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Self-regulation-based learning and mathematical literacy: Exploring the ability of students at singa putih munfaridin islamic boarding school in solving HOTS problems

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Abstract.
Mathematics is an important foundation in developing critical and logical thinking skills, which are reflected through mathematical literacy. However, PISA 2022 scores show that Indonesian students' mathematical literacy is still below the international average, with the main weakness in solving HOTS questions. This qualitative research aims to analyze the relationship between self-regulated learning (SRL) and students' mathematical literacy in solving HOTS problems related to System of Linear Equations of Three Variables (SPLTV) at Singa Putih Munfaridin Islamic Boarding School, Pasuruan. Data were collected through HOTS tests, SRL questionnaires, and interviews with grade X students who were grouped into three SRL categories: low, medium, and high. The results showed that students with high SRL could formulate problems efficiently, apply systematic strategies, and interpret solutions independently. Medium SRL students have difficulty in applying concepts due to inaccuracy and also fail to independently verify solutions, with conclusions often adapted from classmates. Low SRL students only reached the formulation stage and failed at the application and interpretation stages. These findings reinforce Zimmerman & Schunk's theory that SRL involves a cycle of planning, monitoring and self-evaluation.

Keywords:
Mathematical literacy; self-regulated learning; HOTS; SPLTV; problem-solving

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INTRODUCTION

Mathematics plays a crucial role in daily life. Proficiency in this subject is essential for students to navigate rapid scientific advancements, equipping them with logical, analytical, systematic, critical, and creative thinking skills (Fauzan & Anshari, 2024; Mytra et al., 2023). The National Council of Teaching Mathematics (NCTM) established five fundamental mathematical skills: problem-solving, reasoning and proof, communication, connections, and representation (NCTM, 2000). These standards align with current educational curricula, aiming to develop students' abilities in reasoning, analysis, and critical thinking. Mathematical literacy involves the capacity to formulate, employ, and interpret mathematics in diverse contexts, enabling students to communicate and explain phenomena using mathematical concepts (Nuringtyas & Setyaningsih, 2023).

Mathematical literacy is considered proficient when an individual can analyze, reason, articulate mathematical knowledge and skills effectively, and solve and interpret mathematical

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problems. A student capable of solving mathematical problems by applying existing knowledge to novel and unfamiliar situations is considered to possess Higher-Order Thinking Skills (HOTS). HOTS denotes the capacity to utilize knowledge, skills, and values in reasoning, reflection, problem-solving, decision-making, innovation, and creation. It encompasses the ability to integrate, manipulate, and transform existing knowledge and experiences to engage in critical and creative thinking, thereby facilitating decision-making and problem-solving in new contexts (Fanikia & Hidayah, 2024; Khaesarani & Ananda, 2022; Rianti et al., 2022).

The Programme for International Student Assessment (PISA), established by the Organisation for Economic Co-operation and Development (OECD), evaluates reading literacy, mathematical proficiency, and scientific competence among 15-year-old students. Indonesia has participated since 2000. PISA assessments occur triennially. In 2022, Indonesian students scored an average mathematical literacy of 366, while the international average was 472 (OECD, 2023). These results indicate that Indonesian students' literacy abilities, according to international studies, remain unsatisfactory and relatively low. Several studies on Indonesian students reveal their continued difficulty in answering questions requiring higher-order thinking skills.

Higher-Order Thinking Skills (HOTS) questions are assessments designed to evaluate high-level cognitive abilities. HOTS questions demand advanced cognitive processes and reasoning, enhancing critical, logical, reflective, metacognitive, and creative thinking. They develop students' abilities in analysis, evaluation, and creation. Higher-order thinking skills improve problem-solving by fostering critical and creative thinking, ultimately leading to better learning outcomes (Istiqomah & Fitrianawati, 2023; Pelle et al., 2024; Suryapuspitarini et al., 2018; Wahyudi et al., 2023).

