plans and instructional guides specific to each group's treatment condition. Regular monitoring ensured adherence to the instructional protocol across all groups. The specific activities that take place in the groups are summarized in the highlights below:

Group A: Thinking Aloud Strategy

- Students were encouraged to verbalize their thought processes while solving science problems.·
- The teacher modeled metacognitive thinking by posing reflective questions, encouraging students to articulate problem-solving steps, and prompting self-assessment during and after tasks.

Group B: Agree/Disagree Strategy

- Students were presented with conceptual science statements and asked to indicate their agreement or disagreement, followed by justifications.·
- This strategy prompted learners to evaluate evidence, clarify misconceptions, and reflect on their reasoning processes.

Group C (Control): Conventional Teaching

The control group was taught using traditional lecture-based instruction without deliberate metacognitive prompts or student-centered strategies.

Instruments

The research instrument employed for this study was the Physics, Chemistry, and Biology Performance Test (PCBPT). PCBPT is a performance test that contains 30 multiple-choice items. The test was structured on 10 multiple-choice questions each from the 2023 West African Examination Council on topics of motion for physics, atomic structure for chemistry, and microorganisms for biology. The questions were validated as appropriate for senior secondary school one (SS1) students, as the topic selected aligned with the topic in the secondary school one syllabus. The instrument used for this study underwent content validity testing by presenting the questions to experts in science education at a southwestern university in Nigeria. This was done by assessing the instrument, scrutinizing and editing the items in the PCBPT used for gathering and analyzing data, and inspecting and affirming that the instrument could measure students' academic performance in three selected domains. Instructional materials and lesson plans were validated by three experts in science education for content validity. The reliability of the PCBPT instrument was determined using the Kuder-Richardson Formula 20 (KR-20), yielding a reliability coefficient of 0.83, indicating high internal consistency.

DATA COLLECTION AND DATA ANALYSIS

Data Collection

Approval for the study was obtained from the Department of Science and Technology Education. A formal letter of introduction was presented to the principals of the selected schools to gain access and institutional support. Parental and student consent was also sought where necessary. The data was collected by first administering the pretest to all participants, with the pretest consisting of validated science test items covering topics to be taught during the intervention. The pretest lasted 40 minutes and was administered in a classroom setting under the supervision of their teachers. Over the course of four weeks, each group received 12 sessions (3 sessions/week) as described in the methodology. Regular monitoring ensured adherence to the instructional protocol across all groups. Afterwards, the same test (although questions were scattered) was re-administered to all participants as a posttest. The posttest also lasted 40 minutes and was administered under supervision. Throughout the study, efforts were made to control for threats to internal validity by ensuring that the groups were taught simultaneously within the same period to reduce variability due to external events or developmental factors. The same test instrument was used for both the pretest and the posttest. A time gap of four days was maintained between the final lesson and the posttest to reduce memorization effects. All responses were graded by the researcher and cross-checked by a colleague to enhance scoring accuracy. No negative marking was applied. Confidentiality and anonymity of participants were maintained throughout because they did not write their original names but coded names.

Data Analysis

The data collected were manually entered into SPSS version 21. To ensure data quality, we first checked for extreme values, with each question item. Boxplots were used to identify and correct any data entry errors. Data normality was assessed through normality plots and histograms. Descriptive statistics of mean and standard deviation was used to determine the mean gain of student scores in experimental and control group while t-test analysis was used to examine if there is a significant difference in the scores of students in experimental and control group.

RESEARCH ETHICS

The study was conducted after receiving participants' permission and the authors adhered strictly to ethical guidelines, including protecting confidentiality and respecting participant's right to withdraw at any time.

RESULTS

To investigate the level of students' academic performance, the scores were distributed to low, medium and high scores. 1-15 scores were categorized as low, 16-29 were tagged as moderate and 30-40 were tagged as high.

Table 1
Level of Students Performance in the Study

Level	Range	Frequency	Percentage
Low	1-15	8	8.0
Moderate	16-29	74	74.0
High	30-40	18	18.0

Table 1 showed the level statistics of students' academic performance in secondary school science, 8.0% of the respondents possess a low level of academic performance in secondary school science, 74.0% of them possess a moderate level of academic performance in secondary school science, while 18.0% of the respondents had high level of the academic performance in secondary school science. The result implied that most of the participants possess a moderate level of academic performance in secondary school science subjects (Physics, Chemistry and Biology).

