Journal STRANOVIA: Scholarly Teaching Research and New Approaches in Various Academic Innovations
Vol. 1, No. 1, pp. 47-66, 2025
DOI: https://doi.org/10.63011/x4kp2w05
e-ISSN: xxxx-xxxx
https://journalstranoviaa.com/

Mathematical Reasoning in Secondary Classrooms: Problem-Solving Instruction, Cognitive Strategy Use, and Task Complexity

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Received:	Revised:	Accepted:	Published:
20 August 2025	12 September 2025	28 September 2025	2 October 2025

Abstract. Existing scholarship on mathematical reasoning in secondary education frequently prioritizes procedural proficiency and final-answer accuracy, with comparatively limited exploration of how problem-solving instruction interacts with cognitive strategy use and task complexity to shape students' reasoning processes. Addressing this gap, the present study examines how structured problem-solving instruction influences students' mathematical reasoning, focusing on variations in strategy application and responses to tasks with differing cognitive demands. Employing a sequential explanatory mixed-methods design, the study was conducted in secondary classrooms involving 52 students across two grade levels in East Java, Indonesia. Quantitative data were obtained through performance-based reasoning assessments and structured questionnaires measuring cognitive strategy use, while qualitative insights were derived from semi-structured interviews with six selected participants. The findings demonstrate that problem-solving instruction enhances students' ability to construct mathematical justifications, utilize diverse strategies, and engage in conceptual interpretation, particularly when tasks are systematically scaffolded and moderately complex. Nevertheless, disparities were observed in students' capacity to sustain reasoning when encountering highly complex or open-ended problems, with several participants reverting to procedural reliance and exhibiting difficulty transferring strategies across unfamiliar contexts. These outcomes indicate that although problem-solving instruction strengthens analytical engagement and strategic adaptability, its effectiveness is closely influenced by task design, instructional scaffolding, and the integration of metacognitive guidance within classroom practices.

Keywords: cognitive strategies, mathematical reasoning, problem-solving instruction, secondary education, task complexity

INTRODUCTION

Mathematical reasoning occupies a central position in secondary education because it underpins students' capacity to justify solutions, make logical connections among concepts, and apply mathematical knowledge flexibly across contexts. Contemporary curricula and assessment frameworks increasingly emphasize reasoning as a core competency, moving beyond procedural fluency toward explanation, argumentation, and sense-making. Prior studies consistently show that students who engage in reasoning-oriented instruction demonstrate deeper conceptual understanding, stronger problem representation skills, and greater adaptability when confronting unfamiliar tasks (Eriksson & Sumpter, 2021; Hansen, 2022). However, the existing body of knowledge also reveals that mathematical reasoning remains unevenly developed in many secondary classrooms, where instructional practices continue to privilege algorithmic execution and correctness over the articulation of underlying mathematical ideas (Martínez-Sierra & Toral-Rodríguez, 2025; Sokolowski, 2021; Thompson et al., 2017). This tension suggests that while the importance of reasoning is widely acknowledged, there is still limited clarity regarding how specific instructional approaches systematically cultivate reasoning processes in classroom practice.

Problem-solving instruction has been widely proposed as a pedagogical approach capable of fostering mathematical reasoning by situating learning within cognitively demanding tasks that require exploration, conjecture, and justification. Research indicates that problem-solving-oriented instruction can encourage students to analyze conditions, select appropriate strategies, and evaluate the plausibility of their solutions rather than merely applying memorized procedures (Klang et al., 2021; Yapatang & Polyiem, 2022). Empirical studies have documented gains in students' reasoning quality when instruction foregrounds problem interpretation, multiple solution paths, and reflective discussion (Fadzil & Osman, 2025; Rezaei & Asghary, 2025; Santia et al., 2019). Nevertheless, the literature also highlights persistent challenges. Teachers often adapt problem-solving tasks in ways that reduce their cognitive demand, inadvertently limiting opportunities for students to engage in sustained reasoning (Stein & Smith, 1998). Moreover, much of the existing research focuses on the presence or absence of problem-solving instruction, rather than examining how its internal features interact with learners' cognitive processes. As a result, there remains insufficient understanding of the mechanisms through which problem-solving instruction translates into observable differences in students' reasoning performance.

One mechanism frequently identified as central to reasoning development is students' use of cognitive strategies during mathematical activity. Cognitive strategies such as representation, decomposition, analogical reasoning, and self-monitoring enable learners to manage complexity, coordinate information, and regulate their thinking processes (Nugroho et al., 2020; Shaw et al., 2020). Studies have shown that students who employ a wider repertoire of strategies tend to produce more coherent explanations and demonstrate greater flexibility in problem solving (Bicer, 2021; Ngu & Phan, 2024; Rezaei & Asghary, 2025). Instructional environments that explicitly encourage strategic thinking are therefore associated with enhanced reasoning outcomes. Despite these findings, existing research often treats cognitive strategy use as an individual learner trait rather than as a dynamic response shaped by instructional design and task characteristics. Furthermore, quantitative investigations frequently rely on self-reported strategy use, offering limited insight into how strategies are enacted during reasoning processes. This leaves a gap in understanding how problem-solving instruction supports or constrains the deployment of cognitive strategies that are directly implicated in mathematical reasoning.

Task complexity constitutes another critical, yet underexamined, dimension in the study of mathematical reasoning. Complex tasks typically involve multiple solution steps, non-routine structures, or ambiguous pathways, all of which can stimulate higher-order reasoning and sense-making (Harding et al., 2017; Sawatzki, 2017). Research suggests that appropriately challenging tasks promote justification, comparison of strategies, and deeper conceptual engagement (Kafetzopoulos & Psycharis, 2022; Nieminen et al., 2022). At the same time, excessive complexity may overwhelm learners' cognitive resources, leading to surface-level approaches or unproductive struggle (Bagossi et al., 2022; Owan et al., 2023; Syaifuddin, 2020). While prior studies have acknowledged this dual role of task complexity, few have systematically examined how varying levels of complexity interact with problem-solving instruction and students' cognitive strategy use to shape reasoning outcomes. As a result, it remains unclear under what conditions task complexity enhances or constrains mathematical reasoning in secondary classrooms.

