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Diversity in Elementary Students' Mathematical Problem-Solving Based on Polya's Theory

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ABSTRACT

This study aimed to describe elementary school students' mathematical problem-solving abilities based on Polya's problem-solving stages across different problem types (LOTS and HOTS) and school contexts. A descriptive quantitative design was employed involving 95 fourth-grade students from six elementary schools. Data were collected through a mathematical problem-solving test consisting of five essay questions developed according to Polya's four stages: understanding the problem, devising a plan, carrying out the plan, and looking back. The results showed that students achieved the highest performance in the plan stage (63.68%), followed by understanding the problem (60.05%), while lower achievement was observed in devising a plan (40.11%) and looking back (37.63%). The overall average problem-solving achievement was 50.37%. A comparison between LOTS and HOTS problems revealed that students consistently performed better on LOTS tasks across all Polya stages, whereas HOTS tasks presented substantial difficulties, particularly in planning solution strategies and evaluating answers. These findings indicate that procedural skills still dominate students' mathematical problem-solving abilities, while strategic reasoning and reflective thinking remain underdeveloped. The study highlights the importance of instructional practices that explicitly support all stages of Polya's framework through problem-based learning, mathematical justification, guided reflection, and differentiated instruction, thereby strengthening students' problem-solving abilities.

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1. INTRODUCTION

Arithmetic learning in primary schools plays an important role in developing students' logical thinking and problem-solving abilities [1]. One of the key goals of mathematics education is to equip students with the capability to solve problems systematically, logically, and reflectively. However, many elementary school students still struggle with higher-order thinking when solving non-routine mathematical problems, particularly those requiring HOTS skills [2]. Studies in Indonesia have shown that students' abilities to solve HOTS-type problems remain limited and vary across school contexts, indicating persistent challenges in mathematical problem-solving [3], [4]. Mathematical

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literacy also plays an important role in strengthening students' connections to and problem-solving abilities in everyday contexts, as students are expected not only to understand mathematical concepts but also to apply them effectively in real-life situations [5]. In this context, LOTS (Lower Order Thinking Skills) and HOTS (Higher Order Thinking Skills) represent different levels of cognitive demand in mathematical tasks. LOTS problems generally emphasize recalling, understanding, and applying basic concepts, whereas HOTS problems require students to analyze, evaluate, and create solutions for more complex situations. Examining students' performance across both LOTS and HOTS tasks provides a more comprehensive understanding of their development in mathematical problem-solving.

Problem-solving ability is closely related to students' capacity to understand problems, plan appropriate strategies, implement solutions, and evaluate results [6]. Polya's four-stage framework, namely understanding the problem, devising a plan, carrying out the plan, and looking back, provides a comprehensive approach to analyzing students' problem-solving strategies. Recent studies have explained how these stages can reveal students' cognitive strengths and limitations when faced with complex mathematical tasks [7]. The first stage focuses on identifying relevant information and recognizing problem requirements, while the second stage involves selecting appropriate strategies based on prior knowledge. The third stage requires students to execute the chosen strategy accurately, whereas the final stage emphasizes reflection, verification, and evaluation of the obtained solution. Consequently, Polya's framework not only describes procedural steps in problem solving but also serves as a theoretical lens for understanding students' mathematical thinking processes.

Numerous studies have reported that elementary school students tend to perform better in procedural tasks but experience difficulties in strategic planning and reflection stages, especially when dealing with HOTS-type problems. These findings suggest that the cognitive demands of HOTS problems are often associated with challenges in devising plans and evaluating solutions, whereas LOTS problems are generally completed more successfully because they rely on familiar procedures and direct applications of concepts. This condition indicates that students' mathematical problem-solving abilities are not evenly developed across Polya's stages. Differences in educational practices and learning environments may also contribute to variations in students' problem-solving performance across schools [8], [9]. Learning innovation through blended learning and communication-oriented instruction has also been reported to improve students' learning outcomes and communication skills, particularly when learning activities are connected to contextual, meaningful experiences grounded in local wisdom [10].

This condition suggests that students' mathematical problem-solving abilities are not uniformly developed across Polya's stages, while educational practices can significantly influence performance. Understanding how students navigate these stages, particularly in HOTS problems, is essential for designing instructional strategies that foster deeper mathematical thinking. Furthermore, the relationship between LOTS and HOTS performance can be better understood by examining how students progress through each stage of Polya's framework. Students who complete the understanding and planning stages may demonstrate stronger readiness to solve higher-level cognitive tasks, whereas difficulties at earlier stages can hinder performance on more complex problems.

Understanding the profile and variation of students' mathematical problem-solving abilities is important for improving instructional strategies [11]. By identifying strengths and weaknesses at each stage of Polya's problem-solving process, teachers can design learning activities that better accommodate students' diverse abilities [12]. Although previous studies have investigated students' mathematical problem-solving abilities, many have focused either on overall performance or on specific cognitive levels, without simultaneously examining the interaction between LOTS and HOTS problem types across all stages of Polya's framework. In addition, limited attention has been given to comparing variations in students' problem-solving profiles across different elementary school contexts. Therefore, this study seeks to address these gaps by providing a detailed description of elementary school students' mathematical problem-solving abilities, based on Polya's theory, across different problem types (LOTS and HOTS) and across schools. Therefore, this study aims to describe the profile of elementary school students' mathematical problem-solving abilities, based on Polya's theory, across different problem types (LOTS and HOTS) and across schools. The findings of this study are expected to provide insights for mathematics teachers in developing problem-solving-oriented and differentiated instruction.

2. METHOD

This study employed a descriptive, quantitative research design to examine elementary school students' mathematical problem-solving abilities using Polya's problem-solving stages [13]. The participants consisted of 95 fourth-grade students from six elementary schools in two school clusters. The selection of participants aimed to capture variations in students' mathematical problem-solving abilities across schools. A descriptive quantitative approach was selected because the primary objective of this study was to profile and describe students' mathematical problem-solving abilities across Polya's stages rather than to test causal relationships or compare groups using inferential statistical procedures.

Data were collected using a mathematical problem-solving test consisting of five essay questions, including LOTS and HOTS items. The classification of LOTS and HOTS items referred to cognitive levels in Bloom's revised taxonomy. LOTS items measured students' abilities to remember, understand, and apply mathematical concepts, whereas HOTS items required students to analyze, evaluate, and generate solutions to more complex and non-routine problems. Prior to implementation, the test instrument was reviewed by mathematics education experts to ensure content validity and alignment with the intended cognitive levels and Polya's problem-solving framework. The test items were developed based on Polya's four stages, namely understanding the problem, devising a plan, carrying out the plan, and looking back. A scoring rubric accompanied each item to assess students' performance at each stage of the problem-solving process. The rubric assigned scores for every stage based on students' written responses. The scoring rubric used a scale ranging from 0 to 4 for each Polya stage. A score of 0 indicated that no relevant response was provided, while scores of 1 to 4 reflected increasing levels of completeness, accuracy, and appropriateness in demonstrating the expected problem-solving processes. This rubric enabled a more detailed evaluation of students' performance at each stage of the mathematical problem-solving process.

Students' responses were scored according to the established rubric. To enhance scoring reliability, the assessment process followed standardized scoring guidelines developed from the rubric indicators. In addition, the rubric and scoring procedures were reviewed prior to data collection to minimize subjectivity and ensure consistent evaluation in students' written responses. The data were analyzed descriptively by calculating mean scores and percentages for each Polya stage and problem type. Descriptive statistical analysis was considered appropriate because the study focused on identifying patterns, profiles, and variations in students' mathematical problem-solving abilities across schools and problem types rather than examining statistically significant differences between groups. The findings were presented in tables and figures to illustrate variations in students' mathematical problem-solving abilities across stages and schools.

Ethical considerations were addressed by obtaining permission from the participating schools before data collection. Students participated in the study within regular classroom activities, and all collected data were analyzed anonymously to maintain confidentiality and protect participants' privacy.

Table 1. Research procedure and descriptive analysis framework based on Polya's problem-solving stages

Main Stages	Focus of Activities
Identification & Design	This study employed a descriptive quantitative research design to examine elementary school students' mathematical problem-solving abilities in relation to Polya's problem-solving stages.
Instrument & Scoring Rubric	*Crucial*: As the instrument is based on Polya's framework, the scoring rubric was designed with graded score levels (e.g., 0–4) for each stage: understanding the problem, devising a plan, carrying out the plan, and reflecting on the outcome. The instrument underwent expert review to ensure content validity and appropriate classification of LOTS and HOTS items.
Data Collection	The test was administered to 95 students. Uniform testing conditions were maintained across all six schools to ensure objectivity and data consistency. School approval was obtained prior to data collection, and students' responses were treated confidentially.
Descriptive Analysis	Simple descriptive statistics were used to identify general trends. The percentage formula applied was: ($P = \frac{f}{n} \times 100\%$). Mean scores and percentages were calculated to describe students' performance across Polya's stages and cognitive problem levels.
Presentation & Conclusion	Numerical results were transformed into narrative descriptions. For example: *"The 'Looking Back' stage showed the lowest percentage compared to the other stages."*

Note. P = percentage, f = frequency, n = total number of students

3. RESULTS AND DISCUSSION

This phase presents the outcomes of an evaluation of fundamental faculty students' mathematical problem-solving abilities, based on Polya's 4-step problem-solving model. The outcomes are presented in tables and figures to reveal variations across trouble types (masses and HOTS) and differences among colleges.

3.1. Results

3.1.1 Overall Profile of Students' Mathematical Problem-Solving Abilities

The overall profile of students' mathematical problem-solving abilities indicates variations across the six participating elementary schools. Differences in average scores across schools suggest that students demonstrated diverse levels of performance in solving mathematical problems. These variations may reflect differences in learning experiences, instructional practices, and opportunities to engage in problem-solving activities. The comparison of students' average scores across Polya's stages is illustrated in Figure 1.

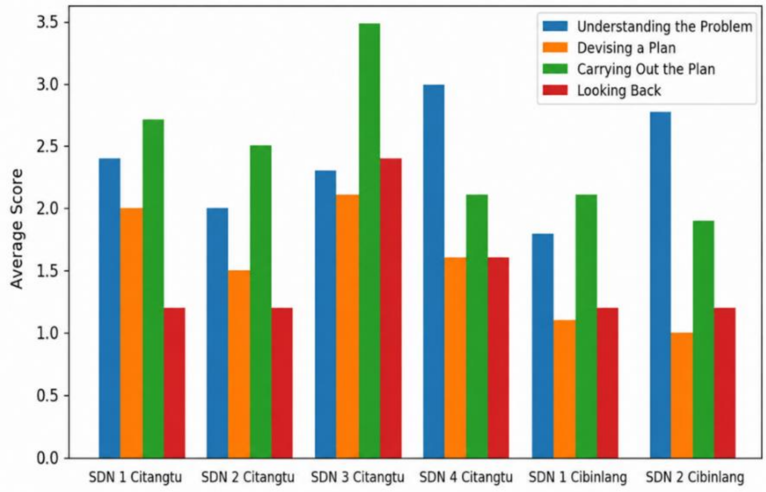

Figure 1. Students' mathematical problem-solving ability based on Polya's stages across schools

Figure 1 illustrates the average scores for students' mathematical problem-solving abilities across six elementary schools, based on Polya's four stages: understanding the problem, devising a plan, carrying out the plan, and looking back. Although performance patterns varied across schools, a similar trend emerged. Students generally achieved higher scores in the carrying out stage, whereas lower scores were consistently found in the devising and looking back stages. The relatively small differences between schools in these stages indicate that the observed pattern was common across the research sites.

3.1.2 Students' Problem-Solving Abilities Based on Polya's Stages

The distribution of students' scores based on Polya's stages is presented in Table 2. Table 2 presents students' mathematical problem-solving abilities across Polya's four stages: understanding the problem, planning a solution, implementing the plan, and checking again. Each stage was assessed using five problem items that represented different mathematical contexts.

The understanding of the problem stage obtained an average achievement percentage of 60.05%. This result indicates that most students were able to identify relevant information and determine what was required in the problem. However, performance varied considerably across items, ranging from 33.16% to 86.32%, suggesting that students' comprehension was influenced by problem complexity and context.

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Table 2. Students' mathematical problem-solving ability based on Polya's problem-solving stages

No.	Polya's Problem-Solving Stages	Indicator	Item Number	Total Score	Percentage (%)
1	Understanding the Problem	Students can identify given and required information	1	328	86.32
			2	276	72.63
			3	164	43.16
			4	126	33.16
			5	247	65.00
		Average			60.05
2	Planning a Solution	Students can determine appropriate strategies or formulas	1	262	68.95
			2	183	48.16
			3	87	22.89
			4	75	19.74
			5	155	40.79
		Average			40.11
3	Implementing the Plan	Students can solve the problem according to the planned steps	1	345	90.79
			2	199	52.37
			3	218	57.37
			4	163	42.89
			5	285	75.00
		Average			63.68
4	Checking Again	Students recheck answers and provide appropriate conclusions	1	324	85.26
			2	100	26.32
			3	35	9.21
			4	65	17.11
			5	191	50.26
		Average			37.63
		Overall Average			50.37

The planning a solution stage produced an average percentage of 40.11%, which was substantially lower than the understanding and implementation stages. This finding indicates that many students experienced difficulties in selecting appropriate strategies or mathematical procedures before performing calculations. The lowest percentages were observed in Items 3 and 4, demonstrating particular challenges when students were required to formulate solution plans independently.

The implementation of the plan stage achieved the highest average percentage (63.68%). This result suggests that once students identified a strategy, they were generally able to execute mathematical procedures correctly. The consistently higher performance in this stage indicates stronger procedural skills compared with strategic and reflective aspects of problem solving.

The checking again stage recorded the lowest average percentage (37.63%). Students rarely reviewed their solutions, verified calculations, or provided complete conclusions. The extremely low percentage in Item 3 (9.21%) further demonstrates limited engagement in reflective thinking and self-evaluation.

Overall, the average mathematical problem-solving achievement across all Polya stages was 50.37%. These results indicate that students demonstrated moderate problem-solving performance, with notable strengths in procedural execution and weaknesses in strategic planning and reflection. To complement the quantitative findings, examples of students' written responses are presented in Figure 2.

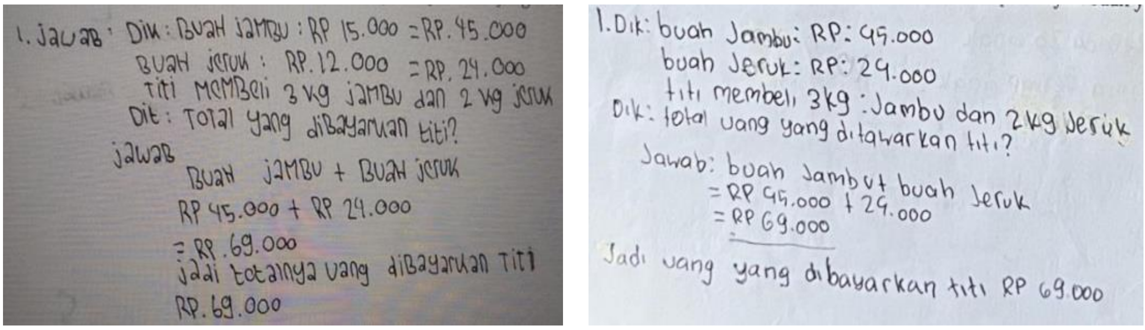

Figure 2. Example of students' written responses reflecting mathematical problem-solving performance based on Polya's stages

Figure 2 presents a student's written response that reflects the overall pattern of students' mathematical problem-solving performance shown in Table 2. The student identified the relevant information, performed the required calculations, and obtained a correct solution. The response demonstrates successful implementation of procedural steps but provides limited evidence of explicit planning and verification activities. This pattern is consistent with the quantitative results, which showed higher achievement in the implementation stage than in the planning and checking stages.

3.1.3 Results Based on Problem Types (LOTS and HOTS)

The analysis of students' mathematical problem-solving abilities by problem type is presented in Table 3. Overall, the results show that students consistently achieved higher scores on LOTS problems than on HOTS problems across all stages of Polya's problem-solving framework.

Table 3. Students' mathematical problem-solving scores based on problem types and Polya's stages

Problem Type	Number of Students	Understanding the Problem	Planning a Solution	Implementing the Plan	Checking Again
LOTS[a]	95	2.65	1.83	2.98	2.05
HOTS[b]	95	2.24	1.11	1.70	0.78
Average		2.48	1.56	2.47	1.54

As shown in Table 3, students performed better on LOTS problems in every stage of Polya's problem-solving process. The highest scores were observed in the implementing the plan stage (2.98), followed by understanding the problem (2.65). These results indicate that students were generally successful in solving routine mathematical tasks that required the direct application of familiar concepts and procedures.

In contrast, students' performance on HOTS problems was considerably lower. Scores decreased across all stages, particularly in planning a solution (1.11) and checking again (0.78). This pattern suggests that students experienced difficulties when confronted with non-routine problems requiring analysis, strategic reasoning, and reflective evaluation.

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LOTS Question	HOTS Question
In an orchard, there are 120 apples and 80 oranges. If all the fruit is distributed equally among 20 children, how many fruits will each child receive?	A rectangular plot of land is 5 meters long and 3 meters wide. The plot will be planted with sunflowers, with 5 cm between each flower. How many sunflower seeds will be needed?
student responses	student responses

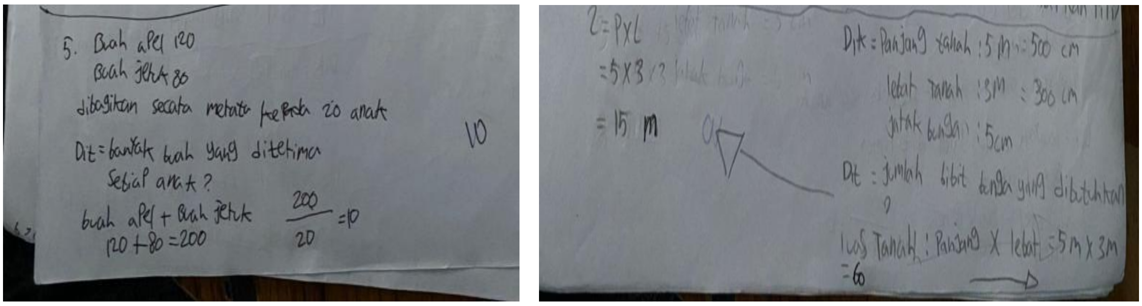

Figure 3. Examples of LOTS and HOTS questions and students' responses in mathematical problem solving

The examples presented in Figure 3 provide additional evidence supporting the quantitative findings. In LOTS problems, students tended to apply known procedures directly and reach correct answers with relatively few difficulties. In HOTS problems, however, students frequently demonstrated incomplete reasoning, inappropriate solution strategies, and omissions in the verification stage.

The largest performance gaps between LOTS and HOTS problems occurred in the planning and checking stages. This finding indicates that higher-order mathematical tasks place greater demands on students' ability to formulate solution strategies and evaluate the validity of their answers. Although many students possessed adequate procedural knowledge, they often struggled to engage in the deeper analytical and reflective thinking required for successful HOTS problem-solving.

Overall, the results confirm that problem type plays an important role in students' mathematical problem-solving performance. Students demonstrated stronger performance when solving routine LOTS problems but encountered substantial difficulties with HOTS problems, particularly during stages that require planning, reasoning, and reflection.

3.2. Discussion

The results of this study reveal clear variations in elementary school students' mathematical problem-solving abilities when viewed through the lens of Polya's theory [14], [15]. Overall, students demonstrated stronger abilities in procedural stages, particularly in carrying out the plan, while weaknesses were identified in strategic planning and reflective evaluation. This pattern is consistent with previous studies showing that elementary school students tend to be more proficient in executing procedures than in planning solutions or evaluating results [16], [17], [18]. The relatively high achievement in the implementation stage indicates that mathematics learning at the elementary level still emphasizes procedural fluency, as also reported in recent studies on mathematics instruction [19], [20]. Although procedural skills remain important, Polya's theory emphasizes that effective problem-solving requires balanced mastery across all stages, including planning and reflection [21].

From a cognitive perspective, the dominance of procedural performance suggests that students have developed operational knowledge for executing mathematical calculations but have not yet fully developed the strategic knowledge required to select and organize solution approaches. Students may be able to apply familiar algorithms when the solution pathway is apparent; however, they often struggle when required to determine which strategy to use independently. This finding indicates that successful mathematical problem solving involves not only procedural competence but also higher-level cognitive processes that support decision-making, reasoning, and strategy selection. The results, therefore, suggest an imbalance between the procedural and strategic dimensions of mathematical learning in elementary classrooms.

The low achievement in the planning stage indicates that students are not yet adequately trained to independently formulate problem-solving strategies. This finding aligns with previous studies reporting that elementary school students often struggle to connect problem information with appropriate mathematical concepts, especially in non-routine or HOTS-type problems [22], [23], [24]. Weak performance in the looking back stage also reflects the limited emphasis on metacognitive activities in mathematics instruction [25], [26]. Evidence from students' written work further supports this finding, showing that many students stopped after obtaining numerical answers without evaluating the correctness or relevance of their solutions. In addition, the performance gap between LOTS and HOTS problems reinforces the indication that students are still unfamiliar with higher-order thinking tasks [27]. HOTS problems require deeper conceptual understanding, strategic reasoning, and reflection, which are closely related to Polya's planning and looking back stages [28], [29], [30].

