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The effectiveness of Polya's problem-solving strategy in enhancing mathematical word problem comprehension among fifth-grade students

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Abstract

Despite its importance, students' difficulty in comprehending and solving mathematical word problems persists in elementary education. This quasi-experimental study examines the effectiveness of Polya's four-step problem-solving strategy in improving this competency. Fifth-grade students (N=45) from SD Negeri 7 Buntok were assigned to an experimental group (taught using Polya's strategy) and a control group (conventional instruction). A pretest-posttest design with a mathematical word problem test, scored via an analytic rubric, measured competency in problem understanding, solution process, accuracy, and answer correctness. Results showed a significantly greater improvement in the experimental group (pretest M=58.2, posttest M=78.6) compared to the control group (pretest M=56.9, posttest M=65.3). Statistical analysis (independent samples t-test) confirmed a significant difference between the groups' posttest scores ($p < 0.05$). The findings demonstrate that explicitly teaching Polya's strategy significantly enhances students' systematic problem-solving skills and conceptual understanding of word problems. This study provides empirical evidence for integrating structured heuristic strategies into primary mathematics curricula to build foundational problem-solving proficiency.

Keywords: Polya's problem-solving strategy; mathematical word problems; conceptual understanding; elementary mathematics education; heuristic learning

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INTRODUCTION

Mathematics education in primary schools aims not only to teach students basic numerical skills but also to develop higher-order thinking skills such as analytical reasoning, critical thinking, and strategic problem-solving. One of the most challenging domains within early mathematics education is solving word problems, which require learners to interpret linguistic descriptions, translate them into mathematical representations, and apply relevant solution strategies (Putri & Toyib, 2025). This multifaceted nature often results in persistent difficulties, particularly at the elementary level, where both linguistic comprehension and cognitive development are still maturing (Vicente et al., 2020).

Students' struggles with word problems are well-documented in the literature and often relate to difficulties in understanding context, identifying relevant information, and selecting appropriate problem-solving strategies (Vilianti et al., 2018). A structured instructional model is therefore necessary to guide learners systematically through problem-solving processes.

Polya's four-step strategy, as described by Alvesya et al. (2025), consists of understanding the problem, devising a plan, carrying out the plan, and looking back, has long been recognized as a pedagogically sound framework that supports systematic thinking and enhances metacognitive awareness (Dookurong et al., 2025). It emphasizes not just the "how" of problem solving, but the "why," thereby deepening students' cognitive engagement with mathematical tasks (Anugraheni et al., 2025).

Empirical studies consistently support the effectiveness of Polya's strategy. A meta-analysis conducted by various researchers indicates that explicit instruction in heuristic strategies like Polya's significantly improves learners' mathematical problem-solving skills, comprehension, and confidence (Govender et al., 2024). Research conducted in Indonesian classrooms shows that when students are guided through Polya's steps, they demonstrate improved mathematical literacy and structured thinking (Tsao, 2024).

Moreover, the role of self-regulation and adaptability in supporting student engagement and learning, especially in problem-solving contexts (Purnomo et al., 2024). These traits, while crucial in online learning, can be equally cultivated in classroom environments through structured strategies like Polya's, which require students to plan, monitor, and evaluate their own thinking processes (Sariev & Savov, 2025).

Despite its proven benefits, the implementation of Polya's strategy in Indonesian elementary schools remains limited. Teachers frequently rely on traditional, rote-based instruction that prioritizes procedural fluency over conceptual understanding (Purnomo et al., 2020). This instructional gap contributes to a disconnect between students' learning needs and the methods used to support them. Research has shown that many students perform reasonably well in identifying a problem but struggle significantly with devising plans, executing them, and reflecting on their solutions, especially among lower-performing learners (Govender et al., 2024).

Furthermore, qualitative findings from classroom-based studies reveal that students' difficulties in solving word problems extend beyond numerical skills to include critical cognitive processes such as reasoning, analysis, and evaluation (Pramudiani et al., 2017). These findings reinforce the need for instructional interventions that make problem-solving strategies explicit and scaffold students' cognitive efforts through all stages of problem engagement.

