

Research Article

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Next-Level Learning: Classifying Self-Regulated Learning in Mathematical Problem-Solving

Muhammad Noor Kholid, Fadhil Naufan

Abstract

Background/purpose. Learning mathematics often presents challenges for students, particularly in problem-solving and establishing mathematical connections. Self-regulated learning allows students to direct, adjust, and control their learning processes. This approach is essential in encouraging students to manage their learning strategies effectively when solving mathematical problems. This study introduces a new classification of self-regulated learning in mathematical problem-solving, which is aligned with the three key aspects of self-regulated learning.

Materials/methods. A qualitative descriptive approach was employed in this research, utilizing purposive sampling to select 20 students from three different islands in Indonesia, all of whom engaged in self-regulated learning while solving mathematical problems. Data collection was carried out through tests, observations, and interviews. The collected data were analyzed through three stages: data reduction, data presentation, conclusion drawing, and verification.

Results. The results of the study reveal three classifications of self-regulated learning in mathematical problem-solving: connective, visualization, and direct.

Conclusion. These findings provide new insights into how students manage their learning in the context of mathematics and offer practical implications for mathematics education in Indonesia. The study highlights the importance of understanding how self-regulated learning can be categorized and applied to improve mathematical problem-solving skills.

1. Introduction

Mathematics holds significant relevance in daily life; however, many individuals perceive it as challenging and confined to academic settings. Mathematical literacy is crucial not only for everyday activities and financial management but also for fostering critical thinking (Serin, 2023). Furthermore, critical thinking constitutes a key competency in mathematical problem-solving (Kholid et al., 2020). Despite its importance, students often face challenges such as anxiety, lack of interest, and negative perceptions of mathematics (Pokhrel, 2023). Beyond academic pursuits, the significance of mathematics extends to personal development and growth in various domains (Sharma, 2021). The ability to apply mathematical concepts to real-life situations is closely linked to the development of learning independence. Mathematics education must focus on cultivating student autonomy through suitable learning models and media to enhance motivation. By fostering learning independence, individuals are empowered to contribute to national competitiveness and understand the value of mathematics in problem-solving. Then a problem means a task for which the solution path is not immediately apparent (NG & TOH, 2023). Educators play a vital role in preparing students for the demands of modern society (Serin, 2023).

The learning of mathematics poses various challenges, particularly in problem-solving and establishing mathematical connections. Research indicates that self-regulated learning (SRL) is an active, goal-oriented process involving regulation of cognition, motivation, and behavior (Puustinen & Pulkkinen, 2001; B. J. Zimmerman, 1986), and that students who effectively engage in SRL strategies tend to achieve higher academic performance (Dent & Koenka, 2016). Recent studies have shown that SRL positively correlates with students' ability to solve mathematical problems through effective planning and reflection (Fauzi & Widjajanti, 2018; Özcan, 2016) and also reflective thinking (Kholid et al., 2022; Sa'dijah et al., 2020). In particular, meta-analytical reviews confirm that SRL instruction leads to moderate to high gains in mathematics achievement across educational levels (Dent & Koenka, 2016; Donker et al., 2014). Meta-analyses also show that extended SRL training significantly enhances achievement in domains including mathematics (Dignath & Büttner, 2008; Donker et al., 2014). While essential in problem-solving, many students struggle to effectively employ SRL. Self-regulated learning involves directing, adjusting, and managing one's learning process, fostering greater independence (Nugroho et al., 2021). Additional studies suggest that students who exhibit higher levels of SRL make fewer errors in understanding inter-topic relationships and in applying mathematical principles to real-world contexts (Ishartono et al., 2023). Moreover, SRL is instrumental in developing a learner's sense of agency, as it provides opportunities for students to articulate their thoughts and observe the cognitive processes of others (Darr & Fisher, 2005). Although SRL is emphasized during online learning, where students must engage independently from home, this study finds that many students still exhibit low levels of SRL, highlighting the need for improvement in students' self-learning attitudes (Rahmadeni, 2021). Students' ability to self-regulate during mathematical problem-solving is positively related to the development of their metacognitive skills (Yorulmaz et al., 2021). While SRL is widely studied in mathematics education, existing research tends to focus on measuring its impact or identifying its components. This study offers a novel contribution by classifying SRL behaviors during mathematical problem-solving, revealing how different students regulate their learning in distinct ways. Such a classification has not been clearly articulated in previous literature and is vital for developing context-specific teaching interventions.

2. Literature Review

Recent research defines SRL in mathematics education as an active and constructive process wherein learners set goals, monitor, regulate, and control their cognition, motivation, and behavior (Mahmoodi et al., 2014). SRL is indispensable for students to manage their learning processes efficiently, particularly in mathematics education (Fauzi & Widjajanti, 2018). This active process

involves students employing self-directed behaviors, thoughts, and actions to achieve their learning objectives (Kumyoung et al., 2024), encompassing cyclical phases of planning, performance control, and self-reflection (Fauzi & Widjajanti, 2018). SRL incorporates various strategies, such as goal setting, self-motivation, and self-evaluation (Fauzi & Widjajanti, 2018; Nugroho et al., 2021). Through SRL, students gain the autonomy to select methods to achieve specific learning goals (Raaijmakers et al., 2018). Furthermore, SRL is closely related to self-efficacy and mastery goal orientation (Mahmoodi et al., 2014). In mathematical problem-solving, SRL encompasses planning, monitoring, controlling, and reflecting on the process (Nugroho et al., 2021). Students with a higher interest in learning tend to achieve better outcomes than their peers with moderate or low interest. Moreover, students with moderate interest tend to outperform those with low interest. In general, SRL has been shown to enhance math achievement and foster the desired affective outcomes (Mahmoodi et al., 2014). Besides, students can be more active in their assessment (Kholid et al., 2019) and also strengthen their mathematical connection (Masduki & Safitri, 2022).

Mathematics is often perceived as a complex subject, which influences students' motivation and receptivity toward it (Bringula et al., 2017). SRL has been demonstrated to support the development of mathematical problem-solving abilities, as students' capacity to manage cognitive processes plays a crucial role in their success in solving problems (Masduki et al., 2020). Mental effort in problem-solving tasks enhances self-monitoring and self-regulation, both at the item level and throughout the task sequence (van Gog et al., 2020). The SRL process in mathematical problem-solving involves the stages of planning, monitoring, controlling, and reflecting (Nugroho et al., 2021). There exists a significant relationship between mathematical problem-solving skills and the three dimensions of SRL: metacognition, motivation, and behavior (Özcan, 2016). With learning independence, students can integrate academic learning and self-control, motivating them to pursue their goals independently. This independence fosters a sense of responsibility for their learning process and encourages the establishment of learning objectives. Moreover, it provides students with the freedom to learn without external pressure, empowering them to become independent learners.

The components of SRL encompass preparation, implementation, and evaluation. According to Ortube et al. (2024) that each aspect is subdivided into several indicators. In the preparation phase, indicators include reviewing learning objectives, determining resources, and selecting appropriate learning strategies. The implementation phase focuses on monitoring learning activities and outcomes. The evaluation phase includes self-reflection on learning outcomes, assessing learning experiences, and deriving conclusions for future learning. These factors align with problem-solving steps such as problem comprehension, planning, execution, and solution evaluation (Bayuningsih et al., 2017). Additionally, motivation, metacognition, and behavior are vital dimensions of SRL that contribute to problem-solving capabilities (Özcan, 2016). Overall, the development of SRL strategies can significantly enhance students' problem-solving abilities in mathematics across different educational levels.

SRL is a process in which students actively regulate, control, and monitor their learning to achieve academic objectives. Recent research has identified several factors and indicators influencing SRL. Internal factors such as knowledge, motivation, and metacognitive abilities are crucial for developing SRL (Kim et al., 2023; Sinkkonen & Tapani, 2024). External factors, including the learning environment, parental support, and quality of instruction, also play a significant role (Duckworth et al., 2014; Panadero et al., 2017). Indicators of SRL include goal setting, learning strategies, monitoring, and the evaluation of the learning process and outcomes (Boekaerts et al., 2000; B. J. Zimmerman, 2000).

Given the aforementioned context, this research seeks to explore the classification of SRL in the context of solving mathematical problems. This gap provides a basis for examining the role of SRL classifications in improving students' problem-solving abilities. Understanding these classifications

will enable the formulation of more effective learning strategies that support the development of students' learning independence and enhance their academic achievements, particularly in mathematics.

Researchers have conducted a review of studies related to self-regulated learning and categorized them into three primary domains: (1) factors influencing self-regulated learning, (2) the impact of self-regulated learning on students, and (3) self-regulated learning in mathematics education.

The first category, focusing on the factors affecting self-regulated learning, highlighted several key elements, including: (1) Personal factors such as metacognition, motivation, and goals (Hindradjat et al., 2022; Persico & Steffens, 2017), (2) Behavioral factors, including learning strategies and self-efficacy (Omari et al., 2020; Panadero et al., 2017), and (3) Environmental factors such as social support and learning environment conditions (Astuti & Rozikin, 2024).

The second category, examining the impact of self-regulated learning on students, identified several outcomes, including: (1) Improvements in academic ability (Ha et al., 2023; Panadero et al., 2023; Pérez et al., 2022; Xu et al., 2023), (2) Development of metacognitive skills (Brenner, 2022; Rahmawati & Retnawati, 2022), (3) Enhancement of reflective thinking skills (Chatti et al., 2023; Suraworachet et al., 2022; Wallin & Adawi, 2018), and (4) Increased learning awareness (Hamzah et al., 2023; Karlen et al., 2024; Lourenço & Paiva, 2024).

The third category, focusing on self-regulated learning in mathematics education, revealed: (1) The impact of self-regulated learning on mathematical problem-solving skills (Amaliyah et al., 2022; Hidayah et al., 2022; Samnia Hammod & Paz-Baruch, 2024), (2) Classifications of students based on their level of self-regulated learning (Alyani & Ramadhina, 2022; Istiqomah et al., 2022; Zhang et al., 2021), and (3) The relationship between self-regulated learning and the learning environment (Gambo & Shakir, 2021; Jin et al., 2023; Yu, 2023). Figure 1 illustrates the research landscape, encompassing both previous studies and prospective areas for further investigation.

Although SRL is often conceptualized as a universal construct, recent studies have highlighted that its expression and effectiveness may differ across cultural contexts (Efklides, 2011; Hofer, 2021; Li, 2012). Cultural norms influence how learners regulate their motivation, cognition, and behavior—for instance, collectivist cultures may emphasize socially mediated regulation, while individualistic cultures promote autonomous regulation. In the Indonesian context, educational practices are shaped by social harmony, teacher-centered norms, and exam-driven environments (Suryadi, 2019), which may influence how students self-regulate their learning in practice. However, studies that explore how SRL manifests in such cultural contexts remain limited.

This study addresses that gap by classifying SRL as observed in Indonesian students' real-time mathematical problem-solving. By situating the classification within Indonesia's socio-educational setting, the research offers culturally relevant insights that may differ from SRL models developed in Western contexts. After reviewing existing literature on self-regulated learning and categorizing the findings into three key areas, the researcher has identified several potential research avenues, including: (1) the classification of self-regulated learning, (2) the assessment of self-regulated learning levels in mathematical problem-solving, (3) the development of technology-based media to enhance self-regulated learning, and (4) the creation of instructional models to improve self-regulated learning. This year's research focuses on the classification of self-regulated learning. The following figure outlines the progression from prior research to future research opportunities.

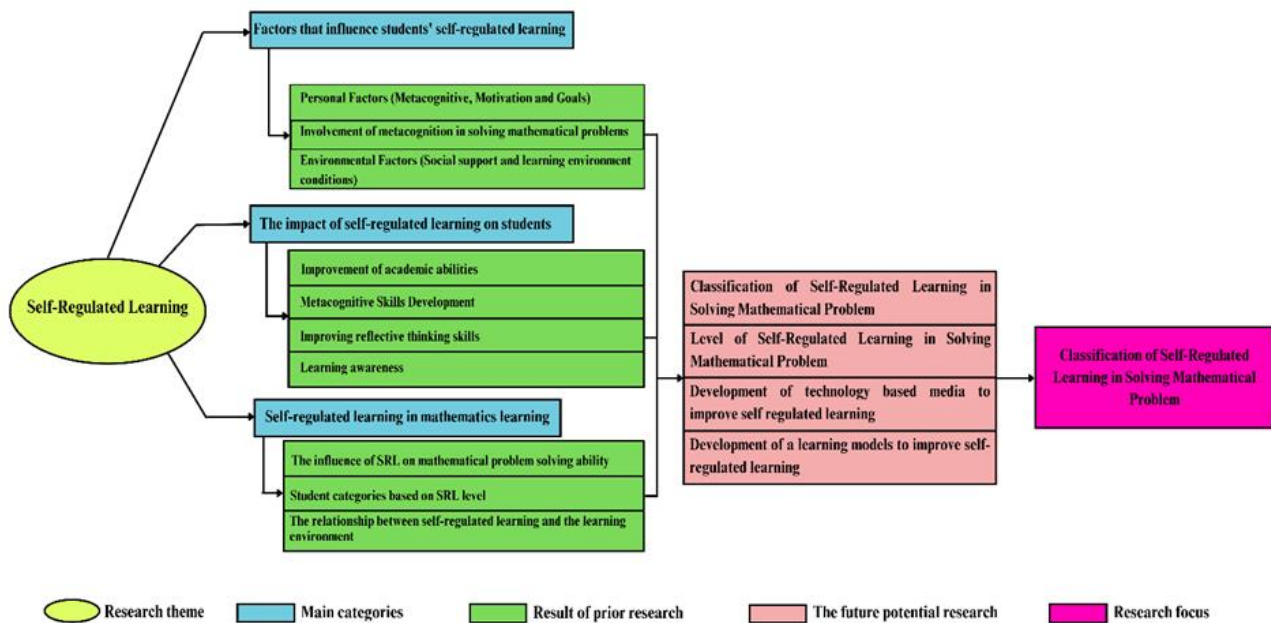


Figure 1. The research position

Following a comprehensive review of research on self-regulated learning, which was categorized into three distinct areas, the researcher identified several promising avenues for future research. These include: (1) the classification of self-regulated learning, (2) the assessment of self-regulated learning levels in mathematical problem-solving, (3) the development of technology-based media to enhance self-regulated learning, and (4) the creation of learning models aimed at improving self-regulated learning. The current year's research is primarily focused on the classification of self-regulated learning. The subsequent figure illustrates the progression from prior research to potential and future research directions.

This study aims to classify students' self-regulated learning abilities in solving mathematical problems, specifically focusing on probability material. Additionally, the study seeks to provide an overview of the grouping of students based on aspects such as motivation, metacognition, and behaviors that emerge during the problem-solving process. The findings of this research are expected to serve as a foundation for educators to develop more effective learning strategies that promote student independence in learning. Furthermore, the results may provide valuable insights for future studies aimed at enhancing students' ability to manage their learning process, particularly in the context of solving mathematical problems.

Classifying students' self-regulated learning in mathematical problem-solving is crucial for advancing educational outcomes. The results of this study will contribute to the theoretical framework for subsequent research aimed at improving students' self-regulated learning skills. This research is in line with the priorities outlined in the National Research Master Plan (RIRN) of Indonesia, which highlights key themes in social humanities, arts and culture, and education from 2017 to 2045, particularly focusing on aspects of education and culture. Figure 2 illustrates the research focus.

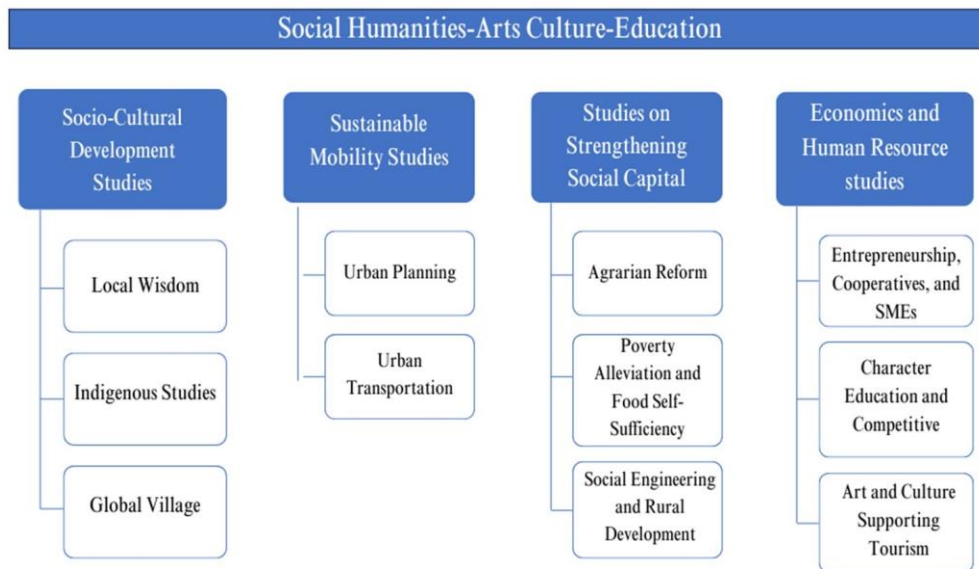


Figure 2. Research Focus: Social Humanities, Cultural Arts, and Education.

3. Methodology

3.1. Research Design

This study employs a qualitative descriptive approach, which is used to obtain an in-depth and accurate understanding of students' self-regulated learning behaviors during mathematical problem-solving. A qualitative descriptive approach is particularly suitable for exploring complex, context-specific educational phenomena that are not yet fully theorized or categorized (Lambert, 2012; Sandelowski, 2000).

The aim of this study is to classify students' SRL strategies as they naturally occur in the context of solving mathematical problems, without manipulating or intervening in the learning environment. