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Mathematical Literacy in Solving PISA Space and Shape Problems : A Self-Regulation Perspective

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Abstract: This study aims to explore the role of self-regulation in enhancing mathematical literacy among high school students solving PISA Space and Shape problems. Employing a qualitative descriptive approach, data were collected through self-regulation questionnaires, PISA-based tasks, and semi-structured interviews from high school students categorized into high, moderate, and low self-regulation groups. The data analysis technique in this study consisting of three stages: data condensation, data display, and conclusion. Results reveal a strong correlation between self-regulation and mathematical literacy, with high self-regulation students excelling in formulating, employing, and interpreting mathematical problems. Moderate self-regulation students displayed partial success, while low self-regulation students struggled significantly, particularly in interpreting and validating solutions. The study underscores the importance of self-regulation strategies such as goal-setting, monitoring, and reflection in improving mathematical literacy. Instructional recommendations include structured goal-setting frameworks, reflective practices, and scaffolded tasks to support learners with varying self-regulation levels. These findings contribute to mathematics education by addressing the interplay between self-regulation and problem-solving in the underexplored Space and Shape domain. Future research should expand on these insights through larger, longitudinal studies to further validate the implications of self-regulation in educational contexts.

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Introduction

In the modern era, mathematical literacy is a critical competency that equips individuals to navigate complex real-world challenges by applying mathematical principles in diverse contexts. The ability to understand, apply, and interpret mathematics extends beyond academic success to informed decision-making in everyday life (Muhaimin, 2024). Mathematical literacy's importance is further emphasized by its correlation with critical thinking and problem-solving skills, foundational for personal and professional growth (Sari et al., 2023; Almarashdi & Jarrah, 2022). The Programme for International Student Assessment (PISA) serves as an international benchmark, evaluating students' competencies in applying mathematical knowledge to real-world problems. Among its key domains, the

Space and Shape category stands out for its emphasis on geometric reasoning and spatial understanding—skills integral to fields ranging from engineering to architecture (Trapsilasiwi et al., 2019).

Despite the increasing focus on mathematical literacy, the PISA results highlight significant gaps in students' performance within the Space and Shape domain. Many students struggle with formulating mathematical representations from contextual scenarios, a foundational skill in this domain (Sa'diyah, 2024; Nisa & Inayah, 2019). These challenges underscore the need for instructional strategies that bridge the gap between theoretical knowledge and practical application. Factors such as socio-economic disparities, educational background, and instructional quality contribute to the observed inconsistencies in performance, particularly in underrepresented student populations (Cheung, 2024; Kusmaryono & Kusumaningsih, 2023).

Self-regulation, encompassing skills like goal-setting, progress monitoring, and reflective practices, has emerged as a critical determinant of academic success (Kusuma et al., 2021; Cheung, 2024; Stacey & Turner, 2015). Research consistently demonstrates that students with robust self-regulation skills exhibit better academic outcomes, including improved problem-solving abilities in mathematics (Kusuma et al., 2021; Cheung, 2024). Self-regulated learners proactively manage their learning processes, from setting clear objectives to evaluating outcomes, which is particularly relevant in domains requiring complex cognitive engagement like Space and Shape. However, the role of self-regulation in enhancing mathematical literacy within this domain remains underexplored, despite its evident potential.

The lack of comprehensive research integrating self-regulation frameworks with mathematical literacy in the Space and Shape domain represents a critical gap. While prior studies have explored general mathematical skills or self-regulation independently, the interplay between these aspects in addressing PISA tasks has not been sufficiently examined. This gap in the literature hinders the development of targeted interventions to improve students' competencies in these areas. This study addresses this gap by investigating how self-regulation influences students' performance in solving PISA problems in the Space and Shape domain. Specifically, it aims to analyze the self-regulation skills of students with varying performance levels and examine the relationship between these skills and their mathematical literacy. The insights gained are expected to inform instructional strategies that foster self-regulation-based learning approaches, ultimately enhancing mathematical literacy outcomes in diverse educational contexts.

