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Research Article

The Impact of Metacognitive Strategy Training on Higher-Order Thinking Skills (HOTS) in High School Mathematics: A Quasi-Experimental Study

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Abstract

Difficulties developing higher-order thinking skills (HOTS) in mathematics education represent a persistent and significant challenge in educational practice. These skills, such as analysis, evaluation, and creation, are essential for students to succeed in complex problem-solving and adapt to the evolving demands of the 21st century. This study assesses how effectively structured metacognitive training improves high school students' mathematical HOTS. The research employed a quasi-experimental pretest-posttest design involving 72 students from a senior high school in Indonesia, divided into two groups: an experimental group ($n = 36$) that received metacognitive training over one semester, and a control group ($n = 36$) that did not receive any intervention. The primary outcome measure was HOTS scores, assessed through standardized pre-test and post-test instruments designed to evaluate students' higher-order thinking in mathematics. ANCOVA results revealed a significant effect of the metacognitive intervention on HOTS post-test scores ($F = 44.36$; $p < 0.001$; $\eta p^2 = 0.391$), even after controlling for pre-test performance. The experimental group exhibited substantially greater HOTS improvements than the control group. These results prove that structured metacognitive training is an effective pedagogical strategy for fostering advanced mathematical thinking. The findings hold significant implications for curriculum designers, educators, and policymakers aiming to improve mathematics instruction, particularly within the Indonesian context. Future studies involving larger sample sizes, diverse school settings, and longitudinal follow-up are recommended to validate and extend the impact of this intervention.

Keywords: Educational Intervention; Metacognitive Training; Mathematics Education; Problem Solving; Student Cognitive Regulation.

1. INTRODUCTION

Higher-order thinking skills (HOTS) are vital competencies in 21st-century education, particularly within mathematics instruction [1], [2]. These skills encompass the ability to think critically, analytically, evaluatively, and creatively, competencies necessary for students to navigate complex, real-world challenges [3], [4]. However, numerous international studies have consistently reported low student performance in HOTS. For instance, the Programmed for International Student Assessment (PISA) has repeatedly highlighted students' difficulties in solving mathematical problems that demand advanced cognitive processes such as critical, analytical, and creative thinking [5], [6]. This persistent challenge underscores the urgent need for innovative and effective instructional approaches to foster the development of students' higher-order thinking [7].

One theoretically promising approach is incorporating metacognitive strategies into the learning process. Metacognition is an individual's awareness, regulation, and control over their thinking processes. It comprises two primary components: knowledge of cognition and regulation of cognition [8]. The first refers to students' understanding of effective learning strategies, while the latter involves planning, monitoring, and evaluating one's cognitive processes during learning [9]–[11]. Moreover, recent studies suggest that metacognitive training promotes student autonomy and fosters self-directed learning—two key elements for developing HOTS [12], [13].

The implementation of metacognitive strategies in mathematics education has demonstrated a positive impact on student academic achievement. Empirical studies suggest that metacognitive interventions significantly enhance student performance across STEM disciplines [14], [15]. For example, Parwata et al. [16] found that training in metacognitive strategies effectively enhanced students' critical thinking skills and mathematics learning outcomes. Similarly, Wang et al. [12] reported that students who received metacognitive training were better able to solve complex mathematical problems requiring higher-order thinking. These findings align with earlier research by Kramarski & Mevarech [17], who demonstrated the efficacy of metacognitive instruction in improving mathematical reasoning and self-regulation.

Moreover, learning environments encouraging students to manage their learning processes actively have also been associated with improved HOTS development. Fowler et al. [18] showed that virtual maker spaces, which provide autonomy and opportunities for collaboration, can significantly enhance students' spatial reasoning and creativity, two key elements of HOTS. This aligns with the constructivist view, which suggests that students learn best when involved in self-directed, meaningful activities [19], [20]. In addition, studies by Kwon et al. [21] highlight that autonomy-supportive learning settings increase students' motivation and engagement factors, which mediate the development of complex thinking skills.

In addition to metacognitive strategies, integrating computational thinking into mathematics instruction has also shown promise in enhancing problem-solving skills. Lehtimäki et al. [22] found that engaging students with computational thinking tasks such as Bebras improved performance in solving complex mathematical problems, primarily through enhanced collaboration and communication. Research by Grover & Pea [23] further supports the integration of computational thinking into mathematics to build algorithmic reasoning and abstraction, which are integral to HOTS. Moreover, Brennan & Resnick [24] emphasize that computational thinking encourages iterative problem-solving, a trait shared with metacognitive processes.

Although increasing evidence supports the advantages of metacognitive strategies, the literature still shows a notable gap regarding their use in senior high school mathematics education. Specifically, there is a lack of rigorous experimental research that designs tailored metacognitive training programs and explicitly measures their impact on students' HOTS. As highlighted by Zohar & Barzilai [4], many previous studies lack clear instructional frameworks for operationalizing HOTS and metacognition simultaneously. The present study aims to fill this gap by providing a well-structured experimental design and empirical evaluation of how metacognitive strategies improve HOTS in senior high school mathematics learning.