Taken together, the existing body of knowledge reveals several interconnected gaps. First, although mathematical reasoning is widely valued, empirical research often isolates instructional approaches, learner strategies, or task features rather than examining their interaction. Second, problem-solving instruction is frequently evaluated in broad terms, with limited attention to how it mediates students' strategic engagement during reasoning processes. Third, cognitive strategy use is commonly measured as a static attribute, leaving insufficient insight into its role as a mediating variable between instruction and reasoning performance. Finally, task complexity is acknowledged as influential but rarely operationalized in relation to both instructional design and students' strategic responses. These gaps point to the need for an integrated investigation that operationalizes mathematical reasoning as students' ability to construct justifications, make logical connections, and evaluate solutions; problem-solving instruction as structured pedagogical practices emphasizing exploration, multiple solution paths, and reflection; cognitive strategy use as the deployment of specific reasoning-supportive strategies during task engagement; and task complexity as the level of cognitive demand embedded within mathematical problems. Examining the relationships among these variables provides a coherent rationale for the present study, which seeks to clarify how instructional design, strategic engagement, and task demands collectively shape mathematical reasoning in secondary classrooms. Based on the identified gaps, the study is guided by the following research questions (RQs):

1. How does problem-solving instruction relate to students' mathematical reasoning when considering variations in cognitive strategy use?
2. How does task complexity influence the relationship between problem-solving instruction, cognitive strategy use, and mathematical reasoning?

REVIEW OF LITERATURE

Conceptualizing Mathematical Reasoning in Secondary Education

Mathematical reasoning is widely conceptualized as a multifaceted cognitive and metacognitive construct encompassing the ability to construct, justify, and evaluate arguments, interpret problem contexts, and connect representations across tasks. It extends beyond procedural execution to include flexible thinking, conceptual understanding, and the capacity to generalize knowledge across domains (Martínez-Sierra & Toral-Rodríguez, 2025; Sokolowski, 2021). Reasoning facilitates students' engagement in higher-order mathematical practices, such as conjecturing, proving, and evaluating claims, which are foundational to developing robust problem-solving skills (Thompson et al., 2017). Empirical studies consistently demonstrate that classrooms emphasizing reasoning-oriented instruction enhance students' adaptive thinking and encourage exploration of multiple solution pathways, thereby fostering deeper conceptual clarity (Eriksson & Sumpter, 2021; Hansen, 2022). Despite these insights, existing research often operationalizes reasoning through isolated indicators, such as the correctness of written justifications or logical coherence of argumentation, which may obscure the dynamic interplay between instructional design, cognitive strategy application, and learner engagement. Moreover, inconsistencies in measurement—ranging from verbal explanations to generalized solution approaches—highlight the lack of a unified framework to capture how instructional conditions systematically cultivate reasoning processes. Consequently, there is a clear need to investigate instructional practices that support sustained reasoning, particularly how students engage with complex tasks while employing varied strategies and reflective thought.

Problem-Solving Instruction as a Catalyst for Reasoning

Problem-solving instruction is recognized as a central pedagogical approach to fostering mathematical reasoning by situating learners in environments that demand interpretation, planning, monitoring, and reflective evaluation. Instructional models emphasize creating opportunities for students to engage with ill-structured or open-ended tasks that require justification of strategic choices, construction of multiple solution pathways, and ongoing self-assessment (Fadzil & Osman, 2025; Yapatang & Polyiem, 2022). Classroom research demonstrates that carefully sequenced problem-solving tasks, when coupled with collaborative discussions and explicit scaffolding, support deeper reasoning and facilitate flexible representational thinking (Klang et al., 2021; Rezaei & Asghary, 2025; Santia et al., 2019). However, findings also indicate that problem-solving tasks are frequently cognitively reduced during classroom implementation to prioritize efficiency, procedural correctness, or time management, which can inadvertently constrain reasoning opportunities. Furthermore, much of the literature evaluates instructional effectiveness through achievement outcomes rather than examining how learners' internal cognitive processes, such as planning, monitoring, and reflection, interact with the instructional design. This gap limits understanding of the mechanisms through which problem-solving instruction translates into reasoning development, highlighting the need for studies that integrate measures of instructional fidelity, cognitive strategy enactment, and reasoning quality across task types.

Cognitive Strategy Use in Mathematical Reasoning Processes

Cognitive strategies serve as essential mediators for navigating complex mathematical tasks, organizing information, monitoring progress, and regulating reasoning processes. They encompass deliberate and goal-directed mental operations, including planning, monitoring, representation, and reflection, which facilitate comprehension, knowledge retention, and adaptive problem-solving (Ngu & Phan, 2024; Shaw et al., 2020). Within mathematics education, empirical investigations demonstrate that strategic questioning, self-monitoring, and use of multiple representational forms enable learners to construct coherent explanations, verify solution accuracy, and generalize knowledge across contexts (Hui & Mahmud, 2023; Nugroho et al., 2020; Xiang et al., 2025). Notably, students who integrate complementary strategies—such as symbolic translation, diagrammatic reasoning, and analogical thinking—

tend to achieve more robust conceptual transfer and demonstrate higher adaptability in non-routine problems. Despite these contributions, the literature reveals persistent limitations. Many studies rely on self-reported strategy use, which may not accurately reflect cognitive engagement in authentic problem-solving settings. In addition, strategy use is often examined in isolation, neglecting the influence of instructional design, task structure, and the interplay between strategy enactment and reasoning quality. Addressing these gaps requires conceptualizing cognitive strategies as dynamic processes that emerge in response to task demands and pedagogical scaffolds rather than as static learner characteristics.