Research Method

This study employs a qualitative descriptive approach to analyze the role of self-regulation in enhancing students' mathematical literacy in solving PISA problems in the Space and Shape domain. A qualitative descriptive method is particularly appropriate as it allows for an in-depth exploration of students' cognitive processes, problem-solving strategies, and the interaction between self-regulation and mathematical literacy. This approach emphasizes capturing rich, detailed data from participants, which is essential for understanding the nuances of how self-regulation influences mathematical problem-solving. The research was conducted at SMA Istiqamah Muhammadiyah Samarinda, East Kalimantan, Indonesia, involving 12 students from Grade XI during the 2024/2025 academic year. Participants were selected based on their self-regulation levels, categorized as high, moderate, and low. Two students from each category were chosen to represent the different levels of

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self-regulation skills. The study's participants were purposefully selected to provide a diverse representation of self-regulation capabilities in mathematical problem-solving.

The instruments used in this study were designed to gather comprehensive data on students' self-regulatory skills, mathematical literacy, and problem-solving approaches within the PISA Space and Shape domain. The Self-Regulation Questionnaire was developed to evaluate eight key indicators of self-regulation: goal-setting, self-monitoring, self-reflection, strategy utilization, time management, emotional regulation, resource management, and decision-making (Kusuma et al., 2021). This instrument provided a detailed measure of students' ability to manage their learning processes, categorizing them into high, moderate, or low self-regulation groups.

PISA Space and Shape Problems were employed as authentic tasks to assess mathematical literacy. These problems, aligned with PISA standards, were carefully selected to evaluate students' spatial reasoning and problem-solving skills in real-world contexts. Finally, the Interview Guide provided a semi-structured framework for conducting in-depth discussions with participants. The guide focused on eliciting insights into students' experiences with problem-solving and their use of self-regulation strategies. This flexible approach ensured that the interviews addressed the research objectives while capturing individual variations in students' approaches to mathematical tasks and learning processes. These instruments collectively supported a robust analysis of the relationship between self-regulation and mathematical literacy in the Space and Shape domain.

The data analysis technique in this study consisting of three stages: data condensation, data display, and conclusion. In the data reduction stage, data from the Self-Regulation Questionnaire were analyzed to classify students into high, moderate, and low self-regulation categories based on eight indicators, such as goal-setting and self-monitoring. To ensure the validity and reliability of the data, this study employed triangulation, specifically methodological triangulation, by comparing findings from multiple data sources, including the questionnaire, PISA-based tasks, and semi-structured interviews. Results from the PISA Space and Shape Problems were calculated as percentage scores based on the PISA rubric, while interview data were thematically analyzed to identify patterns of self-regulation strategies employed by students.

Results and Discussion

The study yielded results from the self-regulation questionnaire and the PISA Space and Shape content test. Based on the questionnaire results, 12 subjects were selected, comprising two subjects each from the high, moderate, and low self-regulation categories. The scoring of the PISA test followed the mathematical literacy rubric, where the "formulate" and "employ" components had a maximum score of 4, while the "interpret" component had a maximum score of 2. Each subject's PISA test score was calculated using the formula: (achieved component score)/(total component score) × 100. The list of the six selected subjects is presented in Table 1 below.

Table 1. Results of the Self-Regulation Questionnaire and PISA Test Scores of Research Subjects

No	Student Inisial	Student Code	Result *Self-regulation*		PISA Test Score
			Score	Category	
1	SSL	S1	85	High	92,5
2	MH	S2	80	High	87,5
3	MHAO	S3	67	Medium	75
4	MFHR	S4	61	Medium	70

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5	HMA	S5	46	Low	55
6	WA	S6	49	Low	37,5

The following outlines the analysis of students' mathematical literacy skills in solving PISA Space and Shape problems based on self-regulation levels.

Analysis of S1 and S2 Data: Subjects categorized with high self-regulation scored 92.5 and 87.5, respectively, indicating high scores on PISA Space and Shape tasks. Both S1 and S2 successfully addressed all three aspects of mathematical literacy—formulate, employ, and interpret. They demonstrated the ability to frame problems accurately based on given and required information, construct mathematical models using variables and symbols, and identify critical information. Moreover, they effectively designed and applied strategies to solve the mathematical problems, provided solutions, interpreted results contextually, and evaluated the solutions' validity in real-world contexts.

