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Mathematical Problem-Solving Abilities in Algebraic Operations through Realistic Mathematics Education (RME)

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Abstract

This study aims to describe the mathematical problem-solving abilities of seventh-grade students in algebraic operations through the RME approach, focusing on two aspects, how the characteristics of RME support or constrain students' problem-solving processes, and students' problem-solving performance based on three of Polyas' stages. Problem-solving abilities were analyzed using three of Polya's stages, understanding the problem, devising a plan, and implementing the plan. The looking-back stage was excluded as this study focuses on processes explicitly documented in students' written responses. This study employed a descriptive qualitative approach with 11 seventh-grade students as research subjects. Data were collected through written tests and interviews. The results of the study show that the indicator implementing a plan was the most frequently mentioned in students' responses. The indicator understanding the problem and formulating a plan remained relatively low, most students did not fully list the given and asked information, nor did they explicitly state their problem-solving strategies. The use of real-world contexts in RME helps students understand problem situations, but it has not yet fully encouraged structured planning. These findings indicate the need to strengthen the early stages of problem-solving in RME instruction so that students can solve problems more systematically.

Keywords: problem-solving ability, algebraic operations, realistic mathematics education

INTRODUCTION

Mathematics is a fundamental subject in curricula worldwide, including Indonesia, that plays a crucial role not only as an academic discipline but also as a foundation for developing students' logical, analytical, critical, and creative thinking skills (Palinussa et al., 2021; Widyaningtyas et al., 2024; Sari et al., 2025). Among the various competencies targeted in mathematics education, problem-solving is considered one of the most essential, as it encompasses the ability to understand, organize, implement, and evaluate solutions to mathematical problems (Putri et al., 2022; Wulandari et al., 2020).

Despite its importance, Indonesian students' problem-solving abilities remain concerning. Data from the Programme for International Student Assessment (PISA) showed that Indonesia's mathematics literacy score declined from 379 in 2018 to 366 in 2022 (A. D. Putri et al., 2024). Mathematical literacy and problem-solving ability are closely related, as both require students to apply mathematical reasoning to interpret and solve real-world problems. A low literacy score therefore reflects weaknesses in students' broader problem-solving capacities. This decline can be attributed to several factors, including teacher-centered instruction that overemphasizes formula memorization rather than conceptual understanding (Yuanita et al., 2018), and an assessment system that fails to measure higher-order thinking skills in non-routine problem contexts (Palinussa et al., 2021).

Conventional learning approaches are widely regarded as ineffective in developing problem-solving abilities, as they tend to focus on routine procedures and offer limited opportunities for students to apply mathematical concepts in meaningful contexts (Tong et al., 2022). One alternative approach that has gained attention is Realistic Mathematics Education (RME), a pedagogy originating in the Netherlands in the late 1960, grounded in Hans Freudenthal's philosophy that mathematics should be a human activity and that knowledge is built through direct experience, discovery, and social interaction (Muhammad et al., 2025; Bayrak & Aslanci, 2022; Payadnya et al., 2023). RME situates learning within real or concrete contexts, motivating students to engage in the mathematization process-transforming contextual situations into formal mathematical concepts (Andzin et al., 2024; Sutarni et al., 2024).

A number of previous studies have reported positive effects of RME on students' mathematical abilities. RME has been shown to improve mathematical reasoning, critical thinking, communication, and literacy skills (Palinussa et al., 2021; Fauzan et al., 2024; Sari et al., 2025), and to increase student motivation through active involvement in the learning process (Yapatang & Polyiem, 2022). However, these findings are not without limitations. Several studies note that the effectiveness of RME is highly dependent on the relevance and clarity of the contextual problems used, the teacher's ability to facilitate the mathematization process, and students' familiarity with the real-world contexts presented (Suparatulatorn et al., 2023; Tong et al., 2022). Furthermore, most existing studies focus on measuring outcomes such as test scores or overall ability levels, with limited attention to the specific processes students undergo during problem-solving within RME-based learning.

One well-established framework for analyzing problem-solving processes is Polya's model, which consists of four stages: understanding the problem, devising a plan, implementing the plan, and looking back (Simatupang et al., 2019; Sinaga et al., 2023). The connection between RME and Polya's framework is conceptually significant: the contextual problems characteristic of RME naturally support the first stage of Polya's model by providing students with familiar situations to understand and interpret. The mathematization process in RME, where students move from situational to formal representations, aligns with the planning and implementation stages of Polya's framework. Despite this conceptual alignment, few studies have examined how RME-based instruction specifically supports or constrains students' performance at each stage of Polya's problem-solving process.