In this context, Polya's strategy represents a theoretically grounded and empirically supported model that aligns with modern pedagogical goals for primary mathematics education. By examining the implementation of this strategy among Grade V students at SD Negeri 7 Buntok, Barito Selatan, this study aims to evaluate its effectiveness in enhancing student comprehension and performance in mathematical word problems. Through this investigation, the research contributes to the expanding body of literature advocating for structured, research-informed, and student-centered instructional practices in mathematics learning.

METHODS

Research Design

This study used a quasi-experimental quantitative design with a pretest–posttest control group structure (Ismail et al., 2019). The goal was to assess the impact of Polya's problem-solving strategy on students' comprehension of mathematical word problems. The design is summarized in Table 1.

Table 1. Research design structure

Group	Pretest	Treatment	Posttest
Experimental	O_1	Polya Strategy	O_2
Control	O_1	Conventional Instruction	O_2

Research Subjects

The participants were fifth-grade students from SD Negeri 7 Buntok. In total, 45 students took part in the study, divided into an experimental group and a control group as detailed in Table 2.

Table 2. Participant distribution

Group	Number of Students	Instructional Approach
Experimental	23	Polya's Problem-Solving Strategy
Control	22	Conventional Teaching Method

Instruments and Research Media

The main research instrument was a word-problem comprehension test developed by the researchers. It consisted of 10 essay-type items reflecting real-world mathematical problems aligned with the Grade V curriculum competencies. The test measured students' ability to:

1. Understand the problem
2. Identify relevant information
3. Apply correct operations
4. Justify and reflect on answers

To illustrate the nature of the problems, sample items from the test are shown in Figure 1 and Figure 2. These word problems involve everyday contexts and require multi-step reasoning, including unit conversions and arithmetic operations to solve.

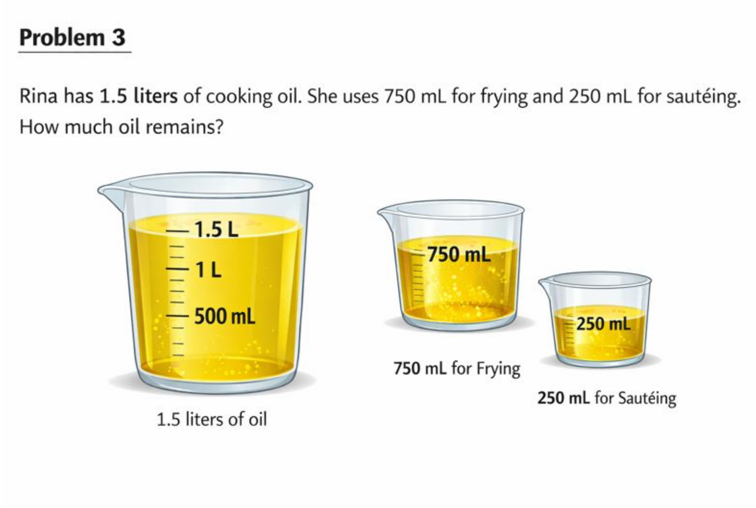

Figure 1. Sample test item

This example problem asks students to calculate the remaining volume of cooking oil after sequential usage for different purposes. It requires understanding a real-life scenario, performing subtraction with volume units, and interpreting the result in context.