Task Complexity and Cognitive Demand in Mathematical Engagement

Task complexity constitutes a critical determinant of students' reasoning quality and cognitive engagement. Complex tasks, which involve integration of multiple solution steps, interrelated representations, and ambiguous problem elements, provide opportunities to exercise planning, monitoring, and reflective strategies (Kafetzopoulos & Psycharis, 2022; Nieminen et al., 2022). Research shows that cognitively demanding tasks stimulate comparison of strategies, justification of reasoning, and generalization of principles, thereby promoting deeper mathematical understanding (Eriksson & Sumpter, 2021; Sokolowski, 2021; Thompson et al., 2017). However, excessively complex tasks can overload students' working memory, resulting in reliance on superficial procedural strategies or disengagement from conceptual reasoning. Additionally, the interaction between task complexity and instructional support remains underexplored; while some studies emphasize either task difficulty or cognitive demand, few examine how learners dynamically adjust cognitive strategies in response to varying task structures and instructional scaffolding. This limitation restricts comprehensive understanding of how task characteristics, in combination with cognitive strategy use and problem-solving instruction, influence reasoning processes. Integrative research is therefore essential to investigate how structured problem-solving instruction and adaptive strategy use operate within tasks of differing complexity to support meaningful engagement and mathematical reasoning development.

METHOD

Research Design and the Participants

The present investigation adopted a sequential explanatory mixed-methods design to examine how structured problem-solving instruction influences students' mathematical reasoning, with particular attention to variations in cognitive strategy use and responses to tasks demonstrating different levels of cognitive demand. The design involved two consecutive phases in which quantitative data were initially collected and analyzed to identify patterns of relationships among instructional exposure, cognitive strategy engagement, and reasoning performance (Ivankova et al., 2006). The qualitative phase subsequently explored the interpretive processes underlying the quantitative trends, allowing for a more nuanced understanding of how students engaged with problem-solving instruction and responded to tasks of varying complexity.

The study was conducted in secondary classrooms in East Java, Indonesia, involving 52 students drawn from two grade levels representing early and middle stages of secondary mathematical learning. Participants were selected using purposive sampling to ensure that students had prior exposure to structured problem-solving instructional approaches implemented through regular classroom instruction. The sampling strategy emphasized heterogeneity in academic achievement levels, allowing the study to capture variations in reasoning performance and strategic engagement across diverse learner profiles. Students ranged between 13 and 15 years of age and had completed foundational coursework in algebraic reasoning and mathematical representation, which provided essential conceptual readiness for participation in reasoning-oriented tasks.

The qualitative phase involved six participants selected through maximum variation sampling based on quantitative results. Students demonstrating high, moderate, and developing reasoning performance were included to provide representative perspectives across different strategic engagement patterns. This selection ensured that qualitative interpretations captured a broad spectrum of reasoning behaviors, strategy application approaches, and responses to cognitive task demands. Classroom teachers facilitated instructional implementation but were not involved in data interpretation to maintain analytical neutrality.

Instruments

Multiple research instruments were employed to ensure comprehensive measurement of the study variables. Quantitative instruments included performance-based mathematical reasoning assessments and a structured cognitive strategy use questionnaire. Qualitative data were obtained through semi-structured interviews designed to explore students' interpretive experiences and reasoning processes during problem-solving activities.

Table 1. Performance-Based Mathematical Reasoning Assessment Blueprint

Component	Description	Cognitive Focus	Scoring Criteria
Problem Interpretation	Tasks requiring students to analyze mathematical scenarios and identify relevant information	Conceptual understanding and problem framing	Accuracy of interpretation, completeness of identified relationships
Strategy Formulation	Tasks requiring development of solution plans	Strategic planning and procedural reasoning	Logical coherence of strategy selection
Mathematical Justification	Tasks requiring explanation and defense of solutions	Logical argumentation and reasoning validity	Clarity, completeness, and mathematical accuracy
Representation Integration	Tasks requiring multiple representations	Conceptual flexibility and transfer	Consistency and accuracy across representations
Generalization and Reflection	Tasks requiring extension of solutions to new contexts	Higher-order reasoning and transfer	Ability to formulate generalized conclusions

The reasoning assessment consisted of eight open-ended tasks organized across three levels of task complexity representing low, moderate, and high cognitive demand. Tasks were constructed to measure reasoning depth through justification, explanation, and solution generalization. The assessment instrument was reviewed by three mathematics education specialists to ensure content validity and alignment with secondary curriculum standards. Inter-rater reliability was established through dual scoring procedures, yielding a reliability coefficient of 0.87, indicating strong scoring consistency. The cognitive strategy use questionnaire consisted of 28 Likert-scale items measuring students' engagement in planning strategies, monitoring strategies, representation strategies, and reflection strategies. The instrument was adapted from established cognitive strategy measurement frameworks and validated through pilot testing involving 20 students outside the primary participant group.

Reliability analysis produced a Cronbach alpha coefficient of 0.91, demonstrating high internal consistency. Semi-structured interviews were designed to explore students' reasoning experiences during structured problem-solving instruction. Interview questions focused on how students interpreted tasks, selected strategies, adapted approaches across different complexity levels, and evaluated solution outcomes. The interviews provided insights into cognitive processes that could not be fully captured through quantitative measures.

Table 2. Cognitive Strategy Use Questionnaire Dimensions

Dimension	Description	Number of Items	Example Focus
Planning Strategies	Students' preparation and organization of problem-solving approaches	7	Identifying known information and selecting solution pathways
Monitoring Strategies	Students' evaluation of solution progress	7	Checking intermediate steps and verifying calculations
Representation Strategies	Use of diagrams, symbolic forms, and alternative representations	7	Translating between algebraic and graphical representations
Reflection Strategies	Students' evaluation of completed solutions	7	Reviewing reasoning accuracy and generalizing solutions

Data Collection Procedures

Data collection occurred across one academic semester to ensure sufficient exposure to structured problem-solving instruction. Prior to quantitative data collection, participating classrooms implemented structured problem-solving instruction through teacher-guided learning sequences emphasizing multi-step reasoning tasks, collaborative discussion, and reflective evaluation. Quantitative data were collected in two stages. The first stage involved administering the cognitive strategy questionnaire to identify baseline strategy engagement patterns. The second stage involved administering the mathematical reasoning assessment following completion of the instructional cycle. Assessments were conducted under standardized classroom conditions to ensure comparability of results across participants. Following quantitative analysis, qualitative data were collected through individual interviews with six selected students. Interviews were conducted in quiet learning spaces to minimize distractions and encourage reflective responses. Each interview session lasted approximately 40 to 50 minutes and was audio recorded with participant consent. Students were encouraged to explain their reasoning processes while reflecting on selected assessment tasks representing different complexity levels. Interview prompts allowed participants to describe decision-making processes, strategy selection rationale, and perceived challenges encountered during problem solving. Instructional materials and assessment tasks were also documented as supplementary data sources to support triangulation. Classroom observation notes were maintained to capture instructional implementation patterns and student engagement behaviors during problem-solving sessions. These observational records supported interpretation of student reasoning behaviors and provided contextual clarification during qualitative analysis.