Analysis of S3 Data: A subject in the moderate self-regulation category scored 67 on the PISA Space and Shape test, classified as a moderate score. S3 successfully met all three aspects of mathematical literacy on tasks 3 and 4 but achieved only two aspects of mathematical literacy on tasks 1 and 2. S3's responses to tasks 1 and 2 can be observed in the excerpts of their answers below.

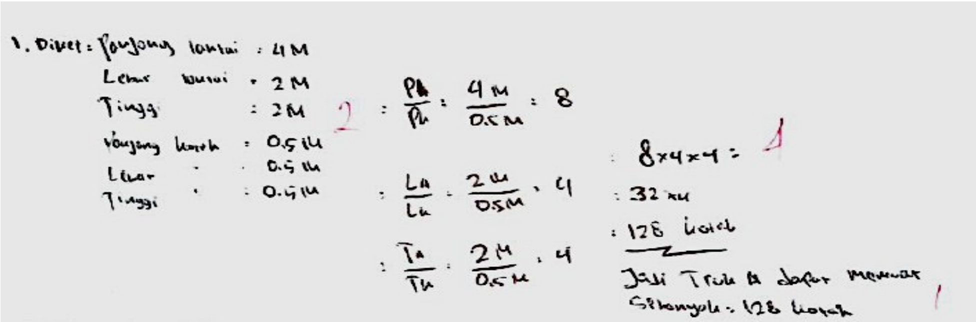

Figure 1. Excerpt of S3's Responses

From the excerpts for tasks 1 and 2 above, it can be observed that S3 met two aspects of mathematical literacy: formulate and employ. This indicates that S3 was able to articulate the problem based on the given and required information, construct a mathematical model aligned with the presented problem, and apply mathematical concepts, facts, and procedures to solve the tasks. Furthermore, S3 successfully designed and implemented strategies to find solutions while utilizing mathematical concepts, facts, and procedures to address the problem.

Regarding the interpret aspect, S3 was able to provide conclusions based on the results obtained; however, the conclusions were incomplete, and the subject exhibited a lack of confidence in explaining the validity of the answers provided. This observation was corroborated through the interview findings.

P: Do you think the answers you provided are relevant to tasks 1 and 2?
S3: I don't know, maybe they are relevant.

In tasks 3 and 4, S3 was able to fulfill all three aspects of mathematical literacy: formulate, employ, and interpret. This means that S3 was able to formulate the problem based on the given scenario, design a solution strategy by determining the appropriate formula and solving it correctly, as well as write a contextual conclusion based on the obtained solution.

Data Analysis of Subject S4: The subject categorized under moderate self-regulation achieved a PISA score of 61 in the Space and Shape content, which falls into the moderate category. S4 was able to fulfill two aspects of mathematical literacy, formulate and employ, in questions 2 and 3, but only one aspect in question 1 (formulate) and question 4 (employ). The responses of S4 for questions 2 and 3 can be observed in the excerpts below.

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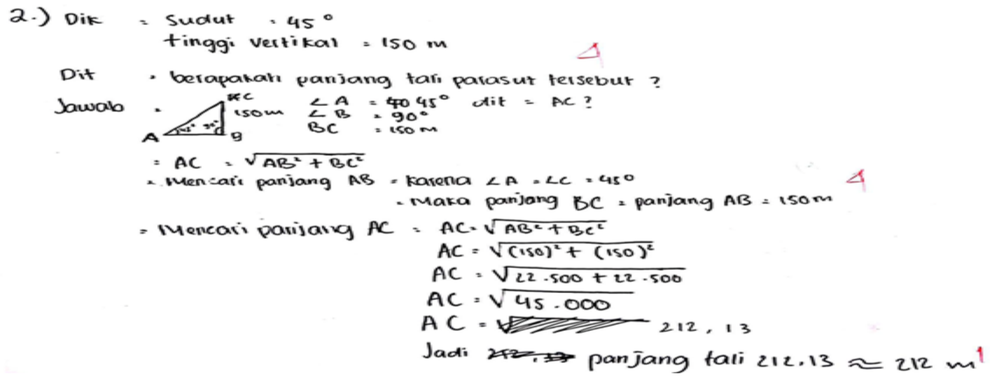

Figure 2. Excerpts of S4's Responses

Based on the excerpts above, S4 successfully fulfilled two aspects of mathematical literacy, namely formulate and employ. This indicates that S4 was able to express the problem according to what was known and asked, construct a mathematical model consistent with the given problem, design and apply a strategy to find a solution, and utilize mathematical concepts, facts, and procedures in problem-solving. However, in the interpret aspect, S4 was less capable of writing complete conclusions based on the obtained solutions and could not confidently justify the validity of the results. S4's answers to questions 1 and 4 are presented in the excerpts below.

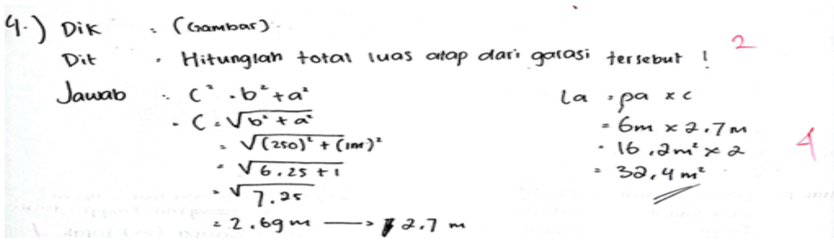

Figure 3. Excerpts of S4's Responses

From the excerpts above, S4 only fulfilled one aspect of mathematical literacy: formulate in question 1 and employ in question 4. For question 1, S4 was able to describe the problem according to the known and asked information and create a mathematical model consistent with the problem. Meanwhile, in question 4, S4 could design and implement a strategy to find the solution and apply mathematical concepts, facts, and procedures. However, this shows that S4 did not fulfill the employ and interpret aspects in question 1, indicating an inability to design and explain a problem-solving strategy, determine the appropriate formula for the problem, and provide a conclusion for the obtained solution. These findings were corroborated by interview results.

> *P: How did you determine the length = 8 boxes, width = 4 boxes, and height = 4 boxes?*
> *S4: Umm… the length… uh, let me see. The 8 boxes are from the truck here, right? Then the width was counted as 4, and this is also 4 because it's in meters.*
> *P: Why didn't you write the conclusion in the answer sheet?*
> *S4: Should I have written it? I thought the answer itself was enough, sir. The time was short, so I didn't write it.*

For question 4, S4 could not fulfill the formulate and interpret aspects, meaning S4 was unable to express the problem according to the given and asked information, create a mathematical model, or write conclusions based on the obtained solution. This is supported by the following interview excerpt.

> *P: What information is provided in question 4?*
> *S4: The information includes the garage layout, roof length, roof height, and the building height of the garage.*

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Data Analysis of Subject S5: The subject categorized under low self-regulation achieved a PISA score of 55 in the Space and Shape content, which falls into the low category. For questions 1, 3, and 4, S5 was able to fulfill two aspects of mathematical literacy: employ and interpret. However, for question 2, S5 could only fulfill one aspect, formulate. The responses of S5 for questions 1, 3, and 4 are presented in the following excerpts.

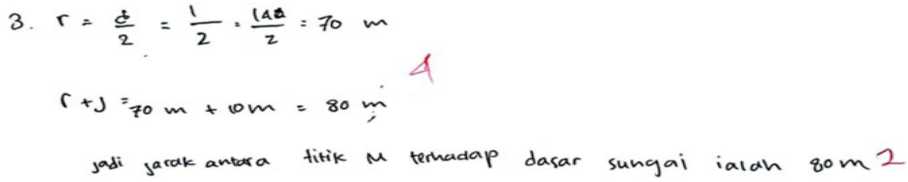

Figure 4. Excerpts of S5's Responses

From the excerpts above, S5 was able to fulfill two aspects of mathematical literacy, namely employ and interpret. This indicates that S5 could utilize mathematical concepts, facts, and procedures to solve problems, design and implement strategies to find solutions, and interpret the obtained solutions contextually. However, S5 could not explain the validity of the answers obtained. This was further supported by interview results.

P: Are your answers relevant to the context of questions 1, 3, and 4?
S5: I'm not sure, maybe they are relevant.

In the formulate aspect, as seen in the excerpts above, S5 could not write the known and asked elements, meaning S5 failed to meet this aspect. The response of S5 to question 2 is provided in the following excerpt.

Figure 5. Excerpt of S5's Response

From the excerpt above, it is evident that S5 was able to write the known elements but failed to state the asked elements. However, based on the interview, S5 was able to articulate the asked elements, thus fulfilling the formulate aspect. In the employ aspect, S5 could design strategies for solving the problem. However, many steps in the solution process were omitted, resulting in an incomplete and disorganized resolution. This was further corroborated by interview results.

P: What steps did you take to solve question 2?
S5: I directly wrote $AC = \sqrt{150^2 + 150^2} = \sqrt{45000} = 212{,}3$.
P: What formula did you use to solve question 2?
S5: I'm not sure about the name of the formula.

In the interpret aspect, S5 could not write conclusions or interpret the mathematical solutions contextually. This was also reinforced by the interview.

P: Why didn't you write a conclusion on the test answer sheet?
S5: I didn't know it was necessary. I thought the answer itself was enough.
P: Are your answers relevant to the context of question 2?
S5: I'm not sure.

Data Analysis of Subject S6: The subject categorized under low self-regulation achieved a PISA score of 37.5 in the Space and Shape content, which falls into the low category. S6 demonstrated limited ability to fulfill the three aspects of mathematical literacy. In the responses to all the questions, S6 only managed to meet the employ aspect, although there were several errors in the written responses. The following excerpt presents S6's answers.

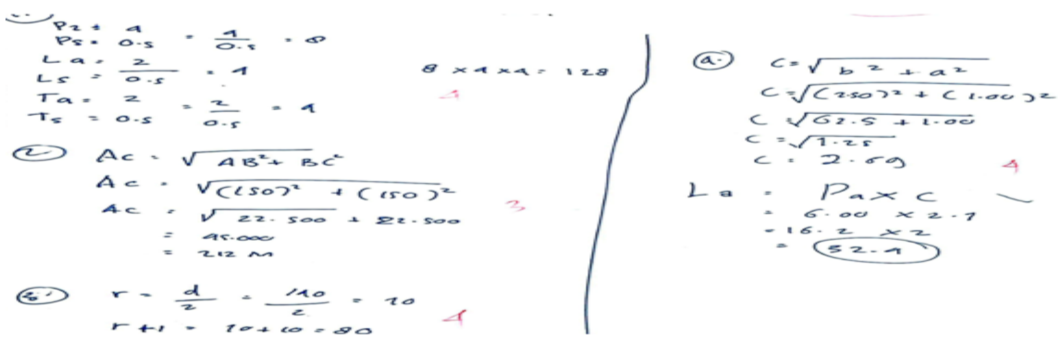

Figure 6. Excerpts of S6's Responses

The excerpt above shows that S6 was only able to fulfill the employ aspect, despite some errors in the written responses. In this case, S6 struggled to meet the formulate and interpret aspects. This means S6 was unable to write the problem according to what was known and asked, failed to create a mathematical model based on the given problem, and could not write a conclusion or explain the validity of the obtained solution in the context of the problem. This was further supported by the interview results.

P: Why didn't you write what was known and what was asked on your answer sheet?
S6: I don't know, I just wrote the answer directly.
P: Are your answers relevant to the context of the problems in questions 1, 2, 3, and 4?
S6: I don't know.

This study highlights the critical influence of self-regulation on mathematical literacy in solving PISA Space and Shape problems. High self-regulation students demonstrated exceptional performance by effectively employing cognitive and metacognitive strategies, including goal-setting, monitoring, and reflection. This aligns with prior research emphasizing the role of self-regulation in enhancing problem-solving abilities (Kusuma et al., 2021; Cheung, 2024). Conversely, students with low self-regulation struggled with key mathematical literacy components, particularly in formulating and interpreting problems, indicating the importance of targeted support to foster these skills.

The Role of Self-Regulation in Problem-Solving: Self-regulation comprises essential strategies like goal-setting, self-monitoring, and reflection that enable students to manage their learning processes effectively (Stacey & Turner, 2015). High self-regulation students, such as S1 and S2, consistently performed well by breaking down problems into manageable parts and using systematic approaches to address task requirements. Moderate self-regulation students, represented by S3 and S4, displayed partial use of these strategies, resulting in inconsistent performance. In contrast, low self-regulation students, including S5 and S6, faced significant challenges across all aspects of self-regulation, particularly in setting clear goals and interpreting mathematical results.