The weakness observed in the looking-back stage is particularly important because reflection is a central component of metacognitive regulation. Students who review their answers are more likely to identify computational errors, evaluate the reasonableness of solutions, and refine their problem-solving strategies for future tasks. The low percentage obtained in this stage suggests that many students approach mathematical problem-solving as a process of obtaining answers rather than reasoning and verification. This finding raises concerns about the long-term development of independent mathematical thinking, as metacognitive skills are essential for transferring knowledge to unfamiliar situations and solving complex problems.

The substantial gap between LOTS and HOTS performance further demonstrates that students' procedural competence does not automatically translate into higher-order problem-solving ability. While LOTS tasks can often be completed through familiar procedures, HOTS tasks require students to interpret information, analyze relationships among variables, justify decisions, and evaluate alternative solutions. The findings suggest that instructional practices emphasizing repetitive exercises and procedural accuracy may successfully support LOTS performance but may not adequately prepare students for cognitively demanding tasks. Consequently, mathematics instruction should move beyond procedural mastery and provide opportunities for students to engage in reasoning, argumentation, and reflective problem-solving activities.

Variations among schools also suggest that differences in instructional approaches and classroom practices contribute to the diversity of students' problem-solving abilities [31], [32]. Schools with more balanced achievement across Polya's stages are likely to implement learning activities that emphasize structured problem-solving processes rather than procedural execution alone. The observed differences among schools indicate that classroom learning environments may play a significant role in shaping students' mathematical thinking. Schools demonstrating stronger performance across the planning and reflection stages may provide more opportunities for discussion, collaborative problem-solving, teacher questioning, and guided reflection. Conversely, schools that focus primarily on procedural exercises may produce students who are proficient in carrying out calculations but less capable of strategic reasoning and self-evaluation. Although the present study did not directly examine classroom practices, the variation among schools suggests that instructional design and teacher facilitation deserve further investigation in future studies.

Rather than merely confirming previous findings, the present study extends existing knowledge by demonstrating that weaknesses in planning and reflection occur consistently across both problem types and school contexts. This pattern suggests that the challenge is not limited to individual students or specific schools but may reflect broader instructional tendencies in elementary mathematics education. The findings therefore support the argument that improving students' mathematical problem-solving abilities requires systematic attention to all stages of Polya's framework rather than focusing predominantly on procedural execution.

These findings also highlight several limitations of procedural-focused mathematics instruction. While procedural fluency enables students to perform calculations efficiently, excessive emphasis on procedures may reduce opportunities for students to develop flexible thinking, strategic decision-making, and reflective reasoning. Students may become accustomed to following predetermined steps without understanding why particular strategies are selected or whether their solutions are logically sound. Such conditions may hinder the development of mathematical literacy and higher-order thinking skills that are increasingly required in contemporary education. Therefore, balancing procedural fluency with conceptual understanding, strategic reasoning, and metacognitive reflection should become a central objective of elementary mathematics instruction.

Overall, these findings highlight the importance of mathematics instruction that explicitly guides students through all stages of Polya's problem-solving process. The integration of problem-based learning and differentiated instruction may help accommodate students' diverse abilities while strengthening their strategic and reflective thinking skills. Problem-based learning can provide authentic contexts that encourage students to analyze problems, formulate strategies, and evaluate solutions, whereas differentiated instruction can address variations in students' readiness and learning needs. By integrating these approaches, teachers can create learning environments that support not only procedural competence but also the development of higher-order thinking and metacognitive skills necessary for effective mathematical problem-solving.

4. CONCLUSION

This study examined elementary school students' mathematical problem-solving abilities based on Polya's problem-solving framework across different problem types (LOTS and HOTS) and school contexts. The findings revealed that students performed better in the plan stage. At the same time, lower achievement was consistently observed in devising a plan and looking back stages, indicating that their problem-solving abilities remain largely dominated by procedural understanding rather than strategic reasoning and reflective evaluation. The comparison between LOTS and HOTS problems constitutes an important contribution of this study, as students achieved higher scores on LOTS tasks across all Polya stages. In contrast, HOTS tasks exposed substantial difficulties, particularly in planning solution strategies and evaluating final answers. These findings highlight the need for mathematics instruction that promotes balanced development across all stages of Polya's framework through problem-based learning, mathematical justification, guided reflection, and differentiated instruction. Nevertheless, this study is limited by its descriptive quantitative design, which focused on profiling students' performance without employing inferential statistical analyses or directly examining instructional practices that may explain variations among schools. Future research is therefore recommended to utilize inferential and mixed-methods approaches to investigate further the relationships among instructional strategies, LOTS–HOTS performance, and students' mathematical problem-solving abilities.

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