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Leveling Up Junior High School Students' Critical Thinking Skills: Mathematical Thinking Patterns through Polya's Theory

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ABSTRACT

This research is prompted by junior high school pupils' low mathematical critical thinking skills in tackling non-routine situations. Students generally struggle with solution formulation and planning, indicating poor systematic and logical thinking. This study examines Junior High School 1 Bulukumba students' mathematical critical thinking skills in solving mathematical problems using Polya's Theory's four steps: Understanding the Problem, Planning a Solution, Implementing the Plan, and Looking Back. Grade VIII pupils of Junior High School 1 Bulukumba are the participants of this qualitative descriptive study. The study collects data through problem-solving tests based on non-routine issues, observation, and in-depth interviews. The results of the study indicate that most research subjects have been able to carry out Stage 1 (Understanding the Problem) well. However, significant weaknesses were identified in Stage 2 (Planning a Solution), where students have not been able to formulate appropriate and coherent strategies, and Stage 4 (Looking Back), where students tend to ignore validation and rechecking answers. A mechanistic approach without reflection still dominates students' critical mathematical thinking. This research helps teachers and schools diagnose pupils' critical thinking skills. These findings can be utilized to construct learning interventions that improve strategic planning and self-evaluation (reflection) skills in problem-solving contexts to "level up" students' mathematical thinking according to Polya's Theory.

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1. INTRODUCTION

Mathematics education is essentially more than just the transfer of knowledge about numbers and formulas but rather a systematic effort to develop a framework for logical, critical, and analytical thinking (Boadu & Bonyah, 2024; Wang et al., 2025). In today's era of information disruption, mathematics plays a central role as a universal language that underpins the development of technology, science, and data-driven decision-making (Yazdi, 2024). Mathematics learning is no longer viewed as a static discipline but rather a dynamic process that equips individuals with systematic methods to solve various life challenges (Alam & Mohanty, 2023).

The primary goal of mathematics education in secondary schools, as outlined in international standards and the national curriculum, is the development of problem-solving skills (Piñeiro et al., 2022; Szabo et al., 2020). These skills encompass the integration of conceptual understanding, procedural procedures, and heuristic strategies. The evidence demonstrates that a student's success in learning mathematics is not measured by how many formulas they memorize, but rather by how deftly they use mathematical logic to find solutions to complex and non-routine situations (Ni et al., 2018; Xhang, 2022).

Theoretically, George Polya defines problem-solving as a conscious effort to find a way out of difficulties to achieve goals that are not immediately achievable (Arfiana & Wijaya, 2018; Widiana et al., 2018). In Polya's view, problem-solving is an intellectual skill at a higher level than simply performing arithmetic calculations. Students are considered capable of solving mathematical problems if they are able to pass through certain cognitive phases: understanding the intent of the problem, planning a solution, executing the plan with accurate calculations, and reflecting or double-checking the results (Pratikno & Retnowati, 2018; Royani & Agustina, 2019).

The complexity of problem-solving by categorizing it into three fundamental interpretations (Wu & Molnár, 2022; Zhang et al., 2022). First, as a primary goal, the primary focus of learning is the end result of students' thinking processes without being tied to any specific material. Second, problem-solving is viewed as a process that emphasizes the methods, strategies, and heuristic steps taken by students. Third, as a basic skill, this perspective views every individual as having mastered problem-solving logic, which is considered a fundamental modality for survival and adaptation in social life. Thus, mathematical problem-solving skills serve as a crucial benchmark for students' readiness to face real-world problems outside the classroom (Nilimaa, 2023; Ventistas et al., 2025).

Despite the universal recognition of the urgency of problem-solving, practical reality often exposes significant discrepancies or gaps. Based on initial observations and in-depth interviews with seventh-grade mathematics teachers at Junior High School 1 Bulukumba, a contradictory phenomenon was discovered. On the one hand, students demonstrated a fairly good ability to identify the "known" and "asked" aspects of a problem. They were able to initially abstract the information presented. However, on the other hand, a degradation of ability occurred when students were asked to advance to a higher level: developing strategies and using appropriate formulas. Students often became trapped in a "procedural gridlock." Many students were only able to solve problems if the question format was identical to the example provided by the teacher. Once the variables or narrative of the problem were slightly modified, they experienced confusion about which arithmetic operation should take precedence—addition, multiplication, or division. This example dependency indicates that their understanding was still instrumental, not relational. Furthermore, anomalies occurred in the verification stage. A small number of students intuitively double-check their answers, but the majority assume that completing a calculation means completing the task. They don't feel the need to validate whether the logic used is consistent with the initial premise of the problem.