Learning outcomes are interrelated phenomena arising from interactions among various student-influencing factors. These influences stem from internal and external factors. Internal factors originate from students themselves, including intelligence, thinking skills, motivation, health, learning strategies, and learning independence. External factors arise from outside students, such as family, educational, and societal environments. Beyond thinking skills, learning independence significantly impacts outcomes. Learning independence entails engaging autonomously in educational activities, driven by intrinsic motivation to master material to overcome relevant challenges. It is crucial for students to cultivate responsibility in self-regulation and discipline and enhance their capacity for autonomous learning. Consequently, an individual's mathematical literacy can be influenced by self-regulated learning (Pelenusa et al., 2023; Rambe & Erika, 2024; Sukarman & Sutomo, 2024).

METHOD

This study employed a qualitative approach to elucidate the mathematical literacy competencies of Year 10 students at MA Unggulan Singa Putih, Munfaridin Singa Putih Islamic Boarding School, Prigen District, Pasuruan Regency. The subjects were selected from at least three distinct categories: low, medium, and high levels of self-regulated learning (SRL). Within these categories, selection was contingent upon the highest test scores within each category, supplemented by teacher assessments of students' daily dispositions. Data were collected through questionnaires (to gauge SRL levels), HOTS tests (to evaluate mathematical literacy, as detailed in Table 1), and in-depth interviews to further enhance the analysis.

Table 1. Mathematical literacy indicators

Indicators	Desciptor
Formulate	Analyze information included in the given problem Develop a mathematical model for the given problem
Employ	Identify appropriate strategies to solve the given problem Perform calculations to solve the given problem
Interpret	Present conclusions relevant to the given problem Re-evaluate the obtained solution

This study employed a Likert-scale questionnaire to evaluate students' self-regulated learning. A five-point Likert scale was utilized, with scores of 5 (always), 4 (often), 3 (sometimes), 2 (rarely), and 1 (never) assigned to positive statements. Conversely, negative statements were scored in reverse order. Positive questionnaire scoring is presented in Table 2.

Table 2. Questionnaire measurement scale

Positive					Negative				
A	O	S	R	N	A	O	S	R	N
5	4	3	2	1	1	2	3	4	5

Following the collection of responses, quantitative analysis classified the results using the criteria outlined in Table 3.

Table 3. Assessment classification

Assessment	Classification
$x \geq (\bar{x} + SD)$	High
$(\bar{x} - SD) < x < (\bar{x} + SD)$	Medium
$x \leq (\bar{x} - SD)$	Low

Reprinted and modified from Arigiyati et al., (2023)

RESULTS AND DISCUSSION

Subject selection commenced by distributing SRL questionnaires to 22 Year 10 students. The results categorized two students as high-level, seventeen as medium-level, and three as low-level. Subsequently, all students completed a mathematical literacy test on three-variable linear equation systems. SRL questionnaire data and test results were analyzed integratively, supplemented by mathematics teacher recommendations, to determine subjects. Three subjects were selected based on the highest test scores per SRL category (high, medium, low), in alignment with teacher input. Subject data are summarized and presented in Table 4.

Table 4. Research subject data

Subject Id	Questionnaire Result	Classification	Test Result	Code
NNA	122	High	88,9	SP_1
MNFAW	108	Medium	85,7	SP_2
BRN	64	Low	84,7	SP_3

The mathematical literacy abilities of students were assessed through a combination of tests (solving Story Problems with Multiple Choice) and interviews. The data were subsequently categorized based on the Student Response Level (SRL) to identify recurring patterns as presented in Table 5.

Table 5. Data analysis framework

Indicator	Descriptor	Data Source	Color
Formulate	Analyze information included in the given problem.	Test Results	Green
	Develop a mathematical model for the given problem.	Test Results	Blue
Employ	Identify appropriate strategies to solve the given problem.	Interview Results	-
	Perform calculations to solve the given problem.	Test Results	Red
Interpret	Present conclusions relevant to the given problem.	Test Results	Yellow
	Re-evaluate the obtained solution.	Interview Results	-

The analysis results are presented in the discussion below.