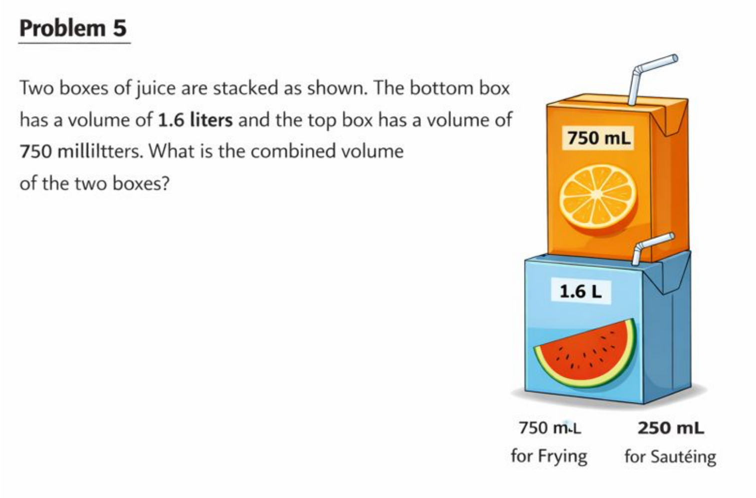

Figure 2. Sample test item

In this second example, students deal with a scenario of combining two quantities of juice given in different units, liters and milliliters. This problem tests their ability to convert units and sum volumes correctly while comprehending the situation described. The test instrument was validated prior to use. A pilot try-out with a parallel class yielded a reliability coefficient of 0.84 (Cronbach's Alpha), indicating strong internal consistency.Table 3 outlines the scoring rubric.

Table 3. Scoring criteria

Criteria	Score 4	Score 3	Score 2	Score 1
Problem Understanding	Complete	Mostly accurate	Partial	Misinterpreted
Strategy & Process	Accurate & logical	Mostly correct	Limited or partially wrong	Illogical
Computation Accuracy	Correct	Minor error	Major error	Incorrect
Final Answer	Correct	Close	Unclear	Incorrect or blank

Scoring criteria: The Students' answers to the word-problem test were evaluated on four criteria, Problem Understanding, Strategy & Process, Calculation Accuracy, and Final Answer. Each criterion was rated on a scale from 1 to 4, with higher scores indicating better performance.

1. Problem Understanding looked at how well students understood the question. A score of 4 was given if the student fully understood the problem. Lower scores were given if the understanding was only partial or incorrect.
2. Strategy and Process evaluated whether the student used a correct and logical method to solve the problem. A high score meant the strategy was accurate and well-organized, while lower scores indicated mistakes or confusion in the process.
3. Calculation Accuracy measured whether the math was done correctly. Students received a top score for correct calculations, and lower scores if there were minor or major errors.
4. Final Answer checked if the student gave the correct solution. A perfect score was given for a correct and clear answer, while unclear or wrong answers received lower points.

This scoring system helped assess not only the final answer but also how well students understood and solved the problems step by step.

Research Procedure

The research procedure was carried out over four weeks and comprised several phases, as depicted in Figure 3. The process began with preparation and pretesting, followed by the intervention (differing by group), and concluded with a posttest.

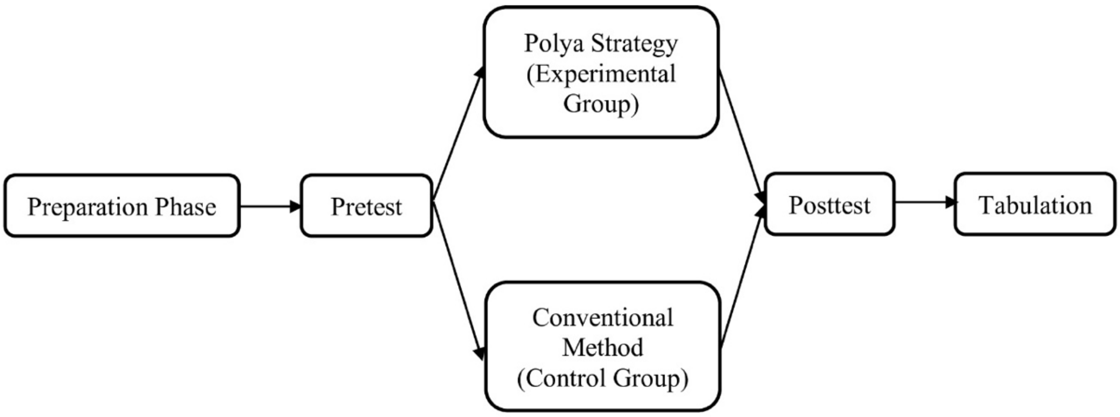

Figure 3. Research procedure

The flowchart illustrates the sequence: a Preparation Phase (instrument validation and coordination), the Pretest for both groups, divergent Treatment paths (Polya's strategy for the experimental group versus conventional method for the control group), and finally a Posttest administered to all students.

Detailed steps:

The following timeline summarizes each phase of the study:

1. Preparation Phase:
    a. Instrument validation and reliability testing
    b. Coordination with the school and classroom teacher to schedule the study
2. Pretest Administration:
   Both groups (experimental and control) were given the same word-problem test before any instruction, to assess baseline comprehension
3. Treatment Phase:
    a. Experimental group, taught using Polya's four-step problem-solving strategy in each lesson (explicitly guiding students through understanding the problem, devising a plan, carrying out the plan, and looking back)
    b. Control group, taught using the conventional method (teacher explanations followed by routine practice exercises), with no explicit heuristic strategy instruction.
4. Posttest Administration:
   Both groups took the same test again after the instructional period, under equivalent conditions, to measure learning gains attributable to the intervention.

Data Analysis Technique

Data were analyzed using IBM SPSS Statistics (version 26). Both descriptive and inferential statistics were employed to evaluate learning outcomes:

1. Descriptive Statistics
   Used to summarize the central tendency and spread of pretest and posttest scores in each group (mean, standard deviation, minimum, and maximum scores).
2. Normality Test (Kolmogorov–Smirnov)
   Conducted to ensure that score distributions for each group (pretest and posttest) did not significantly deviate from normality, which is an assumption for subsequent parametric tests.
3. Homogeneity of Variance Test (Levene's Test)
   Performed to verify that the variances of the two groups were equal for the outcome measure, another prerequisite for comparing group means.
4. Paired Sample t-test
   Employed to compare pretest and posttest scores within the same group (experimental or control) and determine whether the improvement in each group was statistically significant. A significant p-value ($p < 0.05$) indicates a meaningful difference between pretest and posttest, showing that learning occurred.
5. Independent Sample t-test
   Employed to compare the posttest scores between the experimental and control groups, assessing whether any difference in performance could be attributed to the use of Polya's strategy versus conventional teaching. A significant p-value ($p < 0.05$) indicates that the experimental group outperformed the control group, supporting the strategy's effectiveness.

Research Ethics

This study was conducted with full adherence to research ethics. Informed consent was obtained from the school administration, students' parents/guardians, and the students themselves before participation. Student identities and personal data were kept confidential, and participation in the study was voluntary (students were free to withdraw at any time). The instructional intervention (Polya's strategy) was designed to enhance the normal learning experience rather than disrupt it, ensuring no group of students was disadvantaged by the research activities. Ethical clearance and permission were also secured from local educational authorities prior to implementation.

RESULTS AND DISCUSSION

Results

This section presents the findings from the analysis of data collected through the pretest and posttest in both the experimental and control groups. The goal of the analysis was to assess the effectiveness of Polya's problem-solving strategy in enhancing students' comprehension of mathematical word problems.

Descriptive Statistics

The initial analysis examined the average performance of each group before and after the intervention. Table 4 summarizes the mean scores, standard deviations, and score ranges (minimum and maximum) for the pretest and posttest in both groups.

Table 4. Descriptive statistics of pretest and posttest scores

Group	Test Type	N	Mean	Std. Deviation	Min	Max
Experimental	Pretest	23	58.2	9.4	42	73
Experimental	Posttest	23	78.6	7.1	65	90
Control	Pretest	22	56.9	8.7	41	70
Control	Posttest	22	65.3	8.5	52	78

The experimental group's mean score increased notably from 58.2 (pretest) to 78.6 (posttest), while the control group's mean rose from 56.9 to 65.3. This indicates that both groups improved after instruction, but the improvement was much larger for the group that learned via Polya's strategy. The gain of about 20.4 points in the experimental group far exceeded the 8.4-point gain in the control group, suggesting a substantial impact of the Polya-based intervention.