Furthermore, the quality of instructional materials used in mathematics education is another critical factor influencing HOTS development. Fricke and Reinisch [25] emphasize explicitly representing cognitive-epistemic systems within learning materials to support students' higher-order thinking. Similarly, Stylianides & Stylianides [26] argue that tasks that encourage justification, argumentation, and abstraction are necessary to stimulate higher-order reasoning in mathematics. Therefore, this study also incorporates the development of well-designed instructional materials that align with and reinforce metacognitive strategies as a foundational part of the intervention.

Finally, teacher-related factors play a crucial role in supporting HOTS development. Khadka et al. [27] highlight that a humanistic teaching approach characterized by fairness, teacher enthusiasm, and moral support positively impacts students' mathematical achievement. This is echoed by Nind et al. [28], who emphasize the need for emotionally responsive pedagogy in supporting deep learning and engagement. Thus, the effectiveness of any instructional intervention, including metacognitive training, must be considered within the broader ecological context of teacher-student interactions and the socio-emotional climate of the classroom.

The fundamental purpose of this survey is to explore the extent to which implementing metacognitive strategy interventions can enhance students' HOTS in mathematics. The central hypothesis to be tested is that students who receive metacognitive strategy training will demonstrate significantly greater improvements in HOTS scores from pre-test to post-test, compared to those in the control group. This hypothesis builds upon the theoretical foundations of metacognition and the practical need for evidence-based interventions to address persistent shortcomings in mathematics education outcomes.

2. LITERATURE REVIEW

2.1. The Concept of Metacognition in Learning

Metacognition refers to individuals' ability to be aware of, regulate, and reflect upon their cognitive processes [10]. Flavell [8] delineated metacognition into two key elements: metacognitive knowledge and metacognitive regulation. Metacognitive knowledge includes awareness of personal variables, task characteristics, and learning strategies. In contrast, metacognitive regulation involves planning, monitoring, and evaluating learning strategies.

This framework was further developed by Zimmerman [29] through the self-regulated learning (SRL) model, which comprises three phases: forethought (planning and goal setting), performance (monitoring and control during task execution), and self-reflection (post-task evaluation). The SRL model provides a robust foundation for understanding how learners can independently and reflectively manage their learning processes. Fogarty [30] emphasized that metacognitive regulation follows a sequential process: strategy planning before engaging in a task, monitoring during task execution, and evaluating outcomes to support continuous improvement. This sequence is particularly critical in competency-based learning environments and in improving HOTS.

In the context of collaborative learning, Qiao et al. [31] expanded the concept of metacognition by introducing a three-level approach: individual, interpersonal, and group. At the personal level, learners regulate their cognitive activities. At the interpersonal level, they exchange strategies and offer mutual support. At the group level, collective coordination is emphasized when accomplishing shared tasks. Longitudinal studies indicate that skills in evaluation and monitoring tend to develop more slowly than planning abilities, underscoring the need for early and continuous metacognitive scaffolding [32], [33].

2.2. Metacognitive Interventions in Mathematics

A study conducted by Kusaka and Ndihokubwayo [34] on grades 3 to 5 in Rwanda revealed that metacognitive strategies significantly contributed to students' success in solving mathematical word problems. Learners who scored highly in metacognitive aspects demonstrated greater success, particularly when selecting and implementing problem-solving strategies. The strategies employed included articulating logical reasoning, constructing tables or diagrams, and utilizing visualizations to monitor their cognitive processes. The assessment instrument in this study adapted a rubric based on Polya's [35] problem-solving model, which consists of four main stages: understanding the problem, devising a strategy, executing the plan, and reviewing the solution.

While most students exhibited adequate planning skills, the study found that their abilities to monitor their thought processes and evaluate their outcomes remained relatively underdeveloped. This developmental disparity suggests that younger students require explicit instructional support, especially in recognizing errors and reflecting on the strategies they employed. These findings align with Veenman et al. [33], who argued that monitoring and evaluation skills tend to develop more slowly than planning abilities, thus necessitating structured and direct instruction.

Montague [36] further demonstrated that explicit instruction integrating metacognitive strategies systematically can substantially improve students' problem-solving capabilities in mathematics. She developed the Strategic Math Instruction (SMI) approach, which emphasizes direct teaching of cognitive strategies through think-aloud modeling, scaffolding, and repeated guided practice accompanied by structured reflection. This intervention proved particularly effective in enhancing students' mathematical performance with learning difficulties.

Dignath and Büttner [37], through a meta-analysis of 48 experimental studies at the primary and secondary school levels, found that explicitly taught metacognitive strategies significantly positively impacted students' academic achievement. They emphasized that the effectiveness of metacognitive interventions increases when the strategies are embedded within authentic tasks and tailored to students' developmental characteristics. Similarly, Zohar and Peled [38] asserted that elementary school students can develop HOTS, including reflective and strategic thinking, when consistently exposed to metacognitive training.

Additionally, research by Kramarski and Mevarech [17] reinforced the importance of metacognition-based instructional approaches in mathematics education at the primary level. They introduced the IMPROVE model (Introducing new material, Metacognitive questioning, Practicing, Reviewing, obtaining mastery, Verification, and Enrichment), which enhanced conceptual understanding, problem-solving, and self-regulation skills. This model emphasizes metacognitive questioning—such as "What do I understand?", "What alternative strategies can I use?", and "How do I know my answer is correct?"—to directly foster students' monitoring and evaluation processes within mathematical contexts.

A longitudinal study by Kuhn and Dean [39] also demonstrated that reflective and metacognitive thinking skills can be cultivated early through explicit practice in constructing arguments, comparing alternative solutions, and evaluating claims. They highlighted that learning environments encouraging students to question and assess their thinking are far more effective than conventional one-directional instructional approaches.

Metacognitive interventions are not limited to primary and secondary education; they have also been widely implemented in higher education and various academic disciplines. In tertiary education, hypermedia-based technologies and strategic feedback have significantly enhanced students' meta-comprehension accuracy and knowledge transfer abilities. Azevedo and Hadwin [40] emphasized that the effectiveness of such interventions hinges on how well learning systems facilitate students in independently planning, monitoring, and evaluating their learning processes. Interventions such as metacognitive prompting and progress tracking through interactive logs have been found to foster reflective engagement and improve the quality of conceptual understanding among university students [12].

In health education, Sujatmika et al. [41] developed a critical thinking assessment instrument focused on the human circulatory system. This instrument was validated using the Rasch model to ensure item reliability and construct validity. The analysis revealed that the self-regulation subcomponent was the weakest among the measured indicators of critical thinking. These findings suggest that despite students' adequate factual knowledge and conceptual understanding, they still require more systematic training in metacognitive aspects to strengthen their internal control over learning strategies and problem-solving processes in health-related contexts.

In the field of clinical psychology, the Metacognitive Training for Eating Disorders (MCT-ED) program, implemented among adolescents with anorexia nervosa, yielded positive outcomes in enhancing cognitive flexibility and reducing tendencies toward maladaptive perfectionism [42]. However, the effects of this intervention were not sustained long-term and tended to diminish after three months without reinforcement sessions. This highlights the need for metacognitive training to be designed as an ongoing process rather than a one-time intervention. Grant [43] further reinforced this notion by asserting that meaningful changes in mindset and self-regulatory strategies require consistent support to become deeply embedded in everyday behavior.

2.3. Technology-Based and Innovative Approaches

Hypermedia-based learning environments have emerged as effective platforms for facilitating the development of students' metacognitive skills. A study by Wang et al. [44] demonstrated that the combination of metacognitive prompts and external feedback significantly enhances students' metacognitive accuracy, particularly in the dimensions of judgment of learning (self-assessment of understanding) and the ability to transfer knowledge to new contexts. Metacognitive prompts serve as internal cues that encourage reflection on learning strategies, while external feedback helps correct self-assessment biases and strengthens the connection between cognitive processes and learning outcomes. These findings are consistent with the framework proposed by Azevedo and Hadwin [40] on technology-supported self-regulated learning, which underscores the importance of external scaffolding during the initial stages of autonomous learning.

The Stepping Stones program exemplifies a practical application of this model [45]. This program trains elementary school teachers to integrate metacognitive strategies into mathematics instruction through a fading scaffold approach. Initially, teachers are provided with explicit supports such as instructional scripts, worked examples, and curated lists of prompts. Over time, these supports are gradually withdrawn to encourage teacher autonomy in designing instructional strategies tailored to their students' needs. Classroom observations indicated a remarkably high implementation rate of metacognitive strategy, ranging from 93% to 100%, including goal sharing, small group discussions in mixed-trio formats, and using worked examples as collaborative exploration tools.

Moreover, teachers who participated in the training reported substantial improvements in their conceptual understanding of metacognition and increased confidence in delivering mathematics problem-solving instruction reflectively and strategically. These improvements suggest that enhancing teacher capacity in adopting metacognitive approaches transforms instructional practices and strengthens teacher self-efficacy, which, according to Bandura [46], directly influences instructional effectiveness.

These findings align with the meta-analysis by Dignath and Büttner [37], which revealed that teacher training in self-regulated learning and metacognitive strategies significantly positively impacts student learning outcomes at both primary and secondary levels. Furthermore, Hattie [47], in his synthesis of over 800 meta-analyses, identified metacognitive strategy instruction as one of the ten most effective educational interventions, with a substantial effect size ($d = 0.69$). Programs like Stepping Stones underscore the critical role of pedagogical content knowledge in teacher professional development [48]. Teachers must possess a deep understanding of mathematical content and the pedagogical expertise to teach it in ways that concurrently foster students' cognitive and metacognitive development. Within this context, strategies such as reflective questioning, self-explanation, and progress monitoring tools constitute essential components of metacognitively informed mathematics instruction.

2.4. Assessing Higher-Order Thinking Skills (HOTS) in Mathematics

Higher-order thinking skills (HOTS) in the context of mathematics education reflect students' abilities to apply mathematical knowledge to analyze problems, evaluate solutions, and generate original strategies. HOTS go beyond procedural mastery and encompass reflective, critical, logical, and creative thinking skills essential for solving non-routine and complex tasks [3], [49]. The revised Bloom's Taxonomy by Anderson and Krathwohl [50] categorizes HOTS into the three highest cognitive domains: analysis, evaluation, and creation. At the analysis level, students are expected to deconstruct information, identify relationships among components, and recognize patterns. The evaluation level involves making judgments based on logical or argumentative criteria. In contrast, the creation level requires students to develop new solutions, construct models, or devise novel approaches not previously taught.

Effective measurement of HOTS in mathematics demands the development of diagnostic instruments that are psychometrically valid. In their systematic review, Kania & Kusumah [51] recommended that such instruments should address both cognitive and psychological dimensions and be validated using the Rasch model to ensure the reliability and interpretive accuracy of the data. The Rasch model provides detailed insights into item functioning, difficulty levels, and the consistency of students' responses across HOTS indicators [52], [53]. Assessment tools considered adequate for measuring HOTS include open-ended problems, real-world contextualized tasks, and performance-based assessments that require students to explore alternative strategies. The use of analytic rubrics incorporating metacognitive indicators such as strategy justification, solution reflection, and elaboration of alternative approaches has also proven effective in capturing the depth of students' HOTS performance [54].

An effective HOTS assessment instrument must be capable of distinguishing students' levels of cognitive processing while also providing teachers with insights into appropriate follow-up interventions. Therefore, the design of such assessments should be grounded in the principles of construct validity, ensuring that the instrument accurately measures the targeted HOTS. Moreover, robust data analysis techniques—such as Item Response Theory (IRT) or the Rasch model—are essential for developing reliable and informative measurement tools. These methods enable a deeper understanding of item functioning and student response patterns, thereby enhancing the interpretability and diagnostic utility of the assessment [55].

3. MATERIAL AND METHODS

3.1. Research Design and Participant Demographics

This study used a quasi-experimental design with a pretest-posttest control group to investigate the effectiveness of structured metacognitive strategy training in enhancing HOTS in mathematics among high school students. The sample consisted of 72 students (36 in the experimental group and 36 in the control group) drawn from two comparable Grade 11 classes at a public high school in South Sulawesi, Indonesia.

The metacognitive training incorporated three core elements: planning (goal-setting, task analysis), monitoring (self-questioning, tracking progress), and evaluating (error analysis, reflection). Weekly sessions were 90 minutes each, combining guided instruction, group discussions, and reflective exercises. Instructional materials included problem-solving worksheets, metacognitive checklists, and structured reflection journals. The control group followed the standard national curriculum without additional metacognitive instructions.

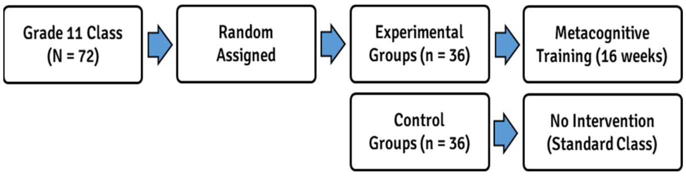

Figure 1. Research Flow Diagram

Figure 1 illustrates the research flow, showing random group allocation, pre-test administration, intervention implementation over one semester, and post-test measurement. The pre-test was conducted to assess baseline HOTS, followed by a 16-week intervention for the experimental group and standard instruction for the control group. Participants were selected using cluster random sampling, with intact classes randomly assigned to either the experimental or control group. Table 1 presents detailed demographic characteristics, including age, gender, and previous academic performance in mathematics.

Table 1. Demographic of Respondents Summary (N=72)

		Experimental Group (n=36)		Control Group (n=36)	
		Frequency	Percentage	Frequency	Percentage
Age	16 years	24	66.67%	21	58.33%
	17 years	9	25.00%	10	27.78%
	18 years	3	8.33%	5	13.89%
Gender	Male	16	44.44%	17	47.22%
	Female	20	55.56%	19	52.78%
Prior Math Achievement	High (>84)	11	30.56%	9	25.00%
	Medium (70–84)	19	52.78%	20	55.56%
	Low (<70)	6	16.67%	7	19.44%

The respondents' demographics (N = 72) were distributed between the experimental and control groups (n = 36). Most students were 16 years old, comprising 66.67% of the experimental group and 58.33% of the control group, followed by smaller proportions aged 17 and 18. Gender distribution was relatively balanced, with males representing 44.44% in the experimental group and 47.22% in the control group. Regarding prior mathematics achievement, most students in both groups were categorized as having medium performance (70–84), accounting for 52.78% of the experimental group and 55.56% of the control group. High achievers (>84) and low achievers (<70) were similarly represented across both groups. These distributions suggest comparable baseline characteristics between the two groups regarding age, gender, and academic background.

3.2. Instrument

Metacognitive awareness was measured using the Metacognitive Awareness Inventory (MAI), a widely recognized self-report instrument developed initially by Schraw and Dennison [10] to assess individuals' awareness and regulation of their cognitive processes. In the context of secondary education, the MAI was adapted to suit the cognitive developmental level and linguistic proficiency of high school students. This adaptation involved simplifying the language to enhance comprehensibility while preserving the instrument's conceptual integrity, reducing the number of items for age appropriateness, and contextualizing the statements to align with tasks commonly encountered in the high school curriculum—particularly those related to reading comprehension and mathematical problem-solving.

Table 2. Knowledge of Cognition (10 items)

No	Statement
1	I know the most effective learning strategies for understanding mathematics.
2	I know which math concepts I understand and which ones I still need to work on.
3	I know when to use a specific formula or strategy to solve a math problem.
4	I understand the procedural steps needed to solve math problems.

No	Statement
5	I know when to use diagrams, tables, or models to help me solve math problems.
6	I know when I should calculate manually or use a calculator.
7	I can explain why I chose a specific method to solve a problem.
8	I know which types of math problems require extra attention.
9	I know what I need to review before a math exam.
10	I can connect one math concept to another.

Table 3. Regulation of Cognition (20 items)

No	Statement
11	Before solving a math problem, I set clear learning goals.
12	I make a step-by-step plan before working on a math problem.
13	While working on a problem, I check whether I follow my initial plan.
14	If I find a problem difficult, I try a different strategy.
15	After solving a problem, I review how I approached it.
16	When I get a question wrong, I try to figure out why.
17	I use notes or formulas I have memorized to help solve problems.
18	I often ask myself whether my method is correct while solving problems.
19	I assess my understanding after learning a new math topic.
20	I compare my answers with the answer key to find my mistakes.
21	I judge whether my answer makes sense.
22	I manage my time efficiently during math tests.
23	I pay special attention to word problems or real-life context questions.
24	I keep track of common mistakes to avoid repeating them.
25	I summarize or make concept maps after studying math material.
26	When studying, I try to explain math concepts in my own words.
27	I make sure I fully understand the problem before I start solving it.
28	I evaluate my math learning strategies after getting my test results.
29	I adjust my study approach if I am unsatisfied with my previous results.
30	I ensure I understand the objective of each math task or exercise.

The adapted instrument showed strong internal consistency, with a Cronbach's alpha coefficient of 0.82, indicating reliability for assessing students' metacognitive awareness and their HOTS in mathematics. All items were rated using a 5-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree). This format enabled quantitative analysis of students' self-perceived metacognitive behaviors across both knowledge of cognition and regulation of cognition domains.

3.3. Data Analysis and Statistical Assumptions

The data were analyzed using Analysis of Covariance (ANCOVA) in SPSS to compare post-test scores between groups while statistically controlling for differences in pre-test scores. Before the analysis, essential statistical assumptions were tested within SPSS, including normality of data distribution, homogeneity of variances (Levene's Test), and homogeneity of regression slopes. The homogeneity of regression slopes, in particular, was assessed to ensure that the relationship between the covariate (pre-test scores) and the dependent variable (post-test scores) was consistent across groups. All assumptions were met, supporting the use of ANCOVA as a valid and robust method for examining the intervention's effectiveness.

4. RESULTS

4.1. Descriptive of Mathematics HOTS

Table 4 presents the descriptive statistics for students' HOTS in mathematics, including pre-test scores, post-test scores, and normalized gain (N-gain) for both the experimental and control groups.

Table 4. Descriptive Summary of Mathematics HOTS Scores

Group	N	Min.	Max.	Mean	Std. Dev.
Pre-Test Control	36	24	90	58.72	18.767
Pre-Test Experimental	36	24	90	58.78	18.262
Post-Test Control	36	50	95	74.64	11.090
Post-Test Experimental	36	60	100	85.64	9.187
N-gain Control	36	-0.36	0.83	0.336	0.271
N-gain Experimental	36	0.35	1.00	0.669	0.183
Valid N	36				

The pre-test mean scores were nearly identical between the two groups, with the control group scoring an average of 58.72 (SD = 18.767) and the experimental group scoring 58.78 (SD = 18.262), indicating comparable baseline HOTS performance before the intervention. However, post-test results showed a notable increase in the experimental group's mean score to 85.64 (SD = 9.187), compared to 74.64 (SD = 11.090) in the control group. This suggests a greater improvement in HOTS among students who received the metacognitive intervention.

Furthermore, the normalized gain (N-gain) scores reinforce this trend. The experimental group achieved a higher mean N-gain of 0.6689 (SD = 0.18277), while the control group obtained a lower mean of 0.3361 (SD = 0.27079). These results indicate that the intervention effectively enhanced students' HOTS in mathematics, as evidenced by the absolute post-test scores and the relative learning gains.

4.2. Normality Test

Table 5 presents the results of normality testing for pre-test, post-test, and N-gain scores using the Kolmogorov-Smirnov and Shapiro-Wilk tests for the control and experimental groups. These tests were conducted to examine whether the data met the assumption of normal distribution required for parametric statistical analysis. Conversely, water quality has been adversely impacted, as shown by a marked increase in nutrient concentrations. Specifically, Total Kjeldahl Nitrogen (TKN) levels rose from 7.42 mg/L to 19.02 mg/L, and total phosphorus increased from 0.22 mg/L to 0.46 mg/L after the project. While the introduction of Best Management Practices (BMPs) achieved a moderate reduction of nutrient concentrations (38%), these interventions were insufficient to restore sediment delivery or fully address the increase in nutrient loading.

Table 5. Tests of Normality

Group		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Pre-test	Control Group	0.153	36	0.033	0.951	36	0.114
	Experimental Group	0.153	36	0.032	0.950	36	0.103
Post-test	Control Group	0.209	36	0.000	0.947	36	0.085
	Experimental Group	0.159	36	0.023	0.940	36	0.051
N-gain	Control Group	0.140	36	0.070	0.947	36	0.083
	Experimental Group	0.164	36	0.016	0.944	36	0.069

a. Lilliefors Significance Correction

Table 6. Homogeneity Test

		Levene Statistic	df1	df2	Sig.
Pre-test	Based on Mean	2.099	1	70	0.152
	Based on Median	2.371	1	70	0.128
	Based on Median and with adjusted df	2.371	1	64.610	0.128
	Based on the trimmed mean	2.131	1	70	0.149
Post-test	Based on Mean	0.526	1	70	0.471
	Based on Median	0.279	1	70	0.599
	Based on Median and with adjusted df	0.279	1	69.717	0.599
	Based on the trimmed mean	0.546	1	70	0.462

Based on the Shapiro-Wilk test, which is generally more appropriate for small to moderate sample sizes, all variables in both groups yielded p-values greater than 0.05, indicating that the data distributions did not significantly deviate from normality. Specifically, the pre-test scores showed non-significant results in both groups ($p = 0.114$ for control; $p = 0.103$ for experimental), and the post-test scores were also within acceptable thresholds ($p = 0.085$ and 0.051, respectively). Although some Kolmogorov-Smirnov results showed significance below 0.05, particularly in the post-test data, this test is more sensitive to minor deviations in larger samples and tends to overestimate non-normality. The normality assumption was considered to be met based on the Shapiro-Wilk test, thereby supporting parametric analyses such as ANCOVA in subsequent hypothesis testing.

4.3. Homogeneity of Variance Test

Table 6 presents the results of Levene's Test for Equality of Variances, which examined the homogeneity of variances—a key assumption for performing ANCOVA. The analysis was performed on pre-test and post-test scores using various central tendency measures, including the mean, median, trimmed mean, and adjusted degrees of freedom.

The Levene statistic based on the mean yielded a p-value of 0.152 for the pre-test scores, while the median-based and trimmed mean results also showed non-significant values ($p = 0.128$ and $p = 0.149$, respectively). Similarly, for the post-test scores, all test variations produced p-values well above the alpha level of 0.05, with the Levene statistic based on the mean yielding $p = 0.471$. These findings indicate that the assumption of homogeneity of variances was satisfied for both pre-test and post-test scores across the control and experimental groups. Therefore, it can be concluded that there were no significant differences in variance between groups, allowing for the use of parametric procedures such as ANCOVA in subsequent analyses.

4.4. ANCOVA Test Results

Table 7 displays the results of the Analysis of Covariance (ANCOVA) conducted to examine the treatment (group) effect on students' post-test scores in mathematics HOTS, while controlling for pre-test scores.

The analysis revealed a statistically significant effect of group membership on post-test scores after controlling for pre-test performance, F (1.69) = 44.360, p<0.001, indicating that the experimental intervention substantially impacted students' HOTS. The partial eta squared value of 0.391 reflects a large effect size, with approximately 39.10% of the variance in post-test scores attributed to the treatment beyond the influence of pre-test scores. The covariate (pre-test) was also a significant predictor, F (1.69) = 79.443, p<0.001, with a partial eta squared of 0.535, suggesting that students' initial HOTS levels strongly influenced post-intervention performance. Overall, the ANCOVA model was highly significant, F (2.69) = 61.992, p<0.001, with R^2 = 0.642 and adjusted R^2 = 0.632, indicating that the model accounted for approximately 64.20% of the variance in post-test scores. These findings prove that the metacognitive intervention effectively enhanced students' HOTS in mathematics.

Table 7. Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial η Squared
Corrected Model	6062.618[a]	2	3031.309	61.992	0.000	0.642
Intercept	20243.388	1	20243.388	413.988	0.000	0.857
Pre-test	3884.618	1	3884.618	79.443	0.000	0.535
Group	**2169.153**	**1**	**2169.153**	**44.360**	**0.000**	**0.391**
Error	3373.993	69	48.898			
Total	471838.000	72				
Corrected Total	9436.611	71				

Dependent Variable: Post-test
[a]R-Squared = 0.642 (Adjusted R Squared = 0.632)

Table 8. Independent Samples Test

		Levene's Test		t-test for Equality of Means						
		F	Sig.	t	df	Sig.	Mean	Std. Error	95% Confidence Interval	
									Lower	Lower
N-gain	Equal variances assumed	3.960	0.051	-6.110	70	0.000	-0.333	0.055	-0.441	-0.224
	Equal variances not assumed			-6.110	61.409	0.000	-0.333	0.055	-0.442	-0.224

4.5. Independent Samples t-Test for N-Gain Scores

Table 8 presents the results of an independent samples t-test conducted to compare the N-gain scores between the experimental and control groups. Before the t-test, Levene's Test for Equality of Variances was performed to assess the assumption of homogeneity of variances. The result was insignificant (F = 3.960, p = 0.051), indicating that the assumption of equal variances was met at the 0.05 significance level.

Based on the equality of variances assumption, the t-test showed a significant difference in N-gain scores between groups, t (70) = -6.110, p < .001, with a mean difference of -0.333 (SE = 0.05445) and a 95% confidence interval from -0.441 to -0.224. The negative mean difference indicates that the experimental group outperformed the control group, as higher N-gain scores reflect greater learning improvement. These results provide strong statistical evidence that the metacognitive intervention significantly positively impacted students' learning gains in mathematics, supporting its effectiveness in enhancing HOTS compared to conventional instruction.

4.6. One-Sample t-Test for N-Gain (Experimental)

Table 9 presents the results of the one-sample t-test. This analysis determined whether the experimental group's mean N-gain score differed significantly from a benchmark value of 0.3, representing a moderate learning gain commonly used in educational research as a reference point.

Table 9. One-Sample Test (Experimental)

	Test Value = 0.3					
	t	df	Sig.	Mean	95% Confidence Interval	
					Lower	Upper
N-gain	12.109	35	0.000	0.369	0.307	0.431

The one-sample t-test yielded a t-value of 12.109 (df = 35, p < .001), showing that the experimental group's mean N-gain score (M = 0.369) was significantly higher than the benchmark value of 0.3. The 95% confidence interval (0.307 to 0.431) further supports the statistical and practical significance of the result. These findings indicate that the experimental group's learning gains exceeded the moderate threshold by a meaningful margin, reinforcing the effectiveness of the metacognitive intervention in improving students' mathematics learning outcomes.

4.7. Scatter Plot Analysis

Figure 2 illustrates the scatter plot of pre-test and post-test scores for the control and experimental groups. Regression analysis examined the relationship between students' initial performance and outcomes after the intervention.

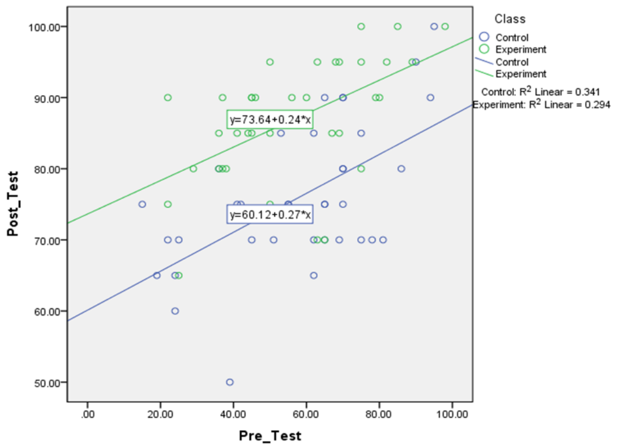

Figure 2. Scatter Plot of Pre-Test and Post-Test Scores

The regression analysis showed that the experimental group had a higher intercept (y = 73.64 + 0.24x, R^2 = 0.294) compared to the control group (y = 60.12 + 0.27x, R^2 = 0.341), indicating that, despite the control group explaining slightly more variance, students in the experimental group consistently achieved higher post-test scores at similar pre-test levels. This suggests that the observed improvements were not solely due to prior ability but were significantly influenced by the metacognitive intervention, providing strong evidence of its effectiveness in enhancing student learning outcomes.

5. DISCUSSIONS

The main finding of this study is that a structured metacognitive strategy training program implemented over one academic semester resulted in statistically and practically significant improvements in high school students' HOTS in mathematics learning. The experimental group that received the intervention demonstrated consistent and substantial gains in test scores compared to the control group. This indicates that metacognitive training can serve as a practical pedagogical approach for enhancing higher-order thinking in the context of secondary mathematics education.