The Mathematical Literacy Test Results for SP_1

In the third question, SP_1 demonstrated a strong initial ability to analyze information by directly assigning variables: x for a small-sized coffee glass, y for a medium-sized coffee glass, and z for a large-sized coffee glass (see Figure 1). SP_1 also clearly identified the central question being posed. During the mathematical modeling stage, SP_1 employed a similar approach as in previous questions by translating key elements into variables. This resulted in the formulation of a system of three equations that represented the mathematical model.

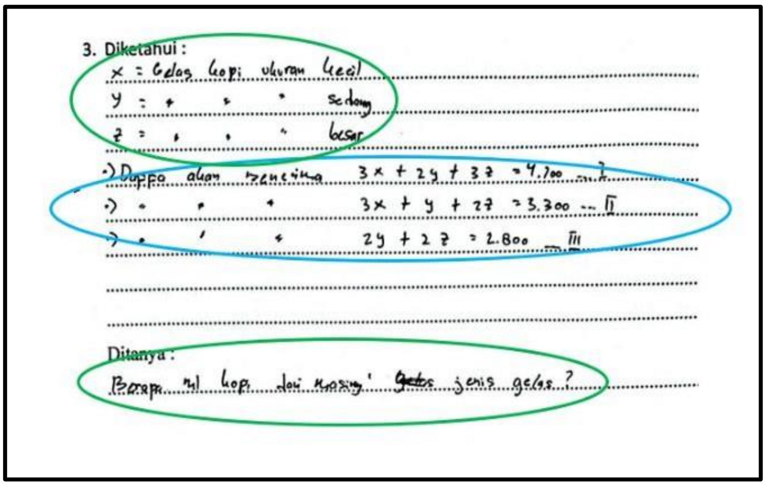

Figure 1. *SP_1* answering question no. 3 regarding formulating indicators

In the identification of a solution strategy, SP_1 employed a mixed-method approach, emphasizing its simplicity and clarity of steps (as illustrated in Figure 2). However, during the calculation phase, SP_1 encountered a significant error. Although the equation z = 1900 - 3x was correctly derived in the second step, SP_1 overlooked the fact that the equation y = 1400 - z is mathematically equivalent to the third equation when multiplied by two. Ideally, SP_1 should have substituted the expression for z into y = 1400 - z, resulting in y = 3x - 500. This oversight underscores a misstep in the substitution process.