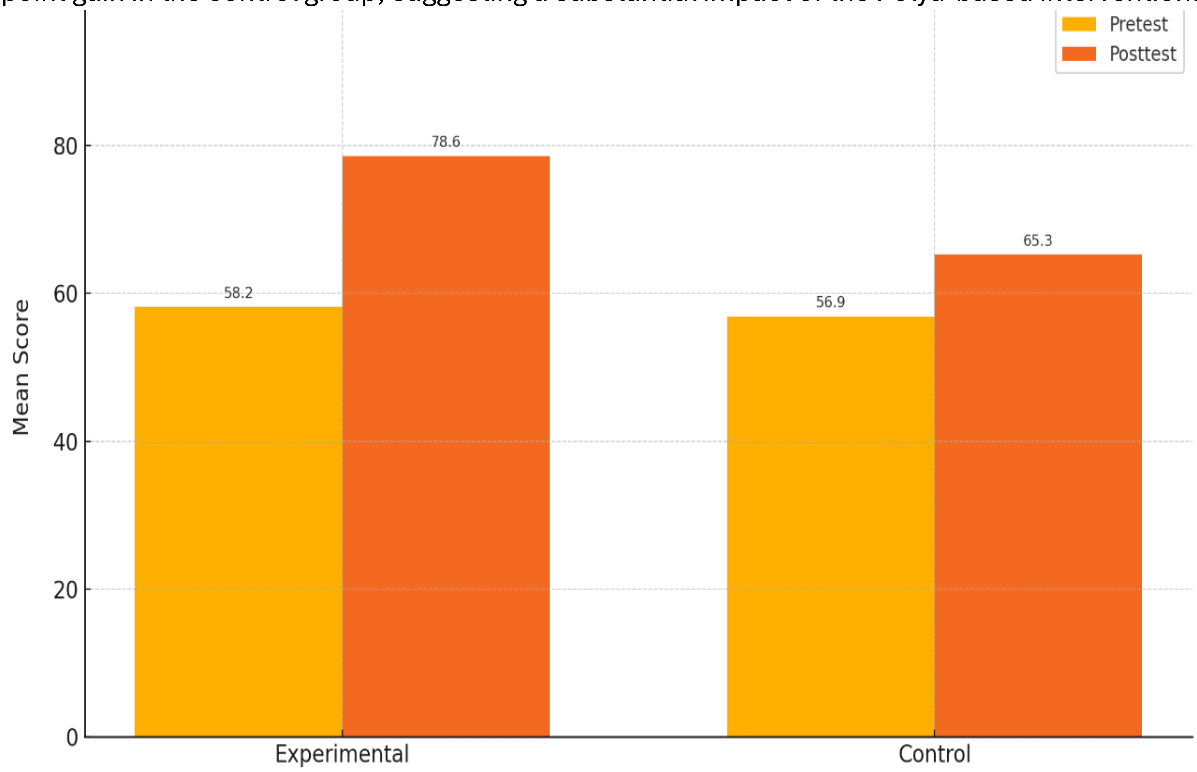

Figure 4. Comparison of average pretest and posttest scores for each group

The experimental group (taught with Polya's strategy) shows a larger increase in mean score compared to the control group (taught with conventional methods), illustrating the greater learning gains achieved under the Polya instructional approach.

Assumption Checks

Before comparing group performances with t-tests, we verified that the data met key assumptions. A Kolmogorov–Smirnov test was used to check for normality of score distributions, and Levene's test was used to check for homogeneity of variance between groups.

Table 5. Normality test

Group	Test Type	Sig. (2-tailed)
Experimental	Pretest	0.127
Experimental	Posttest	0.200
Control	Pretest	0.089
Control	Posttest	0.176

Note: All p-values > 0.05, indicating non-significant deviation from normality.

As shown in Table 5, all significance values (p) are greater than 0.05 for both groups' pretest and posttest scores. Thus, we conclude that the score distributions did not significantly deviate from a normal distribution in any case, satisfying the normality assumption. Next, a homogeneity of variance test was conducted on the posttest scores of the experimental and control groups:

Table 6. Pearson correlation analysis

Test Type	F	Sig. (2-tailed)
Posttest	0.571	0.454

With a p-value of 0.454 (> 0.05) for the Levene's F-test (Table 6), we found no significant difference in score variance between the two groups. This result indicates that the assumption of equal variances holds, validating the use of t-test comparisons for the group means.

Inferential Statistics

After confirming the assumptions, we performed paired sample t-tests to assess within-group improvements and an independent sample t-test to compare the posttest performance between groups.

Within-Group Improvement (Paired t-tests)

Each group's pretest and posttest scores were compared to determine if the gains were statistically significant (Table 7).