In order to determine the mean gain of students taught using metacognitive strategies and compare it to those taught using conventional methods, the mean scores of students in the metacognitive strategy group(s) and the control group were calculated. The result is shown in Table 2.

Table 2

Analysis of the Mean Gain of Students Taught with Metacognitive Strategies and Those Taught with the Conventional Method.

Strategy	N	Mean	Standard deviaton	Mean gain
Metacognitive strategies	50			4.96
Pre-test		11.12	2.25	
Post-test		16.08	2.17	
Conventional method	50			1.20
Pre-test		11.20	1.17	
Post-test		12.40	2.30	

The result in Table 2 revealed that the metacognitive strategy is slightly effective than the conventional method. The experimental group that was taught with metacognitive strategies showed a substantially higher mean gain M = 4.96 compared to the group using the conventional method M = 1.20. This suggests that the intervention utilizing metacognitive strategies was more effective in improving participants' metacognitive abilities.

Additionally, the relatively low standard deviation in the metacognitive strategies group indicates consistency in improvement among participants, whereas the higher standard deviation in the conventional method group suggests more variability in the effectiveness of the intervention.

Testing Hypothesis

To test for the difference in performance of students in biology taught using thinking aloud and agree/disagree instructional strategy, a test analysis was carried out. The result is shown in Table 3.

Table 3

T-test Analysis of the Performance of Students Taught using Thinking Aloud and Agree-Disagree Instructional Strategy.

	N	Mean	SD	Df	t	Sig
Thinking aloud	36	16.28	2.32	48	.678	.501
Agree/Disagree	14	15.84	2.28			

d = 0.19

Table 3 shows that there was no significant difference in the biology performance of students taught using the thinking aloud strategy (M = 16.28, SD = 2.32) and those taught using the agree/disagree strategy (M = 15.84, SD = 2.28), $t(48) = 0.678$, $p = .501$. As the significance level exceeds 0.05, the null hypothesis is not rejected. Also, although the calculated Cohen's $d = 0.19$ indicates a small effect size, suggesting a minimal practical difference between the two strategies, a better advantage for the thinking aloud method is implied.

DISCUSSION

The findings show no statistically significant difference in the academic performance of biology students taught using thinking aloud (TA) and self-assessment (agree/disagree-style) metacognitive strategies. This result is consistent with the findings of Okpara (2018), who also reported no significant difference in students' mean achievement when exposed to similar instructional techniques. It also aligns partially with Asraf and Halim (2024), who emphasized that while thinking aloud enables students to verbalize their thoughts and reflect on their reasoning, its impact on achievement may not always be pronounced in the absence of structured scaffolding or when applied across diverse achievement levels. One possible explanation for the lack of statistically significant differences in academic performance between the metacognitive strategy groups lies in the complexity of metacognitive skill development, which often requires sustained instructional support, repeated practice, and a high degree of learner readiness (de Jong et al., 2023). If teachers are not adequately trained to scaffold metacognitive instruction or to adapt strategies to individual learners' needs, the potential benefits may be diminished.

Recent studies (e.g., Yu et al., 2024; Zhang et al., 2024) underscore the importance of professional development programs that explicitly train teachers to model metacognitive thinking, integrate reflective prompts into lessons, and use formative feedback to guide students' regulation of learning. For metacognitive strategies to be effective, teachers must not only understand the techniques but also feel confident in adapting them to diverse classroom contexts. Therefore, a key implication of this study is the need to embed metacognitive strategy instruction into pre-service and in-service teacher training programs, with a focus on practical application, contextual responsiveness, and culturally grounded examples. Contrary to the non-significant outcomes in this study, some earlier works (e.g., de Boer, 2018; Nbina & Viko, 2010; Sadykova et al. 2024) reported significant differences in student performance between metacognitive strategy groups. Specifically, Nbina and Viko (2010) found that students using self-assessment strategies outperformed those using thinking aloud, attributing this advantage to the development of self-efficacy and greater student autonomy. These conflicting findings suggest that the effectiveness of metacognitive strategies may be influenced by contextual factors such as subject matter, students' prior knowledge, and how the strategies are implemented and supported within the classroom.