Variations in Mathematical Literacy Components: Students' mathematical literacy was evaluated based on three core components: formulating, employing, and interpreting.

Formulating Problems: High self-regulation students excelled in representing problems with diagrams and variables, reflecting findings by Lestari and Putri (2020), which underscore the importance of these skills in mathematical literacy. Moderate and low self-regulation students, however, often struggled to accurately capture problem contexts.

Employing Strategies: While all students displayed some ability to employ mathematical procedures, high self-regulation students were more consistent and iterative in their approaches, leading to better outcomes.

Interpreting Results: Interpretation posed significant challenges for moderate and low self-regulation students, highlighting an area where additional instructional support is crucial.

Comparison with Existing Literature: The findings align with Bandura's Social Cognitive Theory, which emphasizes the interplay between self-efficacy and self-regulation in academic success (Stacey & Turner, 2015). Similar to Kusuma et al. (2021), this study reinforces the importance of self-regulation in fostering mathematical literacy. Furthermore, the study contributes new insights by focusing on the Space and Shape domain within the PISA framework, an area less explored in existing research. While previous studies have examined self-regulation in general mathematical tasks, this research offers a nuanced understanding of its impact on spatial reasoning and geometric problem-solving.

Implications for Instructional Strategie: To address the needs of moderate and low self-regulation students, this study suggests several instructional strategies. Structured Goal-Setting Frameworks: Encouraging students to articulate clear objectives aligned with task requirements (Retnawati & Wulandari, 2019). Reflective Practices: Providing opportunities for students to evaluate their problem-solving processes can improve self-monitoring and strategic adjustments (Ekawati et al., 2020). Scaffolded Tasks: Offering guided support in early problem-solving activities can build confidence and develop self-regulation skills gradually. Formative Assessments: Using continuous feedback mechanisms enables students to track progress and identify areas for improvement. These strategies are particularly valuable for students with moderate and low self-regulation, fostering a supportive environment to enhance their problem-solving abilities.

Contributions to Educational Practice: This research underscores the importance of self-regulation in mathematical literacy, particularly in the Space and Shape domain. By providing actionable insights into the interplay between self-regulation and problem-solving skills, the findings support the development of targeted instructional strategies to improve educational outcomes. Educators and policymakers can leverage these findings to design interventions that bridge gaps in mathematical literacy, equipping students with the skills necessary to succeed in an increasingly knowledge-driven world.

Conclusion

This study demonstrates the significant role of self-regulation in enhancing mathematical literacy, particularly in solving PISA Space and Shape problems. Students with high self-regulation consistently excelled in all three components of mathematical literacy—formulating, employing, and interpreting—by effectively utilizing cognitive and metacognitive strategies such as goal-setting, monitoring, and reflection. Conversely, students with low self-regulation struggled across these components, particularly in interpreting contextual problems and validating their solutions. The findings highlight the necessity for targeted instructional interventions to foster self-regulation skills, especially for students in moderate and low categories. These interventions could include structured goal-setting frameworks, reflective practices, scaffolded tasks, and formative assessments. While this research provides valuable insights, future studies should involve larger sample sizes, longitudinal designs, and considerations of socio-cultural contexts to further validate and expand the findings. Ultimately, integrating self-regulation strategies into educational practices can empower students to excel in mathematics and real-world problem-solving, contributing to their overall academic and personal growth.

Recommendation

To enhance mathematical literacy through self-regulation, teachers should integrate goal-setting strategies, encourage reflective learning, use scaffolded approaches, provide timely feedback, and incorporate real-world problem-solving tasks. Mathematics curriculum developers should embed self-regulation training, develop PISA-based instructional materials, implement adaptive learning approaches, and promote collaborative learning environments. Further researchers should expand studies with larger and more diverse samples, conduct longitudinal research, explore the role of technology in self-regulated learning, examine socio-cultural influences, and evaluate the effectiveness of instructional strategies. Implementing these recommendations can significantly improve students' self-regulation skills and mathematical literacy, equipping them for real-world problem-solving.

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