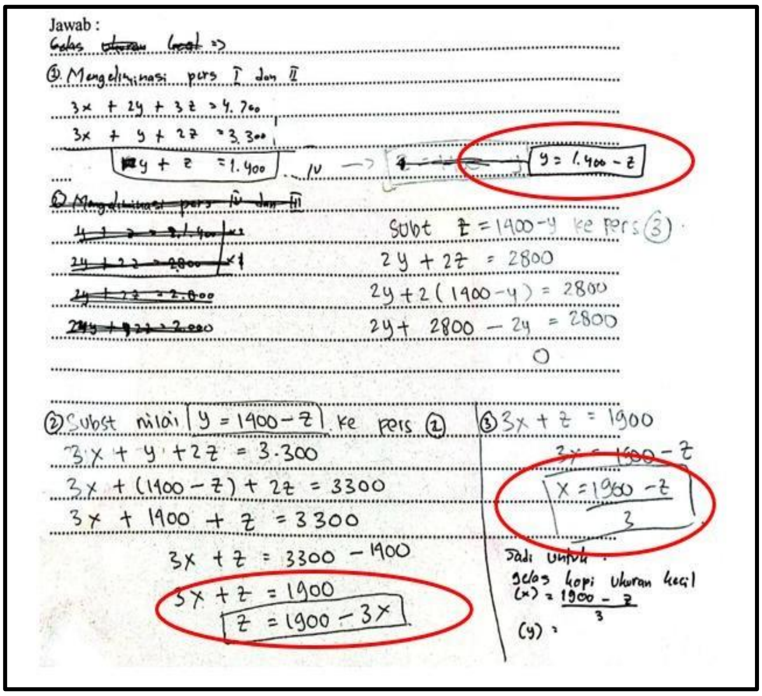

Figure 2. *SP_1* answering question no. 3 regarding the indicator of application

In presenting the conclusion, SP_1 provided an incomplete and partially incorrect response, only writing z = 1900 - 3x and x = (1900 - z)/3, without including the equation for y (see Figure 3). The correct final answer should include both y = 3x - 500 and z = 1900 - 3x, with x as the primary variable. Finally, during the re-evaluation stage, SP_1 candidly acknowledged uncertainty about the solution, expressing confusion because the result remained in the form of an equation. This contrasted with previous questions (Levels C4 and C5), where the answers were numerical values.

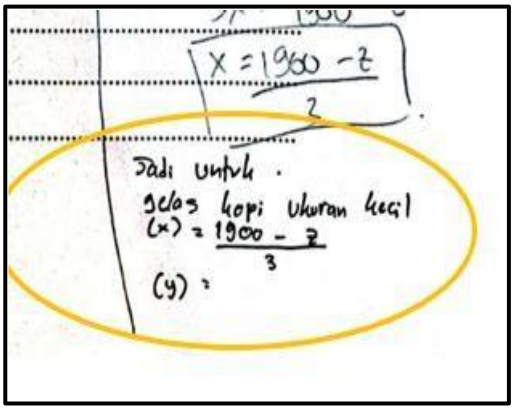

Figure 3. *SP*$_1$ answering question no. 3 regarding interpretation indicators

The Mathematical Literacy Test Results for SP_2

SP_2 commenced by meticulously analyzing the provided data, discerning all pertinent details pertaining to the packages offered by both Store A and Store B. Subsequently, it unequivocally articulated the specific requirements of the inquiry. SP_2 subsequently devised mathematical models by translating the extant information into equations for both establishments. As illustrated in Figure 4.

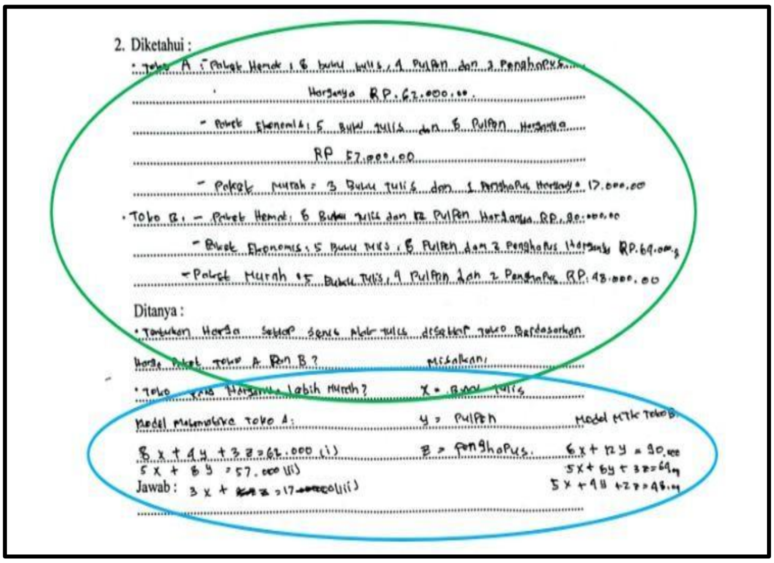

Figure 4. *SP*$_2$ answering question no. 2 regarding formulating indicators

In identifying a strategy, SP_2 consistently opted for the combined method, asserting that it was simpler and more time-efficient. However, during the calculation process, SP_2 encountered several errors. Notably, SP_2 intended to eliminate variable y but mistakenly eliminated x instead. This resulted in an incorrect intermediate result: –44y + 15z = 146,000, which should have been either –44y + 15z = –146,000 or 44y – 15z = 146,000. Another calculation error occurred when SP_2 wrote 224z = 448,000, whereas the correct result should have been 224z = 3,952,000. Despite these missteps, SP_2 managed to arrive at the correct final value for z (2,000), although this appeared to be coincidental rather than the result of accurate computation. Additional writing errors included incorrect substitution steps, such as substituting x into equation 3 instead of z, and inaccurately calculating values (e.g., writing 192,000 instead of –192,000). Interestingly, SP_2's final calculation yielded the correct result due to the mathematical coincidence that subtracting a negative number resulted in the correct positive value, as illustrated in Figure 5. SP_2 admitted to copying the solution from a friend, indicating a lack of understanding and confusion caused by the number of equations and limited time.

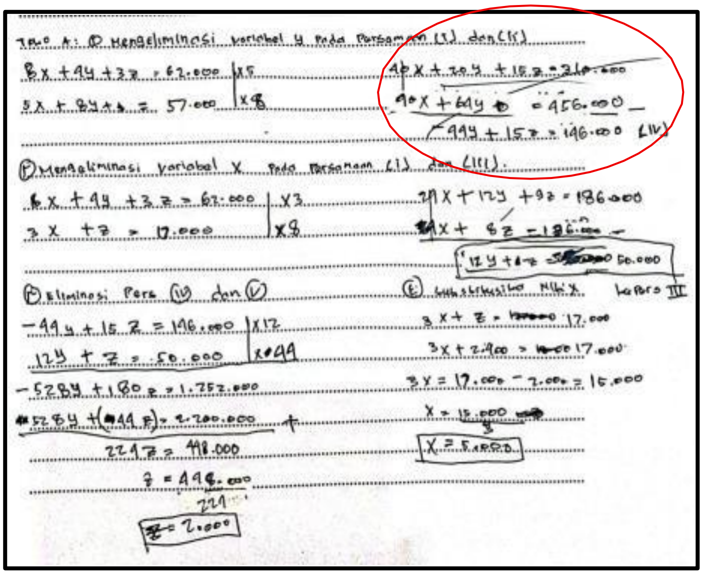

Figure 5. *SP_2* Answering Question No. 2 Regarding Indicators of Implementation

Despite the initial inaccuracies in the calculations, SP_2 successfully concluded that store A's prices were indeed more economical. During a subsequent review, SP_2 admitted to relying on a peer's answer and forgetting the results, but still maintained that store A was the more cost-effective option. This is illustrated in Figure 6.

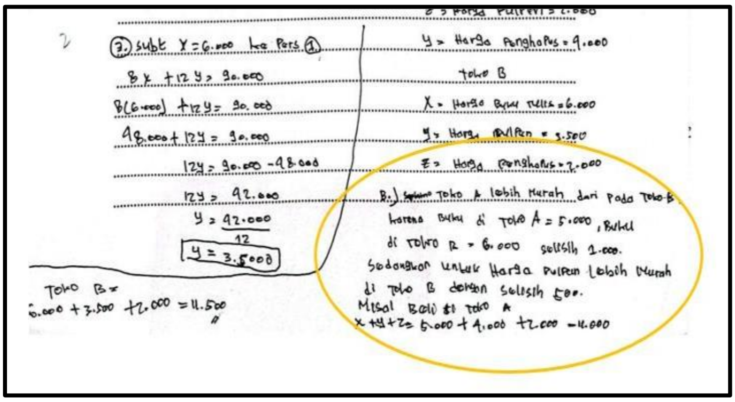

Figure 6. *SP_2* answering question no. 2 regarding interpretation indicators

The Mathematical Literacy Test Results for SP_3

In the first question (Level C4), SP_3 demonstrated an attempt to analyze information by copying the entire question, writing down the question's requirements, and highlighting nearly the entire answer sheet in green—indicating engagement with the information. While developing the mathematical model, SP_3 correctly formulated part of the model but made an error in the second equation, which should have been $x+y+z=16$. As illustrated in Figure 7.