This study therefore aims to describe seventh-grade students' mathematical problem-solving abilities in algebraic operations through the RME approach, focusing on two aspects: (1) how the characteristics of RME support or constrain students' problem-solving processes, and (2) students' problem-solving performance based on three of Polya's stages, understanding the problem, devising a plan, and implementing the plan. By examining students' written responses and interview data at the level of individual problem-solving indicators, this study contributes a more detailed and process-oriented perspective on how students engage with problem-solving within RME-based instruction, an aspect that remains underexplored in the existing literature.

METHODS

This research employed a descriptive qualitative approach, aiming to describe and analyze seventh-grade students' mathematical problem-solving abilities in algebraic operations through the Realistic Mathematics Education (RME) approach. The focus of this study is students' problem-solving processes as observed through three of Polya's stages: understanding the problem, devising a plan, and implementing the plan. The looking-back stage was not included in this study, as this stage requires students to reflect on and verify their completed solutions, which is difficult to observe through written responses alone and is more appropriately examined through longitudinal or observational studies (Simatupang et al., 2019; Sinaga et al., 2023). Although written tests and a scoring rubric were employed as data collection instruments, these were used solely as tools to classify students' problem-solving abilities and to facilitate the selection of interview subjects, not to measure outcomes in a quantitative sense.

This research was conducted in class VII-A of SMP Plus Al-Fatimah, Bojonegoro, on May 1, 2025, with algebraic operations as the topic. The population of this study was all students in class VII-A, consisting of 11 students. Participants were selected using purposive sampling, based on recommendations from the mathematics teacher regarding students' mathematics performance. This technique was chosen because the study required participants who could represent different levels of problem-solving ability, good, adequate, and poor in order to provide a comprehensive picture of students' problem-solving processes within RME-based learning.

Data were collected through two instruments: a written test and an interview. The written test consisted of three contextual essay problems designed in accordance with the RME approach, covering algebraic addition and subtraction. Each problem was structured to address four levels of emergent modeling: situational, referential, general, and formal. Students' responses were scored using a problem-solving assessment rubric adapted from Polya's problem-solving framework, as presented in Table 1. The rubric was developed based on indicators of problem-solving ability commonly used in mathematics education research (Simatupang et al., 2019; Sinaga et al., 2023).

Table 1. Problem-Solving Ability of the Scoring Criteria

Score	Understand the problem	Devising a plan	Implementing the plan
0	Not writing anything	There's no strategy	There's no solution
1	Unclear information	Incorrect strategy	The solution is almost incorrect
2	Just writing a little information	Less precise strategy	Procedural errors
3	Writing most of the information	The strategy is correct but lacks detail	There is a slight error in the calculation
4	Write down all known and requested information accurately	Clear and context-appropriate strategy	All steps are correct and systematic

Based on the total scores obtained from the written test, students were categorized into three performance levels: good (total score 7-12), adequate (total score 3-6), and poor (total score 0-2). Following the written test, three students one from each performance category, were selected for semi-structured interviews to explore their problem-solving processes in greater depth.

Data analysis was conducted following the qualitative data analysis procedures proposed by Zakaria et al. (2023), consisting of three stages: data reduction, data presentation, and drawing conclusions. In the data reduction stage, students' written responses were examined and scored based on the rubric, and interview transcripts were reviewed to identify relevant patterns. In the data presentation stage, findings were organized according to each problem-solving indicator and performance category. Finally, conclusions were drawn by synthesizing the written test results and interview data to produce a comprehensive description of students' problem-solving abilities within the RME-based learning context.

RESULTS AND DISCUSSION

In this research, data were collected through research instruments in the form of three contextual problems designed in accordance with the RME approach. The first problem addressed algebraic addition and the second addressed algebraic subtraction, both structured across four levels of emergent modeling: situational, referential, general, and formal. The third problem was used to assess students' problem-solving abilities based on three of Polya's stages: understanding the problem, devising a plan, and implementing the plan.