This gap between curriculum expectations and reality at Junior High School 1 Bulukumba is reinforced by the research findings of Khoerunnisa and Imami (2020), Agustina and Imami (2022). The study revealed that in the Polya stages, students' abilities at the understanding stage were at a moderate level but declined drastically at the planning stage (low) and reached their lowest point at the reviewing stage, which fell into the very low category.

The innovation of this research lies in its in-depth analysis of the specific causes of student failure at each Polya stage within the geographic and sociocultural context of Bulukumba. Unlike previous research, which may only provide a quantitative snapshot, this study seeks to examine why seventh-grade students—who are transitioning from concrete thinking (elementary school) to abstract thinking (junior high school)—experience difficulties in the hierarchy of arithmetic operations and strategy selection. The study also explores the relationship between students' verification skills and their confidence in solving non-routine problems.

Early problem-solving instruction is a must and cannot be postponed (Likourezos & Kalyuga, 2017; Loibl et al., 2017). Polya's stages (understanding, planning, implementing, and reviewing) are not simply a sequence of steps but rather a powerful diagnostic tool for identifying students' cognitive weaknesses. By identifying which stages students most frequently make errors (error analysis), educators can implement more precise interventions. For example, if the problem lies in the "planning" stage, reinforcement should focus on mathematical representation and modeling, rather than repetitive calculation exercises. Seventh-grade students are at a crucial stage in their cognitive development. Failure to build a problem-solving foundation at this level will impact their mastery of higher-level mathematics, such as complex algebra and calculus. Therefore, a comprehensive study is needed to accurately document their current problem-solving ability profile.

This research focuses on exploring students' mathematical problem-solving abilities through the lens of Polya's theory. Junior High School 1 Bulukumba was chosen as the research location because of its position as a reference school expected to have high numeracy literacy standards, yet it still faces substantial challenges in this cognitive aspect. Specifically, this research will examine the profile of students' abilities in constructing understanding from problem stimuli (Understanding Stage), connecting prerequisite knowledge with new challenges (Planning Stage), technical accuracy and operational logic (Implementing Stage), and critical reflection on the resulting solutions (Reviewing Stage).

Overall, this research is not simply a replication of existing theory, but rather an attempt to provide data-driven solutions to real-world problems faced by students at Junior High School 1 Bulukumba. By understanding students' problem-solving abilities, it is hoped that teachers can design more innovative learning strategies that emphasize not only the end result but also value the thinking process as the core of mathematics education.

2. METHOD

This study employed descriptive design with a qualitative approach. This approach was chosen based on the research objective of in-depth exploration and description of students' cognitive processes and mental activities in solving mathematical problems based on Polya's framework. The focus of qualitative research here is not to generalize the results, but rather to provide a phenomenological understanding of the variations in problem-solving abilities that emerged among the research subjects in a specific context, namely Junior High School 1 Bulukumba.

The research was conducted at Junior High School 1 Bulukumba. The research subjects were selected using a purposive sampling technique, which involves selecting samples based on specific considerations or criteria to obtain information-rich cases.

The subject selection criteria were based on the results of the initial Mathematical Problem-Solving Ability Test (TKPMM) and the considerations of subject teachers. Of all seventh-grade students, three representative subjects were selected, representing different ability levels: one student with high ability, one student with medium ability, and one student with low ability.

In qualitative research, the primary instrument (human instrument) is the researcher themselves. Researchers acted as planners, data collectors, analysts, and reporters of the research results. To ensure objectivity and data depth, two supporting instruments were used that had undergone expert judgment validation:

- Mathematical Problem-Solving Ability Test (TKPMM): This instrument was a written, essay-style test consisting of two questions on Integers. The questions were structured by integrating Polya's indicators (understanding, planning, implementing, and rechecking).
- Interview Guidelines: An unstructured, in-depth interview format was used. This guideline served to elicit information not readily apparent on the written answer sheets, particularly regarding the reasons for strategy selection and any obstacles experienced by students.

Data was collected in two sequential stages to ensure depth of information:

- Written Test: Subjects were asked to complete the TKPMM individually using a simple think-aloud protocol, if possible, to observe the initial process flow.
- In-Depth Interviews: Conducted immediately after the written test to minimize recall bias. The interviews focused on tracing the Polya steps taken by students when solving problems.

The data obtained were analyzed using an interactive model developed by Miles et al. (2014). The analysis was conducted cyclically through three main stages:

- Data Condensation: The process of selecting, simplifying, and transforming raw data from student work and interview transcripts. Researchers removed irrelevant information and categorized data based on Polya's stages.

- Data Display: Organizing the condensed data into descriptive narratives, comparison tables, or flowcharts to facilitate mapping of student ability patterns.
- Conclusion Drawing/Verification: Searching for meaning in the presented data, noting patterns, and verifying them until a solid conclusion was reached regarding the subject's problem-solving ability profile.

To ensure the credibility and validity of the findings, this study employed method triangulation techniques. Researchers carefully compared data obtained from written tests with interview data. If there was consistency between what students wrote and what they expressed verbally, the data was deemed valid. On the other hand, if there is a discrepancy, further investigation is carried out until saturated and convincing data is obtained.

3. RESULTS AND DISCUSSION

Results

The results of the mathematical problem-solving ability exam for seventh-grade students at Junior High School 1 Bulukumba revealed 2 students with high abilities, 3 students with medium skills, and 27 students with low abilities. Additionally, based on the qualification results, three students were chosen as research participants, each representing the high, medium, and low categories. The subsequent subject coding is derived from the students' initials as presented in Table 1.

Table 1. Coding of Research Subjects

No	Category Type	Subject Code
1	High	AAR
2	Medium	AS
3	Low	MA

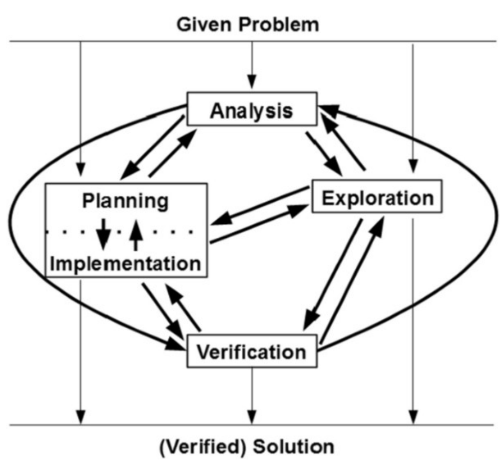

Figure 1. Polya's Framework

The following is a presentation of the test and interview results for subjects in the high, medium and low categories:

Mathematical Problem Solving Ability High Category Subject AAR

The answer provided by the AAR subject to question number 1 was accurate and satisfies the three indicators of mathematical problem-solving ability according to Polya's stages, which are understanding the problem, implementing a solution plan, and re-checking, as indicated by the written test and interview results previously described. In contrast, the AAR subject was able to meet all of the indicators of mathematical problem-solving on question number 2, including understanding the problem, devising a solution plan, implementing the solution plan, and re-checking.

In question number 1, the AAR subject on the mathematical problem-solving indicators according to Polya's stages were: (1) the stage of understanding the problem well because he was able to write down what was known and asked in the problem and explain it in his own words, (2) the stage of developing a solution plan, AAR did not write down the formula or steps to be used, but during the interview AAR was able to state the formula to be used in solving the problem. (3) the stage of implementing the solution plan, AAR immediately worked on the problem correctly, (4) the stage of re-checking, the AAR subject was able to write down the conclusions obtained to summarize what was asked from the problem and re-check by looking at the problem from the known to the solution obtained.

(P): "Let's look at question number 1. Can you explain what the question asks?"
(S): "Yes, Sis. In this question, we are asked to find the temperature difference between the top of the mountain and the bottom. The temperature at the bottom is 28°C and at the top it is 5°C." (Understanding the Problem)
P: "So, how do you plan to find the difference? On your answer sheet, you calculate directly without writing a formula."
S: "Yes, Sis. I immediately remembered that the difference means the larger number minus the smaller number. So, the formula is Bottom Temperature minus Peak Temperature." (Planning a Solution)
P: "How do you calculate it?"
S: "That means 28 - (-5). Since minus and minus add up, so 28 + 5 = 33°C." (Executing the Plan)
P: "Are you sure the result is 33? Have you checked it again?"
S: "Sure, Sis. I've checked the calculations twice. The distance from -5 to zero is 5, and from zero to 28 is 28. So the total distance is 33." (Reviewing)