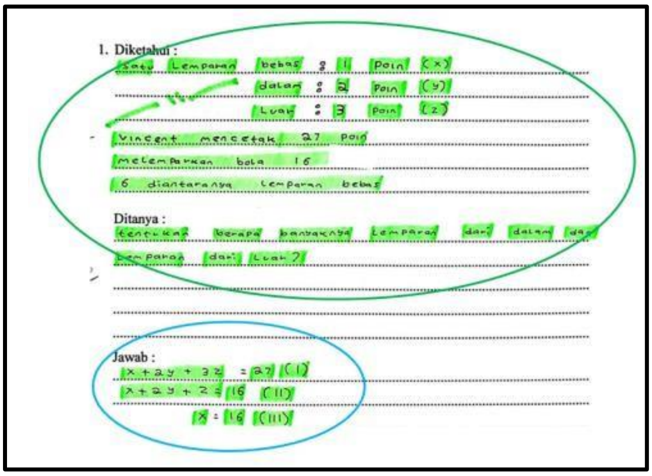

Figure 7. SP_3 answering question no. 1 regarding formulating indicators

In relation to strategy identification, SP_3 employed a mixed method (elimination and substitution), as depicted in Figure 8, akin to SP_1 and SP_2. SP_3 acknowledged its familiarity and comfort with this method, contrasting it with others like the graphical method. However, during the calculation process, SP_3 encountered an error in step three. When multiplying the equation y+z=10 by 2, the correct outcome should be 2y+2z=20, but SP_3 mistakenly wrote 6+y+1=20. Nevertheless, he ultimately arrived at the accurate value of z=1.

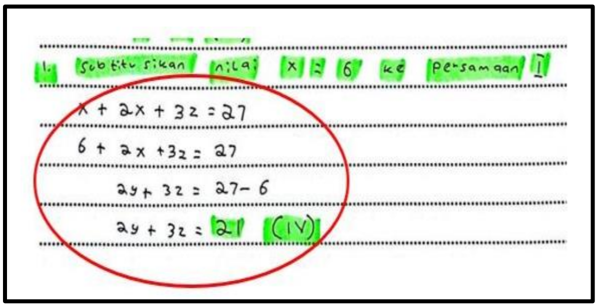

Figure 8. SP_3 answering question no. 1 regarding the indicator of implementation

In presenting the conclusion, SP_3 explicitly stated the final results: x = 6 (free throws), y = 9 (inside shots), and z = 1 (outside shot), as depicted in Figure 9. However, based on the subsequent interview, it was revealed that SP_3 did not fully comprehend the question and had relied on a peer's work, suggesting a deficiency in independent re-evaluation and answer validation.