Data Analysis

Quantitative data were analyzed using descriptive and inferential statistical procedures. Descriptive statistics summarized central tendency, frequency distribution, and variability across reasoning performance and cognitive strategy use dimensions. Pearson correlation analysis examined relationships between structured problem-solving instruction exposure, cognitive strategy use, and reasoning performance. Multiple regression analysis was conducted to determine predictive relationships between cognitive strategy dimensions and mathematical reasoning outcomes. To address task complexity variations, multivariate analysis of variance was performed to compare reasoning performance across low, moderate, and high complexity tasks. This analysis enabled identification of interaction effects between instructional exposure, strategy use, and task demand. Effect size calculations were conducted to determine the magnitude of observed relationships, providing additional interpretive depth. Qualitative data were analyzed using thematic analysis procedures involving iterative coding and theme development. Interview transcripts were transcribed verbatim and analyzed through open coding to identify patterns related to strategy application, reasoning interpretation, and responses to task complexity. Codes were subsequently organized into broader themes representing cognitive engagement processes and adaptive reasoning behaviors (Braun & Clarke, 2006). Triangulation procedures integrated quantitative and qualitative findings to identify convergent and divergent patterns across data sources. Member checking was conducted by sharing summarized interpretations with participants to confirm representational accuracy. Reflexive journaling and audit trail documentation were maintained to enhance transparency and methodological rigor throughout the analytical process.

Ethical Considerations

The study adhered to established ethical research principles to ensure participant protection and data integrity. Institutional approval was obtained prior to data collection, confirming that research procedures complied with educational research standards. Written informed consent was obtained from students and their guardians, outlining research objectives, participation procedures, confidentiality protections, and voluntary participation rights. Participant anonymity was maintained through the use of identification codes replacing student names across all datasets. Audio recordings and transcripts were securely stored in encrypted digital files accessible only to the research team. Participants were informed of their right to withdraw from the study at any stage without academic or institutional consequences. Special consideration was given to minimizing academic pressure during assessment procedures. Students were informed that research assessments would not influence academic grading outcomes. Interview sessions were conducted in supportive environments encouraging honest reflection without evaluative judgment. Data reporting emphasized aggregated findings to prevent identification of individual participants or classrooms. The research design also considered cognitive and emotional well-being by ensuring that tasks aligned with participants' developmental levels and prior instructional exposure. Interview questions were framed to encourage reflective discussion rather than evaluative performance, allowing students to articulate reasoning experiences comfortably. These ethical safeguards ensured that the study maintained methodological rigor while prioritizing participant welfare and research transparency.

RESULTS

RQ1: Relationship Between Problem-Solving Instruction, Cognitive Strategy Use, and Mathematical Reasoning

This section reports the quantitative findings addressing RQ1: How does problem-solving instruction relate to students' mathematical reasoning when considering variations in cognitive strategy use? The results are derived exclusively from the performance-based mathematical reasoning assessment and the structured cognitive strategy use questionnaire administered to 52 secondary students. The analysis proceeds from descriptive statistics to correlational and predictive analyses in order to provide a comprehensive account of students' reasoning performance and strategic engagement patterns.

Table 3. Descriptive Statistics of Mathematical Reasoning Performance *(n = 52)*

Reasoning Dimension	Min	Max	Mean	Std. Dev.
Problem Interpretation	45	90	71.84	10.26
Strategy Formulation	42	88	69.57	9.84
Mathematical Justification	40	86	68.12	10.91
Representation Integration	38	85	66.95	11.04
Generalization and Reflection	35	82	64.73	11.88
Overall Mathematical Reasoning	***41***	***88***	***68.24***	***9.97***

Table 3 indicates that students demonstrated moderate to moderately high levels of mathematical reasoning across all assessed dimensions. The highest mean score was observed in problem interpretation, suggesting that students were generally able to comprehend problem contexts and identify relevant information when engaging with structured problem-solving tasks. In contrast, generalization and reflection yielded the lowest mean score, revealing greater difficulty in extending solutions, articulating broader mathematical principles, and reflecting critically on solution processes. The relatively larger standard deviations for higher-order reasoning components indicate notable variability among students in managing tasks requiring abstraction and transfer.

Table 4. Descriptive Statistics of Cognitive Strategy Use *(n = 52)*

Strategy Dimension	Min	Max	Mean	Std. Dev.
Planning Strategies	2.40	4.80	3.72	0.54
Monitoring Strategies	2.20	4.70	3.65	0.58
Representation Strategies	2.10	4.60	3.59	0.60
Reflection Strategies	2.00	4.50	3.48	0.63
Overall Strategy Use	***2.30***	***4.65***	***3.61***	***0.52***

As shown in Table 4, students reported frequent engagement with cognitive strategies during problem-solving instruction. Planning strategies were most prominent, indicating that students regularly engaged in identifying known information, setting solution goals, and selecting appropriate procedures before attempting solutions. Reflection strategies exhibited the lowest mean, suggesting that evaluative practices such as reviewing solution efficiency or considering alternative methods were less consistently applied. The distribution of scores indicates moderate dispersion, reflecting differences in how strategically students approached problem-solving tasks.

Table 5. Correlation Between Cognitive Strategy Use and Mathematical Reasoning

Strategy Dimension	Overall Reasoning	Interpretation	Strategy Formulation	Justification	Representation	Generalization
Planning	.62**	.58**	.61**	.55**	.49**	.46**
Monitoring	.66**	.54**	.63**	.60**	.52**	.51**
Representation	.59**	.47**	.55**	.57**	.61**	.48**
Reflection	.68**	.45**	.53**	.62**	.58**	.64**

Note: p < .01

The correlation analysis presented in Table 5 demonstrates strong and statistically significant relationships between cognitive strategy use and mathematical reasoning performance. Reflection strategies exhibited the strongest association with overall mathematical reasoning, particularly with justification and generalization components, underscoring the importance of evaluative and reflective engagement for higher-order reasoning. Monitoring strategies were also strongly correlated with reasoning outcomes, suggesting that students who actively checked and regulated their solution processes achieved more coherent and accurate reasoning. While planning strategies were strongly related to early-stage reasoning components such as interpretation and formulation, their association with advanced reasoning processes was comparatively weaker, indicating that planning alone may be insufficient for sustaining deeper reasoning without ongoing regulation and reflection.

Table 6. Multiple Regression Analysis Predicting Mathematical Reasoning

Predictor Variable	**B**	**SE B**	**Β**	**t**	**p**
Planning Strategies	2.18	0.91	.24	2.40	.020
Monitoring Strategies	2.76	0.88	.31	3.14	.003
Representation Strategies	1.95	0.84	.22	2.32	.024
Reflection Strategies	3.12	0.86	.35	3.63	.001

Note: Model $R^2 = .58$

The regression model explained 58 percent of the variance in overall mathematical reasoning performance, indicating a substantial contribution of cognitive strategy use to reasoning outcomes. Reflection strategies emerged as the strongest predictor, followed by monitoring strategies, highlighting the central role of self-evaluation and regulatory processes in sustaining mathematical reasoning during structured problem-solving instruction. Planning and representation strategies also contributed significantly, though their predictive strength was comparatively smaller. These findings suggest that while initial organization and representational flexibility support reasoning, deeper reasoning performance is more strongly shaped by students' capacity to evaluate, regulate, and refine their problem-solving processes.

Collectively, the quantitative results demonstrate that structured problem-solving instruction is closely associated with students' mathematical reasoning through its relationship with cognitive strategy use. Students who reported higher engagement in monitoring and reflection strategies consistently achieved stronger reasoning performance, particularly in justification, representation integration, and generalization. At the same time, notable variability across strategy dimensions indicates that not all students benefitted equally from instructional structures, pointing to differentiated strategic engagement as a key factor shaping reasoning outcomes. These results provide robust empirical evidence that mathematical reasoning is not solely a function of task exposure but is critically mediated by how students strategically engage with problem-solving processes.

Questionnaire Results: Cognitive Strategy Use Dimensions

This section presents an in-depth analysis of students' responses to the Cognitive Strategy Use Questionnaire, which examined four strategic dimensions: planning, monitoring, representation, and reflection. The results provide a detailed exploration of how students strategically approached mathematical problem-solving during structured instructional activities. Each dimension is reported with item-level descriptive statistics to illustrate patterns of strategic engagement and variation in students' responses across Likert-scale categories.

Table 7. Planning Strategies *(n = 52)*

No	Item	SD *n (%)*	D *n (%)*	N *n (%)*	A *n (%)*	SA *n (%)*	Mean	Std. Dev
1	I identify important information before solving a problem	2 (3.85)	4 (7.69)	9 (17.31)	25 (48.08)	12 (23.08)	3.79	0.92
2	I set solution goals before starting a task	3 (5.77)	6 (11.54)	11 (21.15)	23 (44.23)	9 (17.31)	3.56	1.01
3	I determine appropriate formulas or procedures before solving	2 (3.85)	5 (9.62)	12 (23.08)	24 (46.15)	9 (17.31)	3.63	0.96
4	I predict possible solution outcomes before solving	4 (7.69)	8 (15.38)	14 (26.92)	19 (36.54)	7 (13.46)	3.33	1.05
5	I organize steps needed to solve mathematical problems	2 (3.85)	4 (7.69)	13 (25.00)	23 (44.23)	10 (19.23)	3.67	0.95
6	I consider alternative strategies before solving	3 (5.77)	7 (13.46)	16 (30.77)	19 (36.54)	7 (13.46)	3.38	1.02
7	I review problem instructions carefully before starting	1 (1.92)	3 (5.77)	8 (15.38)	26 (50.00)	14 (26.92)	3.92	0.85

The findings indicate that students demonstrated strong engagement in identifying key information and reviewing instructions, suggesting that structured problem-solving instruction effectively encourages preliminary analytical preparation. However, lower agreement on predicting outcomes and considering alternative strategies suggests that anticipatory and flexible planning remains less consistently applied. The distribution of responses indicates that while students adopt structured planning procedures, deeper strategic anticipation and exploration of multiple pathways require further instructional reinforcement.

Table 8. Monitoring Strategies *(n = 52)*

No	Item	SD *n (%)*	D *n (%)*	N *n (%)*	A *n (%)*	SA *n (%)*	Mean	Std. Dev
1	I check my calculations while solving problems	2 (3.85)	3 (5.77)	9 (17.31)	25 (48.08)	13 (25.00)	3.85	0.90
2	I monitor whether my steps follow the correct procedure	2 (3.85)	5 (9.62)	10 (19.23)	24 (46.15)	11 (21.15)	3.71	0.95
3	I revise my strategy when I encounter difficulties	3 (5.77)	6 (11.54)	12 (23.08)	22 (42.31)	9 (17.31)	3.58	1.01
4	I evaluate whether my solution steps are logical	2 (3.85)	4 (7.69)	11 (21.15)	24 (46.15)	11 (21.15)	3.73	0.94
5	I verify intermediate results before continuing	3 (5.77)	5 (9.62)	13 (25.00)	22 (42.31)	9 (17.31)	3.56	0.99
6	I compare my results with expected outcomes during solving	4 (7.69)	6 (11.54)	14 (26.92)	20 (38.46)	8 (15.38)	3.42	1.04
7	I adjust my working pace based on problem difficulty	3 (5.77)	7 (13.46)	15 (28.85)	19 (36.54)	8 (15.38)	3.44	1.02

Monitoring strategies demonstrate consistent engagement, particularly in checking calculations and ensuring procedural correctness. These results suggest that students actively regulate solution processes during structured problem-solving activities. However, comparatively lower agreement in adapting pace and comparing expected outcomes indicates that dynamic regulation processes remain uneven across learners. This pattern suggests that students demonstrate procedural monitoring but may require additional scaffolding to support adaptive regulation in response to emerging problem complexity.

Table 9. Representation Strategies *(n = 52)*

No	Item	SD *n (%)*	D *n (%)*	N *n (%)*	A *n (%)*	SA *n (%)*	Mean	Std. Dev
1	I use diagrams or graphs to understand problems	3 (5.77)	5 (9.62)	11 (21.15)	24 (46.15)	9 (17.31)	3.60	0.97
2	I translate word problems into mathematical equations	2 (3.85)	4 (7.69)	10 (19.23)	26 (50.00)	10 (19.23)	3.73	0.91
3	I switch between symbolic and visual representations	3 (5.77)	6 (11.54)	13 (25.00)	21 (40.38)	9 (17.31)	3.52	1.00
4	I use tables or charts to organize numerical information	4 (7.69)	7 (13.46)	14 (26.92)	19 (36.54)	8 (15.38)	3.40	1.05
5	I compare multiple representations to verify solutions	4 (7.69)	6 (11.54)	15 (28.85)	19 (36.54)	8 (15.38)	3.40	1.04
6	I create visual models to explain mathematical ideas	3 (5.77)	8 (15.38)	14 (26.92)	19 (36.54)	8 (15.38)	3.40	1.03
7	I select representations that best fit problem requirements	3 (5.77)	6 (11.54)	13 (25.00)	21 (40.38)	9 (17.31)	3.52	1.00

Representation strategy results indicate that students commonly translate verbal information into symbolic mathematical expressions and utilize visual aids to support comprehension. Nevertheless, the relatively lower agreement in comparing multiple representations suggests that integrative representational reasoning remains an emerging skill. Students appear to favor single representation modes rather than flexibly shifting between representations to deepen conceptual understanding.

Table 10. Reflection Strategies *(n = 52)*

No	Item	SD *n (%)*	D *n (%)*	N *n (%)*	A *n (%)*	SA *n (%)*	Mean	Std. Dev
1	I review my final answer to ensure accuracy	2 (3.85)	4 (7.69)	10 (19.23)	25 (48.08)	11 (21.15)	3.75	0.92
2	I evaluate whether my solution method is efficient	3 (5.77)	7 (13.46)	15 (28.85)	19 (36.54)	8 (15.38)	3.40	1.02
3	I analyze mistakes to improve future performance	2 (3.85)	6 (11.54)	13 (25.00)	22 (42.31)	9 (17.31)	3.58	0.98
4	I explain my reasoning after completing a task	3 (5.77)	6 (11.54)	12 (23.08)	22 (42.31)	9 (17.31)	3.54	1.00
5	I compare my solutions with alternative methods	4 (7.69)	8 (15.38)	16 (30.77)	17 (32.69)	7 (13.46)	3.29	1.05
6	I generalize solution patterns to other problems	5 (9.62)	7 (13.46)	17 (32.69)	16 (30.77)	7 (13.46)	3.15	1.08
7	I reflect on how problem-solving strategies help learning	3 (5.77)	6 (11.54)	14 (26.92)	21 (40.38)	8 (15.38)	3.48	1.01

Reflection strategy responses reveal that students consistently review final solutions and evaluate errors, demonstrating awareness of solution accuracy and procedural correctness. However, lower agreement regarding generalizing patterns and comparing alternative methods indicates that deeper metacognitive reflection and transfer of reasoning remain less consistently practiced. These findings suggest that while students engage in outcome-based evaluation, reflective conceptual abstraction requires further reinforcement.

Across all four dimensions, students demonstrated moderate to high engagement with cognitive strategies during structured problem-solving instruction. Planning and monitoring strategies appear most frequently applied, supporting students' procedural organization and regulation during solution processes. Representation strategies illustrate emerging flexibility in translating mathematical ideas across formats, although integrative representational reasoning remains uneven. Reflection strategies, while present, indicate that students tend to emphasize verification rather than conceptual generalization and strategic transfer. The variation across dimensions demonstrates that structured problem-solving instruction facilitates strategic engagement, yet strategic depth varies depending on the cognitive demands of each strategy type. Foundational strategies associated with task organization and procedural monitoring appear more consistently applied, whereas higher-order reflective and integrative strategies show greater variability, highlighting important differences in how students engage with reasoning-intensive mathematical tasks.

RQ2: Influence of Task Complexity on Strategy Application, Cognitive Engagement, and Adaptive Mathematical Reasoning

Qualitative findings illuminate how variations in task complexity shape students' application of cognitive strategies, depth of reasoning, and adaptive learning behaviors during structured problem-solving instruction. Thematic analysis of interview transcripts revealed several interconnected patterns demonstrating how students interpret, negotiate, and respond to mathematical tasks that differ in cognitive demands. Three dominant themes emerged: strategic adaptation in response to task complexity, interpretive reasoning development across cognitive demand levels, and emotional-cognitive regulation in complex problem-solving contexts. The themes collectively illustrate how students' reasoning processes evolve when encountering tasks that require varying levels of abstraction, integration, and strategic flexibility.

The first theme, strategic adaptation in response to task complexity, reflects how students modify planning, monitoring, and representation strategies when confronting tasks with differing levels of difficulty. Students consistently described adjusting their approaches based on perceived task demands, indicating that cognitive strategy use is not static but dynamically influenced by complexity. When responding to the question, "*How do you change your problem-solving approach when mathematical tasks become more difficult or require deeper thinking?*", participants highlighted shifts in planning depth and solution organization. P1 explained, *"When the problem is simple, I just follow the steps I learned before, but when it becomes more complicated, I try to break it into smaller parts and plan each step carefully."* Similarly, P3 stated, *"If the task has many conditions or information, I spend more time deciding which formulas or strategies are suitable before solving."* These responses demonstrate that increased complexity encourages students to engage more deliberately in planning strategies, particularly through segmentation of tasks and deliberate selection of solution pathways.

Monitoring behaviors also intensified as task complexity increased. Participants described heightened awareness of errors and solution verification when working on cognitively demanding problems. In response to the question, "*How do you monitor your progress when solving multi-step or unfamiliar mathematical problems?*", P2 noted, "*When problems are longer or unfamiliar, I check every step because I am afraid of making mistakes that affect the final answer.*" P5 similarly commented, *"I usually compare my intermediate results with what I expect, especially when the problem involves several operations."* These reflections indicate that complex tasks stimulate metacognitive regulation processes, encouraging students to engage in continuous monitoring to maintain procedural accuracy. However, some participants revealed that excessive monitoring occasionally slowed their progress, suggesting that while complexity promotes metacognitive engagement, it may also introduce cognitive load that influences efficiency.

Representation strategies also demonstrated adaptive variation based on task demands. Students reported increased reliance on diagrams, symbolic transformations, and visual aids when tasks required conceptual integration. Addressing the question, *"How do visual or symbolic representations help you understand complex mathematical problems?"*, P4 stated, *"For difficult problems, drawing diagrams helps me see relationships that are not clear from the numbers alone."* P6 similarly remarked, *"I often rewrite word problems into equations and sometimes draw graphs to make the problem easier to understand."* These findings indicate that complex tasks encourage students to engage in multi-representational reasoning, enabling them to transform abstract information into structured and interpretable forms. Nevertheless, several participants noted difficulty in selecting appropriate representations, suggesting that representation flexibility remains a developing cognitive skill influenced by task familiarity and prior experience.

The second theme, interpretive reasoning development across cognitive demand levels, reflects how task complexity shapes students' conceptual interpretation and logical reasoning. Participants reported that tasks requiring higher-order thinking encouraged them to justify solutions, connect mathematical concepts, and explore alternative methods. When responding to the question, "*How do complex mathematical tasks influence the way you explain or justify your solutions?*", P1 stated, *"More difficult tasks make me think about why my solution works, not just how to calculate it."* P3 added, *"Sometimes I need to explain my reasoning step by step, especially when the problem involves multiple concepts."* These insights indicate that increased task complexity promotes deeper conceptual reasoning, encouraging students to articulate logical connections between procedures and underlying mathematical principles.

Students also described engaging in comparative reasoning when confronted with complex tasks. In response to the question, *"Do challenging problems encourage you to consider alternative solution methods or compare different approaches?"*, P5 noted, "*When problems are challenging, I try different methods to see which one is easier or more efficient.*" Similarly, P2 commented, *"If my first solution does not work, I try another strategy and compare the results.*" These responses demonstrate that complex tasks stimulate exploratory reasoning and strategic flexibility, allowing students to evaluate the effectiveness of multiple approaches. However, several participants expressed uncertainty when encountering unfamiliar problem types, indicating that while complexity promotes deeper reasoning, insufficient conceptual scaffolding may limit students' confidence in applying alternative strategies.

The third theme, emotional-cognitive regulation in complex problem-solving contexts, highlights the interaction between cognitive engagement and students' emotional responses when working on demanding tasks. Students reported that complex problems often required persistence, motivation, and self-regulation to sustain engagement. Addressing the question, *"How do you feel and respond when you encounter mathematical tasks that are more difficult than usual?"*, P6 stated, *"At first, I feel confused, but if I keep working step by step, I usually find the solution."* P4 similarly explained, *"Difficult problems sometimes make me frustrated, but I try to stay focused and review what I have learned before."* These reflections suggest that complex tasks encourage resilience and persistence, which are essential components of adaptive reasoning development.

Students also described using cognitive reflection to regulate emotional responses during challenging tasks. In response to the question, *"What strategies help you remain focused when solving complex mathematical problems?"*, P3 noted, *"I usually pause and re-read the problem carefully to avoid misunderstanding."* P1 added, *"I remind myself that difficult problems help me learn new strategies, so I try not to give up quickly."* These responses demonstrate that students employ reflective thinking to maintain engagement, suggesting that emotional regulation supports sustained cognitive processing during complex reasoning tasks.

Across themes, the qualitative findings reveal that task complexity acts as a catalyst for strategic adaptation, interpretive reasoning expansion, and emotional-cognitive regulation. Students demonstrate increased engagement in planning, monitoring, and representation strategies when tasks demand higher levels of abstraction and integration. Complex tasks also encourage deeper conceptual reasoning, enabling students to justify solutions and explore alternative problem-solving approaches. However, variability in students' confidence and representation flexibility indicates that while task complexity enhances reasoning depth, it also introduces cognitive and emotional challenges that influence strategy application.

Collectively, the qualitative findings suggest that structured problem-solving instruction facilitates adaptive reasoning by encouraging students to dynamically adjust cognitive strategies in response to task complexity. The interaction between task difficulty, strategic engagement, and emotional regulation highlights the multifaceted nature of mathematical reasoning development. Students' responses illustrate that complex tasks do not merely increase difficulty but serve as catalysts for deeper cognitive engagement, reflective thinking, and strategic flexibility, thereby shaping the overall trajectory of reasoning development in secondary mathematics learning contexts.

DISCUSSION

The findings of the present study deepen contemporary understanding of mathematical reasoning by demonstrating that structured problem-solving instruction serves not only as a procedural learning mechanism but also as a catalyst for students' strategic cognition and adaptive reasoning development. The results indicate that problem-solving instruction encourages students to engage in deliberate planning, monitoring, representation, and reflection processes, reinforcing the multidimensional nature of reasoning competence. These findings align with prior scholarship emphasizing that structured problem-solving environments support metacognitive regulation and systematic thinking by guiding students through explicit reasoning phases rather than relying on algorithmic memorization (Hansen, 2022; Sokolowski, 2021). However, the present study extends this body of knowledge by revealing that the effectiveness of problem-solving instruction is strongly mediated by students' ability to dynamically adjust cognitive strategies in response to varying task demands. Earlier studies frequently conceptualize reasoning development as a linear outcome of instructional exposure, whereas the current findings highlight reasoning as an adaptive process shaped by continuous negotiation between instructional scaffolding, task characteristics, and individual cognitive engagement (Eriksson & Sumpter, 2021; Thompson et al., 2017).

The results further demonstrate that cognitive strategy use plays a central mediating role in linking instructional approaches with reasoning performance. Students who actively engaged in planning and monitoring strategies exhibited more structured solution pathways and greater conceptual coherence, reinforcing earlier research suggesting that strategic self-regulation enhances mathematical comprehension and transferability across problem contexts (Martínez-Sierra & Toral-Rodríguez, 2025). Nevertheless, the present findings reveal that representation strategies, although beneficial, remain unevenly developed among learners, indicating that students often struggle to flexibly translate between symbolic, graphical, and verbal mathematical forms. This observation expands existing literature that primarily emphasizes the importance of representation as a cognitive support tool but gives less attention to the developmental complexity associated with representation selection and transformation processes (Bagossi et al., 2022; Syaifuddin, 2020). The study therefore suggests that structured problem-solving instruction must incorporate explicit representation training to cultivate deeper conceptual integration, as reasoning competence depends not only on procedural mastery but also on students' capacity to coordinate multiple representational systems.

Task complexity emerges as a significant contextual factor influencing how students activate and sustain cognitive strategies during problem-solving. The findings indicate that cognitively demanding tasks stimulate deeper interpretive reasoning, encourage justification of solutions, and promote exploration of alternative problem-solving pathways. These patterns resonate with theoretical perspectives asserting that higher cognitive demand tasks foster conceptual understanding by requiring students to engage in analytical reasoning rather than procedural reproduction (Nugroho et al., 2020; Shaw et al., 2020). However, the study also reveals that increased task complexity introduces cognitive load that can impede efficiency and confidence, particularly when students lack sufficient scaffolding or prior conceptual knowledge. This observation contributes to ongoing academic debates concerning the balance between productive struggle and cognitive overload in mathematics instruction, suggesting that optimal reasoning development requires carefully calibrated task sequencing that gradually increases cognitive demands while maintaining strategic support (Hui & Mahmud, 2023; Xiang et al., 2025). The findings therefore challenge instructional models that treat task complexity solely as a driver of learning intensity, emphasizing instead the necessity of integrating scaffolding mechanisms that sustain strategic engagement without overwhelming learners' cognitive capacity.

Another critical contribution of the study lies in its identification of emotional-cognitive interactions as integral components of reasoning development. The results demonstrate that students' persistence, motivation, and self-regulation significantly influence their engagement with complex mathematical tasks. While previous studies frequently address affective factors as supplementary influences on academic performance, the present findings illustrate that emotional resilience and reflective regulation function as embedded elements of reasoning processes (Fadzil & Osman, 2025; Klang et al., 2021; Santia et al., 2019). Students who demonstrated reflective coping strategies were more likely to sustain engagement during challenging tasks and to explore alternative reasoning pathways. This insight extends existing theoretical frameworks by positioning emotional regulation not merely as a motivational support but as a cognitive enabler that sustains analytical processing during complex problem-solving. Consequently, reasoning development should be conceptualized as an integrative process involving cognitive strategy use, affective regulation, and instructional scaffolding operating simultaneously.

The study also highlights the importance of teacher-guided structured problem-solving instruction in cultivating adaptive reasoning behaviors. Findings indicate that structured instructional approaches encourage students to internalize systematic reasoning routines, which subsequently enhance their ability to independently navigate complex tasks. Prior research consistently supports the value of teacher scaffolding in promoting reasoning development, yet often treats scaffolding as a temporary support that gradually diminishes as learners gain autonomy (Hansen, 2022; Nieminen et al., 2022). The current findings complicate this perspective by demonstrating that structured guidance remains influential even at advanced stages of reasoning development, as it provides cognitive frameworks that students continue to apply when encountering unfamiliar or cognitively demanding tasks. This suggests that effective reasoning instruction may require sustained integration of structured guidance alongside opportunities for independent exploration rather than a complete transition toward unguided problem-solving environments.

In sum, the findings contribute to the growing discourse on mathematical reasoning by presenting it as a dynamic, context-sensitive construct shaped by instructional design, cognitive strategy application, and task complexity interactions. The study advances current theoretical perspectives by demonstrating that reasoning competence evolves through iterative cycles of strategic adaptation, interpretive evaluation, and reflective self-regulation. While prior studies often examine these variables independently, the present research underscores their interdependence, suggesting that instructional effectiveness depends on the alignment between problem-solving structures, cognitive strategy development, and progressively calibrated task complexity. These insights highlight the necessity of rethinking mathematics instruction as an integrated cognitive ecosystem where reasoning growth is facilitated through deliberate coordination of pedagogical structure, learner strategy development, and contextual task design.

CONCLUSION

The present study provides comprehensive evidence that structured problem-solving instruction plays a pivotal role in strengthening students' mathematical reasoning by fostering systematic cognitive strategy use and supporting adaptive responses to varying task complexity. The findings demonstrate that reasoning development is not solely determined by exposure to challenging mathematical tasks but emerges through the interaction between instructional scaffolding, students' metacognitive regulation, and their ability to flexibly apply planning, monitoring, representation, and reflection strategies. Students exhibited enhanced conceptual organization, strategic problem interpretation, and sustained engagement when instructional structures explicitly guided reasoning processes. However, the study also reveals that heightened task complexity can generate cognitive strain when students lack sufficient strategic support, indicating that effective reasoning instruction requires balanced task sequencing and sustained scaffolding. The findings further highlight that emotional regulation and persistence significantly influence students' engagement with cognitively demanding tasks, suggesting that reasoning competence develops through integrated cognitive and affective processes. These insights imply that mathematics instruction should emphasize structured reasoning routines, explicit strategy instruction, and gradual increases in cognitive demand to optimize learning outcomes. Despite its contributions, the study is limited by sample size and contextual scope, which may constrain broader generalizability. Future research should explore longitudinal investigations, diverse educational settings, and experimental instructional interventions to further clarify how structured problem-solving environments can sustainably enhance mathematical reasoning across varied learner populations.

ACKNOWLEDGMENTS

The author expresses sincere gratitude to all individuals and institutions that contributed to the completion of this study. Special appreciation is extended to the participating students and teachers for their willingness, cooperation, and valuable engagement throughout the data collection process. The author also acknowledges the support and encouragement provided by colleagues and academic mentors whose constructive insights strengthened the research design and interpretation of findings. In addition, the author is grateful to the school administration for granting permission and facilitating the implementation of the research activities. Lastly, heartfelt thanks are conveyed to family members and close supporters for their continuous motivation, understanding, and encouragement during the completion of this study.

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