Importantly, this study expands ongoing discourse in science education by showing that while overall performance did not differ significantly between the two metacognitive strategies, observable differences were present in students' classroom engagement, interest, and active participation; factors that are increasingly valued in global science education reform. The experimental groups demonstrated higher levels of engagement, and students displayed greater metacognitive awareness as they learned to reflect on their thinking processes. This reinforces prior studies (e.g., Nasaruddin et al., 2024) that argue for the utility of metacognitive strategies not just in improving test scores, but in fostering deeper cognitive engagement and autonomy.

Furthermore, the findings support the global push toward student-centered pedagogies in science education, such as inquiry-based learning and reflective practice. The shift in performance trends between the pre-test and post-test periods underscores the potential of metacognitive strategies to cultivate reflective thinking over time, especially when students are explicitly taught how to monitor and regulate their learning. The differential effects observed among achievement bands suggest that the benefits of metacognitive strategies might not be uniformly distributed, echoing studies like that of Sadykova et al. (2024), where it was found that high-achieving students tend to benefit more from structured metacognitive interventions.

Critically, this study contributes to the limited but growing literature that investigates how metacognitive strategies interact with prior achievement levels. While most existing research treats student achievement as a background variable, this research provides preliminary evidence that the implementation of TA and A/D strategies could yield nuanced outcomes across low, medium, and high achievement bands, an area that remains underexplored in science education scholarship. The findings of this study emphasize that while the use of metacognitive strategies may not yield immediate or statistically significant gains in academic performance in the present study, it nonetheless holds considerable pedagogical value. Metacognitive instruction shapes how students approach learning, fosters deeper engagement, and can lay the foundation for long-term academic resilience, particularly when implemented within supportive and reflective learning environments. These insights are especially important for science educators navigating the challenges of differentiated instruction, equity, and learner variability in increasingly diverse classrooms.

To build on these findings, future research should incorporate qualitative methodologies such as classroom observations, teacher interviews, and student reflective journals. These approaches can capture the more nuanced aspects of learner engagement, strategy use, and reflective thinking dimensions that standardized tests often overlook but are essential to understanding how metacognitive strategies are internalized over time (Darling-Hammond et al., 2020; Reeve et al., 2019). By moving beyond test scores, such methods allow researchers to explore the complex, process-oriented nature of metacognitive learning. A limitation of the present study lies in the unequal sample sizes across the experimental groups, thinking aloud ($n = 36$) and Agree/Disagree ($n = 14$), which may have contributed to the absence of a significant difference observed between the two groups and potentially reduced statistical power. Nonetheless, this did not compromise the robustness of the reported findings, as statistical power does not always equate to practical or real-world significance in medical and scientific research (Leppink et al., 2016). To address this, future studies should aim to recruit more balanced and sufficiently large samples or consider applying advanced statistical techniques, such as bootstrapping or Bayesian estimation. Replicating the study with more evenly distributed cohorts would enhance the reliability and external validity of the findings and provide deeper insight into the comparative effectiveness of specific metacognitive strategies across diverse educational contexts.

CONCLUSION

This study set out to investigate the differential effects of Thinking Aloud (TA) and self-assessment metacognitive strategies on the academic performance of secondary school biology students across three achievement levels: high, medium, and low. The findings revealed no statistically significant difference in students' performance between the two instructional strategies, nor across the three achievement bands. These results contribute to the growing but nuanced body of literature suggesting that metacognitive strategies such as TA and self-assessment may not yield uniform benefits across student populations. While Thinking Aloud allows for verbal expression of cognitive processes and self-assessment fosters reflection and autonomy, their efficacy seems to be context-dependent and possibly moderated by factors such as instructional design, scaffolding, students' metacognitive awareness, and subject-specific complexity.

RECOMMENDATIONS

The study proposes the following recommendations.

1. Think aloud and the Agree/Disagree instructional strategy should be incorporated into the science curricula.

2. Schools should provide training for teachers on how to effectively implement metacognitive techniques, such as thinking aloud and self-assessment, to foster deeper understanding and better retention of scientific concepts among students.
3. The study shows that metacognitive strategies help in improving the academic performance of students by empowering them to take charge of their learning. To maximize this benefit, educators should tailor these strategies to meet the individual learning needs of students, especially those with moderate to low academic performance. This personalized approach can help bridge the gap and elevate the performance of all students, ensuring a more equitable learning environment.

ACKNOWLEDGEMENT

The authors express gratitude to the participants who participated in the study. The authors also express gratitude to the anonymous reviewers whose contributions have substantially enhanced the manuscript.

FUNDING

No particular grants or financing are available from any public, commercial, or profit or non-profit organizations.

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