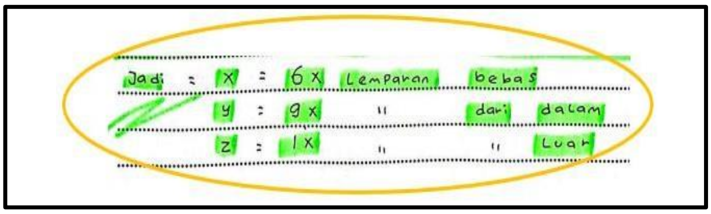

Figure 9. SP_3 answering question no. 1 regarding interpretation indicators

The findings of the study indicate that the majority of students exhibit a low to moderate level of self-regulated learning, with a distribution of two students (high), seventeen students (moderate), and three students (low). Data collection employed the Higher Order Thinking Skills (HOTS) test instrument based on the Three-Variable Linear Equation System (SPLTV), which encompasses mathematics literacy levels four, five, and six. The test results revealed variations in students' responses to the questions. Students with high levels of Self-Regulated Learning (SRL) demonstrate effective analytical capacity in mathematical literacy, as evidenced by three key indicators. During the formulation phase, they are capable of reducing crucial information directly through reading the question and immediately converting it into a mathematical model without rewriting the problem's details. This efficiency is facilitated by internalized learning habits and mastery of concepts through repeated practice (Bahruddin in Fadilah et al., 2021), supported by learning discipline characteristics, task consistency, and intrinsic motivation such as self-efficacy and goal setting (Mukhid, 2008; Zimmerman & Schunk, 1989). During the application phase, despite employing systematic strategies (e.g., elimination-substitution), vulnerabilities to errors were identified due to carelessness and negligence in verifying calculation results. Although these errors can be rectified through recalculation, they reflect failures in the verification process (Utami in Nadiya et al., 2024). In the interpretation phase, students were able to conclude solutions and evaluate their validity through variable value substitution verification, demonstrating comprehensive mastery of problem-solving strategies (Santika & Khotimah, 2023). The integration of SRL with mathematical literacy demonstrates holistic dynamics and metacognitive awareness in reflecting on errors, aligning with the SRL cycle (planning, monitoring, evaluation) of Zimmerman and Schunk (1989). Interpretation ability is contingent upon conceptual understanding and self-assessment habits (Pintrich, 2004). Consequently, educators are advised to: (1) integrate metacognitive strategies (think-aloud protocols, peer-review, Cornell notes) to enhance formulation and verification (Schunk & Greene, 2017; Zimmerman & Schunk, 1989); (2) combine motivational reinforcement (self-efficacy) with time management training (e.g., Pomodoro technique) to allocate time for review and minimize errors (Panadero et al., 2017); and (3) implement Problem-Based Learning (PBL) or Project-Based Learning (PBL) that effectively trains the three indicators of mathematical literacy and SRL phases in an integrated manner (Panadero et al., 2017; Pintrich, 2004).

Students with moderate levels of Self-Regulated Learning (SRL) exhibit typical limitations in mathematical literacy across all three phases: (1) in the formulation phase, despite their ability to identify key points, information reduction is mechanical without conceptual elaboration, reflecting suboptimal metacognitive planning abilities and reliance on rote learning (Santika & Khotimah, 2023; Zimmerman & Schunk, 1989); (2) in the application phase, they are susceptible to technical errors due to weak procedural understanding and neglect of verification, as evidenced by significant reliance on peers' answers, reflecting low self-efficacy and a tendency to cheat (Astuti et al., 2024; Bandura et al., 1999; Fauziah & Astutik, 2022); and (3) in the interpretation phase, the conclusions drawn tend to be adaptive and less reflective, indicating a gap between verbalization and conceptual understanding related to cognitive overload and a fixed mindset (Astuti et al., 2024; Dweck, 2006; Sweller, 2011). External factors, such as a classroom culture that is permissive of non-academic practices and the limited application of process-based formative assessment, further exacerbate this phenomenon (Black & Wiliam, 2009). Consequently, a multidimensional intervention is required, encompassing: (a) introducing metacognitive strategies (e.g., graphic organizers, self-questioning) through scaffolding; (b) the implementation of formative assessment based on open-ended problems to build cognitive resilience; (c) the development of a growth mindset through feedback focused on effort (Dweck, 2006); and (d) systematic collaboration between teachers and educational psychologists for early identification and targeted support for students with moderate SRL (Zohar & Barzilai, 2013).

Students with low levels of Self-Regulated Learning (SRL) exhibit significant limitations in solving complex problems. These limitations are primarily observed at the formulation stage, where students demonstrate limited abilities in mechanical activities such as variable substitution. However, they fail to apply and interpret information effectively due to cognitive-metacognitive deficits. This phenomenon highlights the correlation between low SRL and minimal mastery of material and a lack of learning organization skills. Internally, weak intrinsic motivation leads to reactive learning and surface learning, characterized by memorizing procedures without contextualizing concepts. This results in the failure to activate prior knowledge in novel situations. Externally, an unsupportive learning environment, such as the absence of problem-based learning and insufficient encouragement of active interaction, exacerbates this condition.