In question number 2, the AAR subject was able to fulfill all the indicators of mathematical problem solving according to Polya's stages, namely: (1) at the stage of understanding the problem, the AAR subject was able to write and state all the information contained in the question, both known and asked, clearly. (2) at the stage of formulating a plan, the AAR subject was able to determine the formula to be used in solving the problem by writing it on the answer sheet and was able to state it verbally. (3) at the stage of implementing the solution plan, the AAR subject was also able to carry out the plan according to the strategy that had been prepared by entering what was known into the predetermined formula to obtain the answer. This was reinforced during the interview, the AAR subject was able to explain the steps used to obtain the correct final result. (4) at the stage of re-checking, the AAR subject was able to write a conclusion from what was asked and re-check it by looking at and re-reading the question and matching it to the answer sheet.

P: "For question number 2, what information did you obtain?"
S: "There's a score for the math test. A correct answer gets 4, an incorrect answer gets -2, and an unanswered answer gets -1. So, the student answered 35 questions correctly and 5 questions incorrectly out of a total of 50." (Understanding the Problem)
P: "What's the first step you take to find the total score?"
S: "I'll first find the number of incorrect questions, Sis. Since there are 50 questions in total, and 35 were answered correctly and 5 were unanswered, that means the incorrect answers are 50 - (35 + 5) = 10 questions. Only then will I plug them into the total score formula." (Planning a Solution)
P: "Can you explain how you worked on this answer sheet?"
S: "Yes. It's (35 x 4) + (10 x -2) + (5 x -1). The result is 140 - 20 - 5. So the final total score is 115." (Executing the Plan)
P: "Have you double-checked these results?"
S: "Yes, Sis. I reread the questions to see if I missed anything, then I recalculated the multiplication and addition on the scratch paper. The results were still the same, so I wrote the conclusion below." (Reviewing)

Based on the interview results above, the problem-solving ability profile of AAR subjects can be summarized in Table 2 below.

Table 2. Problem-solving Ability Profile of AAR Subjects

Polya's Stages	AAR Subject Competency Description
Understanding the Problem	Very good; able to retell the main points of a problem in one's own words without relying on the text.
Planning a Solution	Strategic; able to connect existing information into a logical mathematical model.
Implementing the Plan	Accurate; possesses strong integer computational skills (understanding negative operations).
Reviewing	Critical; performs verification not only by recalculation but also by alternative logic.

Students with high ability (AAR) tend to rely more on memorizing formulas than just formulas, but also possess strong mathematical intuition. A key characteristic of this student is their ability to review, a skill often overlooked by students in other categories. AAR ensures that their solutions align with the context of the original problem, minimizing careless errors.

Mathematical Problem Solving Ability Subject Category Medium AS

Building upon the written test and interview results obtained during the study, subject AS met three indicators of mathematical problem-solving ability according to Polya's stages in questions 1 and 2: understanding the problem, implementing a solution plan, and reviewing.

In question 1, subject AS's mathematical problem-solving indicators according to Polya's stages were: (1) understanding the problem. AS could only write down some known information and was able to write down the questioned elements correctly, but during the interview, AS was able to cite all the information in the problem. (2) developing a solution plan. AS did not write down a formula or solution plan on his answer sheet but instead directly implemented the solution plan by working the problem accurately and correctly. During the interview, AS also did not mention the formula to be used; he directly explained the steps used to solve the problem. (3) checking the problem. AS was able to write down the final conclusion and review the solution results written on his answer sheet.

Table 3. AS Subject Problem Solving Interview Results (Question Number 1)

Polya's Stages	Interview Dialogue	Researcher Analysis
Understanding the Problem	*P: "Can you explain what is known from question number 1?" AS: "Yes, Sis. Here, there is (mentioning all the data), and the question is (mentioning the question)."*	AS can verbally state all information, even if the information on paper is incomplete.
Planning and implementing	*P: "There's no formula in your answer, how did you do it?" AS: "I'll just calculate it, Sis. So, first, I multiply the data by this, then divide the result..."*	AS does not use formal formulas in writing or verbally but understands the logical steps of the process.
Reviewing	*P: "Are you sure about this answer? How did you confirm it?" AS: "I'm sure, Sis. I've double-checked the calculations from above and made the conclusion below."*	AS verifies the results and writes the conclusion correctly.