Table 7. Paired sample t-test

Group	Mean Difference	t	df	Sig. (2-tailed)
Experimental	20.4	9.121	22	0.000
Control	8.4	4.633	21	0.000

Both groups showed statistically significant improvement from pretest to posttest (p = 0.000 for both). However, the experimental group's mean increase (20.4 points) was much larger than the control group's increase (8.4 points), reflecting the greater efficacy of the structured Polya intervention. In summary, while both instructional methods led to learning gains, the Polya's strategy produced a significantly larger improvement in students' word-problem scores.

Between-Group Comparison (Independent t-test)

To directly evaluate the effectiveness of Polya's strategy relative to conventional teaching, we compared the posttest scores of the two groups using an independent sample t-test (Table 8).

Table 8. Independent sample t-test

Comparison	Mean Difference	t	df	Sig. (2-tailed)
Experimental vs Control	13.3	5.229	43	0.000

The independent t-test results show a significant difference in posttest performance between the experimental and control groups ($t = 5.229$, $df = 43$, $p = 0.000$). The experimental group's scores were, on average, 13.3 points higher than the control group's scores. This finding confirms that the class taught using Polya's problem-solving strategy outperformed the class that received conventional instruction, providing strong evidence for the strategy's effectiveness.

In summary, the quantitative results can be encapsulated as follows: Polya's problem-solving strategy significantly improved students' ability to solve mathematical word problems. The experimental group not only demonstrated a substantial increase in their own scores from pretest to posttest, but also scored markedly higher on the posttest than the control group. Both the within-group and between-group statistical analyses (paired and independent t-tests) support the conclusion that Polya's structured four-step method had a positive and significant impact on student learning outcomes in mathematics word problems.

Discussion

The findings of this study provide robust evidence that Polya's problem-solving strategy significantly enhances elementary students' ability to comprehend and solve mathematical word problems. Students in the experimental group, who received Polya-based instruction, showed a substantial mean score increase from 58.2 (pretest) to 78.6 (posttest). In contrast, the control group, taught through conventional methods, exhibited a more modest improvement from 56.9 to 65.3. The 20.4-point gain in the experimental group far exceeded the 8.4-point gain in the control group, reinforcing the argument that a structured heuristic approach fosters deeper cognitive growth than traditional techniques.

The statistical analysis further supports this conclusion. Both groups demonstrated significant within-group improvement, as indicated by the paired sample t-tests, $p < 0.001$ for both. Yet, the independent sample t-test confirmed a significant difference in posttest performance between the experimental and control groups (mean difference = 13.3, $t = 5.229$, $p < 0.001$). These results align with prior studies that report the efficacy of Polya's strategy. For example, the significant improvements in students' mathematical literacy and problem-solving ability when learners were systematically guided through Polya's four stages: understanding, planning, executing, and checking (Suryadi et al., 2024).

The outcomes of this study are consistent with theoretical frameworks emphasizing the importance of structured problem-solving models in mathematics education. Polya's model, like similar heuristic frameworks, provides a clear cognitive scaffold guiding students through complex reasoning tasks (Powell & Fuchs, 2018). Specifically, Polya's phases encourage learners to build mental representations of problems, select effective strategies, carry out logical steps (Li et al., 2025), and reflect on the validity of results, processes that are often underemphasized in conventional instruction, which tends to prioritize procedural practice over strategic thinking (Guntur & Purnomo, 2024).

Further empirical support for structured problem-solving instruction can be found in studies examining each stage of the problem-solving process. For instance, the students' proficiency can decline in later stages of Polya's framework, students often perform well in understanding the problem but struggle more during planning and reflection (Gjoneska et al., 2022; Voskoglou, 2011). This trend underscores that while many learners can identify given information, they have difficulty with strategic planning and metacognitive evaluation. These are precisely the skills that strategies like Polya's aim to cultivate (Polya, 1945), by explicitly teaching students how to think about their thinking.

Moreover, broader research on mathematical reasoning suggests that students who receive explicit strategy instruction not only improve their solution accuracy but also develop higher-order thinking skills such as critical analysis and strategic planning (Istikomah et al., 2025). Studies of Polya's method in various contexts (e.g., secondary school settings and across different mathematical topics) similarly report that structured heuristics enhance logical reasoning and systematic problem-solving (Yang & Kaiser, 2022). Together, these findings highlight that heuristic approaches contribute to developing general problem-solving competencies and cognitive skills beyond the immediate context of a single math problem.