This is evidenced by reluctance to ask questions due to feelings of incompetence and an exclusive classroom culture. Therefore, multidimensional interventions are critically necessary. These interventions include: (1) progressively scaffolding tasks from simple to complex to train concept application; (2) providing regular formative feedback to facilitate reflection on mistakes; (3) instilling a growth mindset by normalizing failure as a part of learning; and (4) applying structured questioning techniques, such as the 5-why method, to reduce anxiety. Peer collaboration, specifically the think-pair-share method, can serve as a catalyst for enhancing SRL if directed productively. In this context, the teacher plays an essential role in modeling effective collaboration to prevent negative dependency and foster individual responsibility.

The majority of students encounter holistic challenges in solving systems of equations, characterized by procedural calculation skills that lack an understanding of the mathematical representation of solutions. This indicates a multidimensional (cognitive-affective-social) understanding gap that necessitates integrated intervention (Wiliam, 2018). Effective solutions include: (1) shifting the teaching paradigm from a focus on numerical answers to conceptual understanding through regular formative assessment and technology-assisted visualization of systems of equations (Hwang et al., 2023); (2) strengthening the role of teachers in scaffolding and diagnostic formative assessment (Hattie & Timperley, 2007); and the application of contextual problem-based learning (PBL) to enhance relevance; (3) integrating growth mindset training (Dweck, 2006) and stress management to reduce math anxiety; and (4) ecosystem collaboration involving parents in monitoring routines and utilizing AI-based digital platforms for personalized practice (Akmam et al., 2019). This multidimensional implementation is anticipated to foster conceptual understanding and metacognitive capacity, with policy implications in the form of curriculum design that ensures coherence of material and equitable access to quality learning resources, particularly for students from disadvantaged backgrounds (Nabila et al., 2024).

CONCLUSIONS

Based on research findings, the mathematical literacy of SPM students in solving HOTS questions exhibits a significant correlation with their level of Self-regulated Learning (SRL). High SRL students demonstrate the most robust capability, effectively solving problems up to C5 (PISA level 5) by efficiently formulating problems through information reduction and modeling, employing systematic mixed strategies, and independently interpreting and verifying results. However, their emphasis on speed can result in technical errors. Medium SRL students achieve up to C4 (PISA level 4), but their approach is mechanistic, lacking depth in analysis and susceptible to procedural errors and reliance on peers; their interpretation is adaptive (imitative) rather than reflective. Low SRL students nominally reach C4, but essentially achieve this through cheating and lack genuine mathematical ability. They can only perform basic problem formulation (e.g., variable substitution) and fail at strategy application and interpretation due to low intrinsic motivation, surface learning, and an unsupportive environment, placing their true capability below PISA level 4.

To simultaneously enhance students' self-regulated learning (SRL) and mathematical literacy, a multidimensional strategy targeting key stakeholders is essential. Teachers must implement metacognitive strategies such as think-aloud and error analysis, utilizing organizational tools like Cornell notes and graphic organizers, while delivering differentiated SRL interventions: the Pomodoro Technique for high-SRL students to reduce hasty errors, scaffolding for medium-SRL learners to build independence, and growth mindset development coupled with simple contextual tasks for low-SRL students. This necessitates teacher training in formative and remedial assessment and revitalizing classroom culture through process-based assessments (e.g., portfolios) to foster an inclusive, mistake-tolerant environment. Concurrently, students must optimize strategies aligned with their SRL level: high-SRL learners focusing on time management (Pomodoro), medium-SRL students engaging in active collaborative learning to boost confidence, and low-SRL students internalizing a growth mindset (emphasizing effort), tackling contextual tasks, using organizational tools, and viewing errors positively for reflection. Researchers should prioritize developing new instruments to measure mathematical literacy and thinking skills, further explore the link between mathematical literacy and SRL across diverse topics or its correlation with other factors, and methodologically enhance external validity by scrutinizing population definition, sampling, and subject selection. Collectively, this approach equips students with adaptive, systematic, and reflective strategies to tackle higher-order thinking skills (HOTS) challenges and develop sustainable critical thinking.

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