RME Characteristics in Algebraic Operations Learning

Problem 1: Algebraic Addition

The first problem was presented in the context of Ms. Diana and her family who regularly purchase bakpia, requiring students to determine the total amount of bakpia purchased over two weeks. At the situational level (Figure 1), students were introduced to the contextual problem. The use of a familiar daily-life context helped students identify the relevant information in the problem, supporting the initial stage of problem-solving, namely understanding the problem. However, several students showed difficulty in distinguishing which information was relevant, suggesting that familiarity with the context alone does not guarantee complete comprehension.

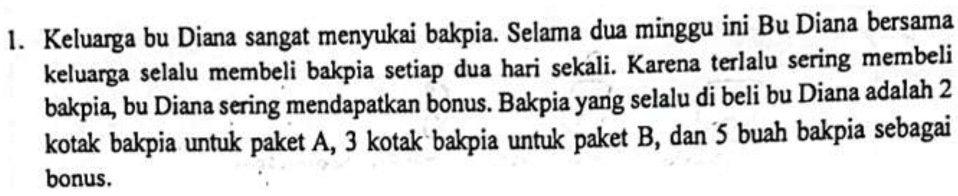

1. Keluarga bu Diana sangat menyukai bakpia. Selama dua minggu ini Bu Diana bersama keluarga selalu membeli bakpia setiap dua hari sekali. Karena terlalu sering membeli bakpia, bu Diana sering mendapatkan bonus. Bakpia yang selalu di beli bu Diana adalah 2 kotak bakpia untuk paket A, 3 kotak bakpia untuk paket B, dan 5 buah bakpia sebagai bonus.

Figure 1. Situational level in Problem 1

At the referential level (Figure 2), students were asked to represent or describe the bakpia purchased by Ms. Diana using drawings or diagrams. This stage encouraged students to begin organizing information visually, which corresponds to the early stages of devising a plan in Polya's framework. However, many students produced incomplete representations, indicating that the transition from contextual understanding to mathematical representation still posed a challenge..

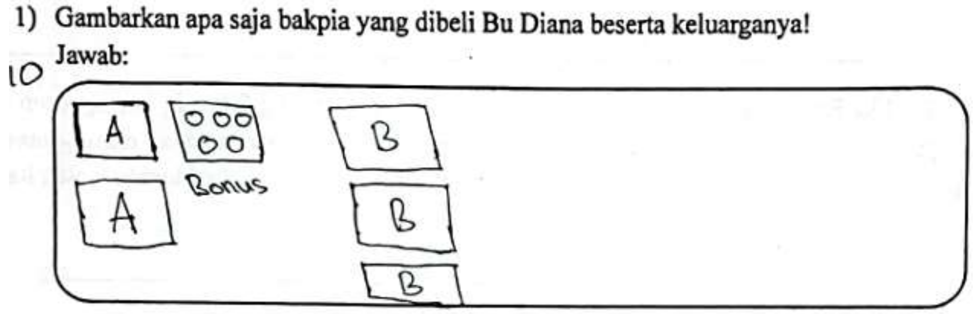


Figure 2. Referential level in Problem 1

At the general level (Figure 3), students were guided to apply logical reasoning to determine how much bakpia Ms. Diana would have over two weeks, recognizing that purchases were made every two days rather than daily. This stage supported students in developing a more structured plan. Nevertheless, students who had not fully understood the context at the situational level struggled to apply correct reasoning at this stage.