The results of this study strongly support the metacognitive theory introduced by Flavell [8], which defines metacognition as the awareness and regulation of one's cognitive processes. The three core components of metacognition, planning, monitoring, and evaluating, formed the foundation of the training provided to the experimental group and were shown to contribute significantly to the development of HOTS. Training focused on planning encouraged students to design problem-solving strategies before initiating tasks. For example, using "Problem-Solving Plan" worksheets, students were guided to anticipate solution steps and identify potential challenges. This form of engagement aligns with Paris & Winograd [56], who emphasize the critical role of planning in activating effective learning strategies. The monitoring component enabled students to track and assess their understanding throughout the problem-solving process. Techniques such as self-questioning and self-explanation were employed to help students identify gaps in their knowledge. As noted by Moshman [57], monitoring plays a crucial role in detecting comprehension failures and adapting learning strategies in real time.

The evaluation phase involved reflecting on the learning process and outcomes, enhancing metacognitive awareness, and promoting learning transfer [58]. Practical evaluation also supports forming more stable mental models of abstract mathematical concepts, facilitating sustained HOTS development. The intervention is also consistent with Zimmerman's (2000) Self-Regulated Learning (SRL) model, which conceptualizes learning as a three-phase cycle: forethought, performance, and self-reflection [59]. Applying SRL explicitly within mathematics contexts helped students develop cognitive autonomy, which fostered intrinsic motivation and self-efficacy [60]–[62].

Furthermore, the role of metacognition in mathematics learning has been confirmed by numerous studies showing that students with high metacognitive awareness are better at solving non-routine problems and grasping the conceptual structure of mathematics [62]–[66]. In this sense, metacognition supports cognitive processes and bridges strategic thinking with mathematical decision-making. Integrating these metacognitive components in the intervention demonstrates that metacognition is not merely a supportive element in learning but a foundational condition for developing HOTS [33], [67]. This further strengthens the argument that HOTS can be cultivated systematically through strategy-based instruction, rather than through increased content exposure.

These findings are consistent with the meta-analysis by Dignath & Büttner [37], which concluded that metacognitive instruction significantly positively affects mathematics achievement across educational levels. However, this study extends prior work by explicitly focusing on the development of HOTS, including analysis, synthesis, and evaluation, rather than general academic performance or procedural skills [49], [50]. The intervention model used in this study was explicitly structured, addressing previous criticisms such as those by Veenman et al. [33], who noted a lack of clarity in how metacognitive strategies are implemented in many empirical studies.

In a broader context, this research aligns with findings from Wang et al. [12], who demonstrated that monitoring strategies such as delayed Judgments of Learning (JOL) significantly enhance metacognitive accuracy and retention, particularly when engaging with complex material. Such methods allow learners to reflect on their understanding before measuring learning progress, which is highly relevant in mathematics education, which demands conceptual precision and logical reasoning. JOL-based strategies have been shown to improve students' readiness to engage with HOTS-type problems more reflectively and strategically [68].

A study by Balzan et al. [69] on adolescents with anorexia nervosa adds a cross-domain perspective, revealing that metacognitive training not only enhances cognitive flexibility but also reduces maladaptive perfectionism. These two traits are frequently observed in mathematics learning environments, where the pressure to "always be right" can inhibit students' willingness to explore alternative solutions. These findings support the notion that HOTS development must address cognitive and affective aspects of learning [70].

Moreover, the present findings relate closely to August et al. [71], who implemented a visual-linguistic approach to support academic language development and mathematical comprehension among English as an Additional Language (EAL) students. This strategy shares similarities with metacognitive interventions, as both aim to clarify students' cognitive representations, especially when working with technical terms and complex procedures. In another relevant study, Fowler et al. [18] found that guided autonomy in a virtual maker space environment fostered creativity and spatial reasoning—two skills closely aligned with HOTS in geometry and mathematical modeling.

Collectively, the findings of this study not only confirm the effectiveness of metacognitive interventions and place them within the broader framework of Self-Regulated Learning (SRL), where metacognition serves as the central engine [72]. However, it is essential to note that the success of such interventions does not occur in a vacuum. Their effectiveness may be moderated by students' prior knowledge and task complexity [73], [74]. Therefore, this research's key contribution lies in reaffirming the general effectiveness of metacognitive strategies and refining their scope: demonstrating that a systematic and structured metacognitive approach can enhance higher-order thinking in mathematics. This enriches the literature by offering a replicable instructional design model that is theoretically grounded and pedagogically practical.

6. CONCLUSION

This study offers compelling empirical support for the effectiveness of explicit metacognitive strategy training in significantly improving HOTS in secondary school mathematics. The intervention fosters critical competencies such as analysis, evaluation, planning, and self-monitoring skills central to solving non-routine, multi-step problems in mathematics and beyond by equipping students with procedural knowledge and the ability to regulate and reflect on their cognitive processes. The results underscore a critical pedagogical shift: teaching students how to think is as essential as teaching them what to think. This cognitive empowerment enables learners to engage more deeply with mathematical content, transfer their thinking strategies across domains, and become autonomous problem solvers. Such skills are indispensable in 21st-century learning demands, particularly STEM disciplines requiring flexibility, innovation, and sustained cognitive effort.

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