The pedagogical significance of our findings is particularly relevant in the context of Indonesian mathematics classrooms, which have historically emphasized memorization and routine practice. The evidence from this study reinforces calls in mathematics education for instructional approaches that elevate conceptual understanding and metacognitive regulation rather than focusing solely on procedural fluency. Polya's model supports this shift by making the implicit cognitive processes of problem solving explicit to learners and by fostering self-regulated thinking. Such cognitive scaffolding aligns well with 21st-century skills, including adaptability, analytical reasoning, and reflective thinking (Lindström et al., 2025). By engaging students in thinking about how they solve problems, Polya's strategy helps them become more adaptable and reflective learners.

Despite the clear benefits demonstrated, some limitations of this study should be acknowledged. First, the research was conducted in a single school with a modest sample size (N = 45), which may limit the generalizability of the findings. The student population and school context in this study might not fully represent the diversity of educational settings elsewhere. Second, the study focused on short-term learning gains as measured by an immediate posttest. We did not track long-term retention of problem-solving skills or the transfer of these skills to unfamiliar problems. Nor did we measure changes in students' attitudes or motivation toward mathematics, areas that could be influenced by the use of a strategy like Polya's. These are important considerations for future research.

For future studies, a few avenues are recommended. Longitudinal research could examine whether the benefits of Polya's strategy are retained over time and whether students continue to apply the four-step method independently in subsequent learning. Incorporating mixed-methods approaches would also be valuable: qualitative data (such as classroom observations, student "think-aloud" problem-solving protocols, and teacher interviews or reflections) could complement test scores to provide deeper insight into how students internalize and use each step of Polya's framework. Such rich data could shed light on the learning processes behind the observed performance gains and help identify any challenges or misconceptions students encounter at each stage of the strategy.

In conclusion, the discussion underscores that Polya's structured four-step problem-solving strategy not only boosts immediate performance on mathematical word problems but also aligns with broader educational goals of nurturing critical thinking and metacognition. The strategy's success in this study adds to a growing body of evidence advocating for explicit teaching of problem-solving heuristics to young learners. Implementing such strategies more widely could be a key step in improving mathematics education outcomes in Indonesia and beyond.

CONCLUSION

This study concludes that implementing Polya's four-step problem-solving strategy significantly improves elementary students' comprehension of mathematical word problems. The quantitative results demonstrated a substantial increase in the experimental group's mean score (from 58.2 to 78.6) compared to a more modest gain in the control group (from 56.9 to 65.3). Statistical tests confirmed that these differences were not only educationally meaningful but also statistically significant, indicating that Polya's structured approach fosters deeper understanding and more effective cognitive engagement when tackling non-routine problems.

Furthermore, rubric-based analysis revealed that students in the experimental group exhibited stronger conceptual understanding, more logical strategy use, and higher computation accuracy on the posttest. These qualitative dimensions of performance suggest that the Polya strategy helped students not just arrive at correct answers, but also develop better problem interpretation and solution processes. Such findings reinforce the value of heuristic approaches that promote metacognitive thinking, particularly in educational contexts where traditional instruction may limit opportunities for strategic reasoning.

Based on the evidence, it is recommended that mathematics educators, especially at the upper-primary level, integrate Polya's problem-solving strategy into regular teaching practice. This model enhances students' mathematical achievement and also equips them with transferable problem-solving skills that are essential for future academic work and real-life challenges. By repeatedly guiding students through the stages of understanding, planning, executing, and reflecting, teachers can help build students' confidence and independence in solving complex problems.

Finally, while the present study provides encouraging results, further research should explore Polya's strategy across diverse mathematical domains (e.g., geometry, data analysis) and in different educational settings. Expanding the scope of investigation can validate the generality of the strategy's effectiveness and examine how it might be adapted or combined with other instructional approaches. Longitudinal studies could also assess the long-term impact on students' problem-solving abilities and their sustained use of the strategy over time. Through such continued inquiry, educators and researchers can better understand how to harness Polya's timeless problem-solving principles to enrich mathematics learning in varied contexts.

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