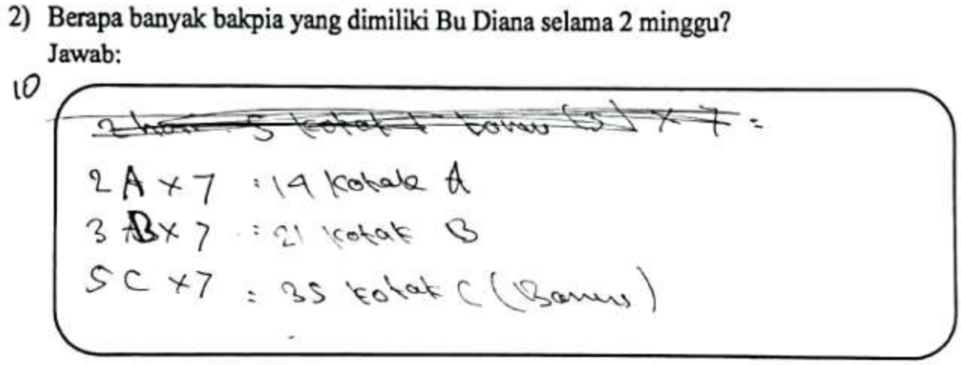


Figure 3. General level in Problem 1

At the formal level (Figure 4), students were required to express the problem using algebraic symbols, with "A", "B", and "C" representing different types of bakpia. This stage corresponds to the implementing the plan stage in Polya's framework. Students who had successfully navigated the previous levels were able to construct correct algebraic expressions, while those who had struggled at earlier levels produced incomplete or incorrect formal representations.

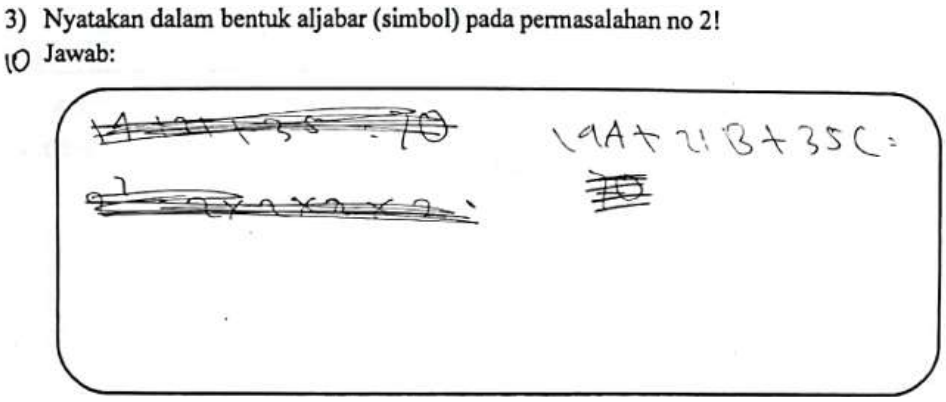


Figure 4. Formal level in Problem 1

Problem 2: Algebraic Subtraction

The second problem was presented in the context of Eid al-Fitr hampers to be distributed in different packaging types. At the situational level (Figure 5), students were given information about hampers packaged in boxes, cloth bags, and without packaging, and were required to apply mathematical reasoning to determine how much syrup to purchase. The contextual nature of the problem helped students engage with the situation, though some students found it difficult to identify the mathematical structure underlying the context..

2. Rania telah membeli sirup sebagai hampers lebaran untuk keluarganya. Sirup tersebut dikemas dalam 1 kotak, 2 tas kain, dan 3 sirup tanpa kemasan. Ayah dan ibu Rania akan mendapatkan kotak sirup, keempat om dan tante Rania akan mendapatkan sirup yang dikemas dalam tas kain, sedangkan kelima sepupu Rania akan menerima sirup tanpa kemasan.

Figure 5. Situational level in Problem 2

At the referential level (Figure 6), students represented the hampers that Rania would distribute. As with Problem 1, this stage required students to translate contextual information into a visual or symbolic representation, a process that several students found challenging.

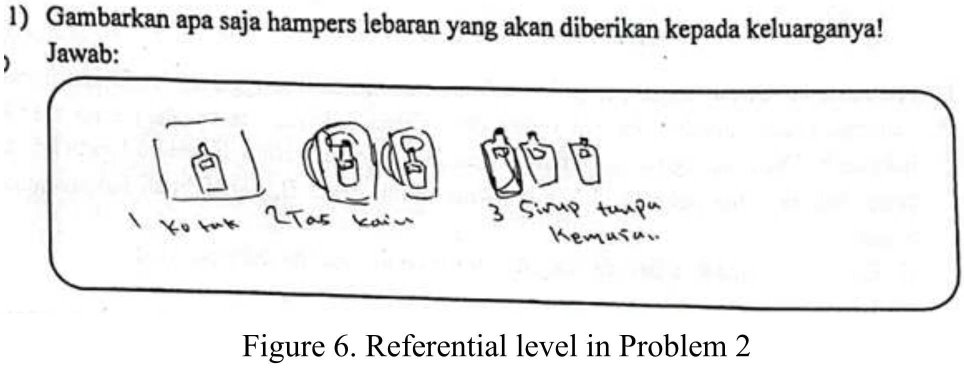


Figure 6. Referential level in Problem 2

At the general level (Figure 7), students determined the quantities of each packaging type to be repurchased, demonstrating an ability to apply general reasoning within the given context.

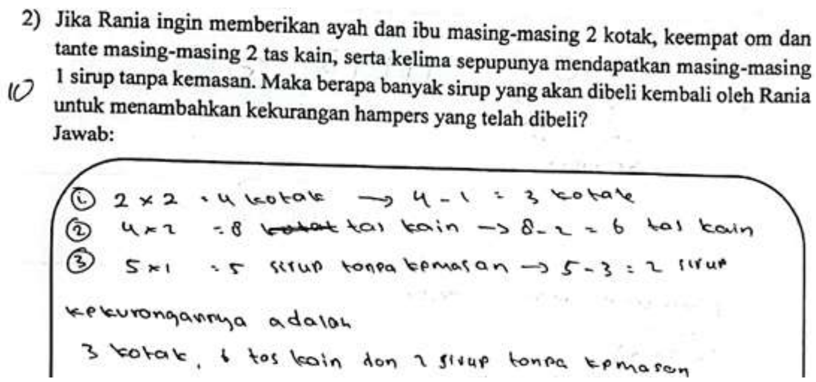


Figure 7. General level in Problem 2

At the formal level (Figure 8), students used algebraic symbols — "a" for box packaging, "b" for cloth bag packaging, and "c" for no packaging — to construct a mathematical model and perform algebraic subtraction.

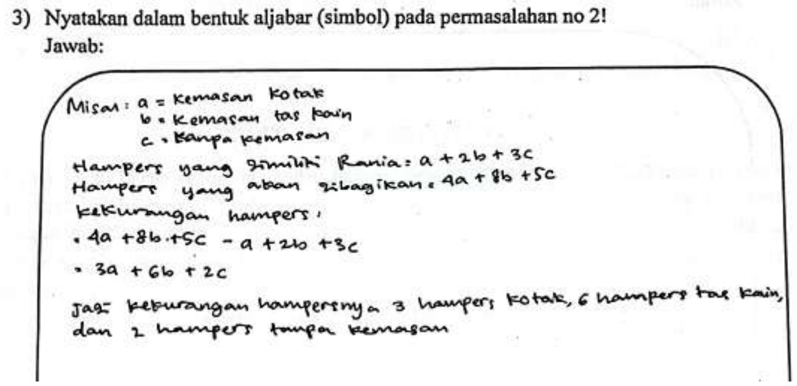
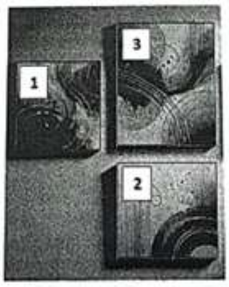


Figure 8. Formal level in Problem 2

Overall, the four levels of emergent modeling in Problems 1 and 2 demonstrate that the contextual characteristics of RME effectively supported students in engaging with the problem situations. However, the effectiveness of RME in supporting structured planning and formal representation varied considerably across students, suggesting that contextual familiarity alone is insufficient to ensure systematic problem-solving.

Problem Solving by Students in Completing Algebraic Operations in RME Learning

Based on the test results, seventh-grade students at a junior high school in Bojonegoro were categorized into three problem-solving ability categories: students with good problem-solving abilities, students with adequate problem-solving abilities, and students with poor problem-solving abilities. The students' problem-solving problems are displayed in Figure 9.


3. Terdapat tiga lukisan persegi yang memliliki ukuran berbeda seperti ditunjukkan dibawah ini!

Lukisan pertama berukuran 10 cm lebih kecil dari lukisan kedua dan lukisan ketiga berukuran 1,5 kali lebih besar dari lukisan kedua. Selisih keliling lukisan ketiga dan pertama adalah 50 cm. Berapa ukuran sisi lukisan kedua?

Figure 9. Problem-Solving Ability Test

Figure 9 shows a problem-solving question given to students. The question contains several square-shaped drawings of various sizes. Using the above information and algebraic processes, students are expected to calculate the length of the painting's second side.

Of the 11 students who took the problem-solving test, four students had good problem-solving skills, one student had adequate problem-solving skills, and six students had poor problem-solving skills. In the good category, one of them was LZL (Score: 7), in the adequate category one of them was ZA (Score: 3), and in the poor category, one of them was AMA (Score: 0). Figure 10 displays the outcomes of the students' responses in the good category.

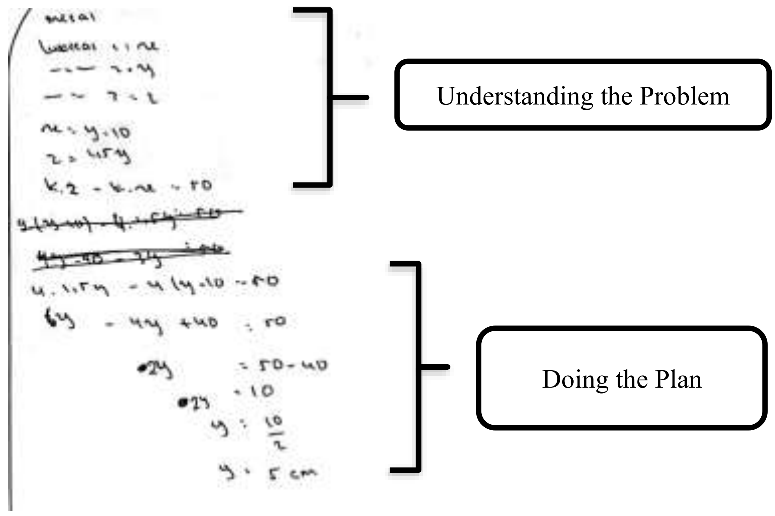


Figure 10. The Result Answer LZL Category are Good

Below are the interview test results:

P : "When you first read question number 3, did you understand the meaning of the question?"

LZL : "I understand the meaning of the question well enough"

P : "In your answer, you did not write what was asked in the question. Is there a specific reason for this?"

LZL : "I feel that I understand the question. Therefore, I will proceed to answer it directly. I believe there is no need to rewrite the question."

P : "Then, did you make a plan on how to solve the problem before you started working on it?"

LZL : "Sure, I think about the steps first before doing it."

P : "However, that plan is not visible on your answer sheet. Did you not write it down?"

LZL : "Yes, I didn't write it down. I thought the important thing was to get the answer right, so I just went ahead and did it."

Based on the written test results and interview, the following is an analysis of LZL's problem-solving abilities per Polya's indicator:

Understanding the Problem (Score: 3): LZL demonstrated sufficient verbal understanding of the problem but did not write down the known and asked information in the answer sheet. LZL felt that mentally understanding the problem was sufficient without needing to document it in writing. This resulted in LZL not receiving a perfect score for this indicator.

Devising a Plan (Score: 0): LZL acknowledged that he had mentally planned the solution steps beforehand but chose not to write them down, prioritizing getting the correct answer over documenting the process. As a result, LZL received no score for the devising a plan indicator.

Implementing the Plan (Score: 4): Despite not documenting the understanding and planning stages, LZL was able to solve the problem correctly and systematically. All solution steps were accurate, and LZL received a perfect score for this indicator.

Then, for students in the adequate category, only one problem-solving indicator appeared in their solutions. The answers of students in the adequate category can be seen in Figure 11.

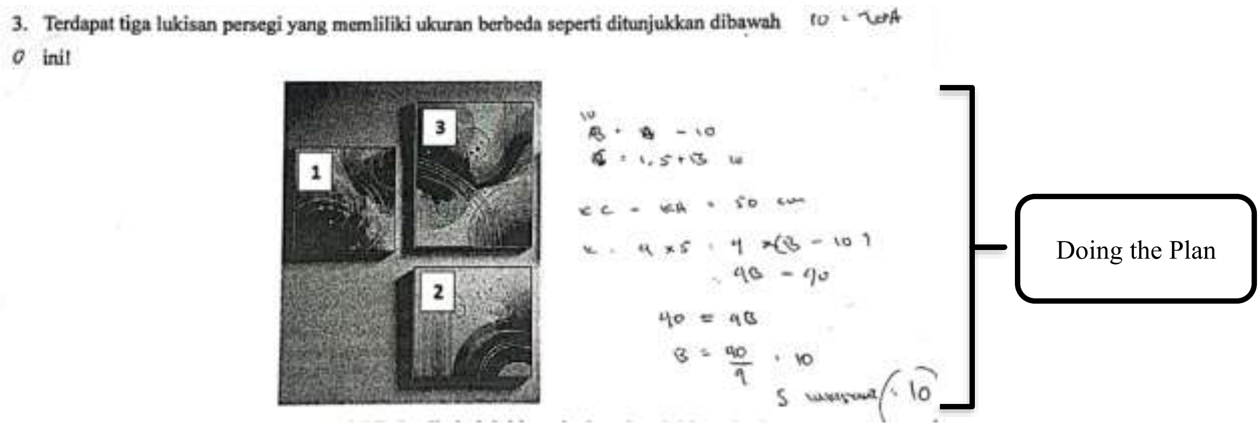


Figure 11. The Result Answer ZA Category is Fair

Below are the interview test results:

P : "When you first read question number 3, what did you understand from the question?"

ZA : "I see three paintings of different sizes, and the question asks me to find the length of the side of painting 2."

P : "In your answer, you did not write down the information you knew. Why didn't you write it down?"

ZA : "Because I think that information that is already known does not need to be written down."

P : "Okay. As for the steps to resolve the issue, did you have time to make a plan first?"

ZA : "Yes, I outlined the steps to solve it, but I didn't write them in my answer."

P : "In your answer, it appears that you tried to solve the problem, but there is an error in your solution. In your answer, you wrote $B = A - 10$ and $C = 1{,}5B$. What do A, B, and C mean in your answer?"

ZA : "In my previous answer, I made a mistake in writing that. It should be $A = B - 10$, not $B = A - 10$, because I don't have the x type, so I just bolded it. As for the meaning of A, B, and C themselves, A is the first painting, B is the second painting, and C is the third painting."

P : "Okay, so you wrote down $K_C - K_A = 50\ cm$, but why did you only find the side of the second painting using the perimeter of the first painting?"

ZA : "Yes, I made a mistake because I was in a hurry while doing it."

Based on the written test results and interview, the following is an analysis of ZA's problem-solving abilities per Polya's indicator:

Understanding the Problem (Score: 0): ZA was able to verbally identify what was being asked in the problem, but did not write down the known or asked information in the answer sheet. ZA believed that already-known information did not need to be recorded. This incompleteness resulted in ZA receiving no score for the understanding the problem indicator.

Devising a Plan (Score: 0): ZA stated that she had mentally outlined the solution steps but did not document them in the answer sheet. The absence of a documented plan contributed to the errors that occurred during implementation.

Implementing the Plan (Score: 3): ZA attempted to solve the problem but made procedural errors, writing $B = A - 10$ instead of $A = B - 10$ and applying an incorrect formula in calculating the length of the second painting's side. ZA acknowledged that the errors occurred due to rushing. Nevertheless, ZA demonstrated sufficient conceptual understanding and received a score of 3 for this indicator.

Furthermore, for students in the poor category, their solutions only addressed one indicator. The results of the answers from students in the "below average" category can be seen in Figure 12.

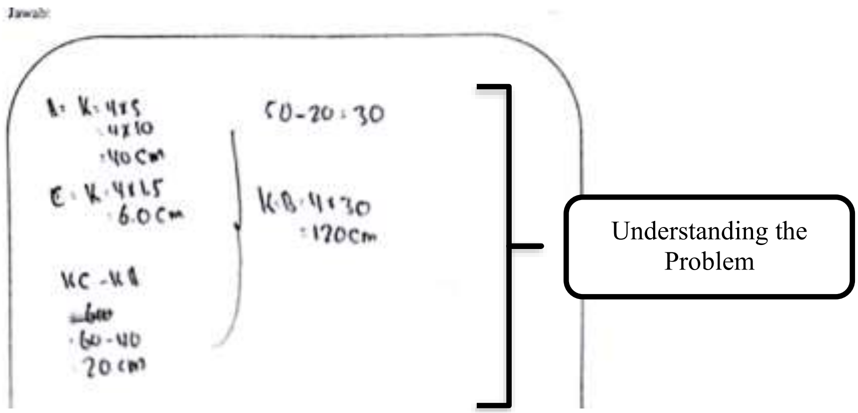


Figure 12. The Result Answer AMA Category is Poor

Below are the interview test results:

P : "When you first read question number 3, what did you understand from the question?"

AMA : "There are three squares of different sizes, then there is information about the difference in the circumference of the painting."

P : "On your answer sheet, I see that you wrote down the calculation without writing down what was known and what was asked. Why didn't you write it down?"

AMA : "Yes, because I felt the information was clear, so I just calculated it."

P : "Okay, so before beginning the math, did you have a plan for the steps to solve the problem?"

AMA : "I just recalled the perimeter formula."

P : "Alright, after reviewing your calculation, it's not accurate. Can you explain the calculation process you used?"

AMA : "I calculated the perimeter of the first painting, which is $4 \times 10\ cm$*, and the third painting, which is* $4 \times 1{,}5\ cm$*. Then I subtracted the perimeter of the third painting from the first painting, which is* $60 - 40 = 20\ cm$*. Next, I subtracted* $50 - 20 = 30\ cm$*. Then I calculated the perimeter of the second painting, which is* $4 \times 30 = 120\ cm$*."*

P : "Try reading question 3 again. What is being asked in the question."

AMA : "Oh, right, what's being asked is the length of the second painting's side. I misunderstood the question."

Based on the written test results and interview, the following is an analysis of AMA's problem-solving abilities per Polya's indicator:

Understanding the Problem (Score: 0): AMA did not write down the known or asked information in the answer sheet, believing the information was already clear enough. More critically, AMA misunderstood the problem, assuming the question asked for the perimeter of the painting rather than the length of its side. This fundamental misunderstanding became the root cause of all subsequent errors in the problem-solving process.

Devising a Plan (Score: 0): AMA did not formulate an adequate solution plan. The only strategy employed was recalling the perimeter formula, without developing a more comprehensive set of solution steps. The absence of proper planning further compounded the errors arising from the misunderstanding at the problem comprehension stage.

Implementing the Plan (Score: 0): Due to misunderstanding the problem and lacking an appropriate plan, all calculations performed by AMA were irrelevant to what was being asked. AMA calculated the perimeters of the first and third paintings and performed subtraction operations that did not align with the problem context. Consequently, AMA received no score for this indicator.

From the analysis of the three students above, it was found that implementing the plan was the most commonly observed indicator in students' responses, although the quality of implementation varied considerably. This is consistent with Simatupang et al. (2019),who found that students tend to move directly to the implementation stage without careful planning, resulting in errors in problem-solving.

The devising a plan indicator was absent in all three students' written responses. Most students proceeded directly to writing their answers without documenting their solution strategies. This is consistent with García et al. (2019), who found that students frequently skip the planning stage when solving problems, resulting in incomplete and unsystematic solutions.

The understanding the problem indicator also remained low across all students. Although some students were able to verbally identify what was being asked, they did not document it in writing. This is consistent with Sinaga et al. (2023), who found that many students fail to completely write down the known and asked information at the problem understanding stage. The case of AMA particularly illustrates that a failure to deeply understand the problem can have cascading consequences across the entire problem-solving process.

Students found it easier to engage with problems when presented in familiar real-world contexts. This is consistent with Khoirunnisa et al. (2024), who state that the use of real-world contexts can help students develop critical thinking and problem-solving abilities. However, the contextual nature of RME alone was insufficient to encourage students to document their problem-solving processes in a systematic and structured manner.

CONCLUSION

The findings demonstrate that the contextual characteristics of RME effectively supported students in engaging with and making sense of problem situations through four levels of emergent modeling. However, RME-based instruction did not sufficiently encourage students to explicitly document their understanding and planning processes, suggesting that contextual familiarity alone does not guarantee systematic problem-solving. Analysis of three representative students revealed that implementing the plan was the most commonly observed indicator, although its quality varied considerably across performance levels. Both understanding the problem and devising a plan indicators remained low, as most students proceeded directly to calculation without documenting their reasoning. The case of AMA illustrates that failure to deeply understand the problem can lead to fundamental errors throughout the entire problem-solving process. These findings suggest that teachers implementing RME should explicitly scaffold the initial stages of Polya's framework by requiring students to document their understanding and planning in writing before proceeding to implementation. Future research could examine the influence of different contextual problems on students' problem-solving processes across Polya's stages, or investigate the role of teacher facilitation in supporting structured mathematical reasoning within RME classrooms.

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