In question 2, subject AS's mathematical problem-solving indicators according to Polya's stages were: (1) understanding the problem. AS wrote down known information but did not write down the question asked in the problem. However, during the interview, AS was able to state the information known and asked for clearly and correctly. (2) In the planning implementation stage, AS immediately carried out the plan without first writing down the formula or steps used, and in solving the problem, AS obtained the correct answer. Although during the interview, AS said he had difficulty solving the problem. (3) In the final stage, namely the re-examination stage, AS re-examined the answer obtained by reviewing the answer from the known answer to the solution and writing down the conclusion.

Table 4. AS Subject Problem Solving Interview Results (Question Number 2)

Polya's Stages	Interview Dialogue	Researcher Analysis
Understanding the Problem	*P: "For number 2, what exactly is this question asking?" AS: "Oh, this question asks us to find (state the question) based on the available data (state the information), sis."*	AS verbally understood the aspects of the questions, although he didn't write them down on the answer sheet.

Polya's Stages	Interview Dialogue	Researcher Analysis
Planning and implementing	*P: "It seems like you just started calculating without any prior planning, huh?"* *AS: "Yes, sis. I was a bit confused earlier, but I just followed the steps I knew until I got the result."*	Despite the difficulties, AS was still able to implement the plan until the final answer was correct.
Reviewing	*P: "How do you know if this answer is correct?"* *AS: "I calculated backwards, sis. I double-checked what I knew and went back to the solution steps, and then I wrote down the conclusion."*	AS rechecked using the method of backtracking from known data.

Mathematical Problem Solving Ability of Low Category Subject MA

Building upon the written test and interview results obtained during the study, in question number 1, subject MA met two indicators of mathematical problem solving according to Polya's stages: implementing the solution plan and reviewing. However, in question number 2, subject MA was only able to meet one indicator of mathematical problem solving according to Polya's stages: implementing the solution plan.

In question number 1, subject MA's mathematical problem solving indicators according to Polya's stages were: (1) understanding the problem; MA did not write the known and asked elements on the answer sheet, but during the interview, the subject was able to cite the information contained in the problem completely and correctly. (2) developing the solution plan; MA did not write the formula to be used in solving the problem, but instead immediately implemented the plan by working on the problem, obtaining the correct answer, and writing down the conclusions drawn after working on the problem.

Table 5. MA Subject Problem Solving Interview Results (Question Number 1)

Polya's Stages	Interview Dialogue	Researcher Analysis
Understanding the Problem	*P: "There's no known information on the answer sheet. Do you understand the question?"* *MA: "I understand, Sis. So, the story is, (states the question information), and what you're looking for is (states the question)."*	Complied (Verbal): The subject was able to grasp the information completely, despite being lazy or forgetting to write it down.
Planning and implementing	*P: "You just calculated it without writing the formula first, right?"* *MA: "Yes, Sis, I just did it. The method is this, add this, then multiply..."*	Complied: The subject immediately executed the plan without formulaic formalities, but the steps were correct.
Reviewing	*P: "How are you sure the result is correct?"* *MA: "I read the answer again, then I wrote the conclusion down here, Sis."*	Complied: The subject wrote down the conclusion as a form of review.

In question number 2, subject MA's mathematical problem solving indicators according to Polya's stages were: (1) understanding the problem; MA did not write down all the information contained in the problem. During the interview, MA admitted that he did not understand the meaning of the problem because it was too complicated. (2) At the stage of developing a solution plan, MA was unable to plan and write the formula that would be used to answer the problem. (3) At the stage of implementing the solution plan, MA only wrote a small part of the solution and obtained an inaccurate answer because he did not understand the problem from the beginning, MA also did not write a final conclusion of the problem.

Table 6. MA Subject Problem Solving Interview Results (Question Number 2)

Polya's Stages	Interview Dialogue	Researcher Analysis
Understanding the Problem	*Q: "For number 2, what information did you get from the question?" MA: "Honestly, I'm confused, Sis. The question is too complicated; I don't really understand what the question means."*	Not Met: The subject's main obstacle was an inability to understand the meaning of the complex questions.
Planning and implementing	*Q: "Why are there only a few answers and not all the way through?" MA: "Because I don't know what formula to use. I tried to do my best, but I know it's probably wrong."*	Not Met: Without a clear plan, the execution of answers was partial and inaccurate.
Reviewing	*Q: "Did you double-check the final result?" MA: "No, Sis. I didn't write a conclusion either because I wasn't sure about the result."*	Not Met: The subject skipped the examination stage because they felt they had failed early on.

Discussion

The results of the study showed significant differences in the mathematical problem-solving abilities of seventh-grade students at Junior High School 1 Bulukumba, categorized as high, medium, and low. The analysis was conducted using the four Polya stages: understanding the problem, planning a solution, implementing the plan, and checking back.

Analysis of High-Ability Subjects (AAR)

Subjects with high ability demonstrated near-perfect mastery of the Polya stages. AAR enabled a deep understanding of the problem, as evidenced by their ability to write and explain the known and questioned elements in their own words. Although in question 1, the subjects did not explicitly write a solution plan on paper, interview results confirmed that the subjects had a clear mental plan and were able to verbally state the formula.

AAR's success in implementing the plan and checking back (verification) demonstrated good accuracy. This aligns with the findings of Saputri and Mampouw (2018) that high-ability students sometimes skip the formal writing of the plan to save time, while still maintaining a sound understanding of the strategy.

Analysis of Medium-Ability Subjects (AS)

Students with moderate ability demonstrated fairly stable performance but lacked formal writing skills. AS was able to understand the problem, but tended not to write down all the information completely on the answer sheet, even though they understood it during the interview.

Subject AS's main obstacle lay in the planning stage. They tended to jump straight into calculations without first writing down formulas or strategic steps. AS also acknowledged difficulty explaining their work process, even though the final result was correct. This aligns with research by Rahayu and Aini (2021), which stated that subjects with moderate ability were able to understand the problem but were less consistent in documenting their solution plans.

Overall, these differences in ability categories reflect the extent to which students were able to integrate each stage of the Polya. High-Ability students were able to overcome technical obstacles, moderate students were able to solve problems but were weak in planning structures, while low-Ability students required intensive guidance, especially in understanding basic concepts and problem-solving strategies.

Analysis of Low-Ability Subjects (MA)

Subjects with low ability experienced significant difficulties in almost all stages of the Polya, especially on more complex problems (question number 2). MA did not write down the known and questioned elements and admitted to having difficulty understanding the meaning of the questions, which she considered too complex.

The most significant weakness was her inability to accurately plan and implement solutions. MA only worked through a small portion of the solution procedure and produced incorrect answers due to a lack of understanding at the initial stage. This finding supports research by Haryati and Warmi (2019) that found that low-ability students often fail due to their inability to design solution strategies and fail to double-check their work.

This study strengthens the relevance of Polya's problem-solving stage theory in analyzing the cognitive abilities of seventh-grade students in integer material (Loibl et al., 2017; Pradana, 2024). It contributes by mapping the specific characteristics of the obstacles experienced by students at each ability level (high, medium, and low). This enriches the literature on the psychology of mathematics education, especially regarding how differences in initial abilities influence problem-solving strategies. For mathematics teachers, it can serve as evaluation material and reference in developing more differentiated learning strategies. Teachers can adjust the treatment for low-category students who are proven to have difficulty in the initial stage (understanding the problem) compared to high-category students who need more reinforcement at the rechecking stage. For students, it can provide an overview to students about the importance of a systematic thought process (not directly to the answer), so that they are aware of the importance of the planning and rechecking stages in solving mathematics problems. In addition, the results of this study can be the basis for making academic policies, such as providing enrichment programs for high-category students and remedial programs or special mentoring for low-category students to improve the quality of graduation.

4. CONCLUSION

The findings of this study indicate that high-ability subjects are able to complete all Polya stages very well. Subjects are able to understand the problem, develop a plan, carry out calculations accurately, and double-check the final results. Medium Ability Subjects: Able to understand the problem and implement a solution plan, but tend to be less consistent in formally writing down the planning steps. These subjects seldom systematically double-check their answers. Meanwhile, low-ability subjects experienced difficulties in almost all Polya stages. Subjects had difficulty understanding the meaning of complex problems, were unable to develop a solution strategy, and often produced inaccurate answers due to a lack of understanding at the initial stage. In general, the majority of students remained in the low problem-solving ability category, with the main obstacles lying in the inability to transform information from word problems into mathematical models (planning) and a lack of habitual review of their work.

As a recommendation, teachers are expected to further familiarize students with solving problems based on Polya stages sequentially, rather than solely focusing on the final result. This research is limited to integers. Further researchers are advised to conduct research on different materials or by using certain learning models (such as problem-based learning) to see whether there is an increase in students' problem-solving abilities in the low and medium categories.

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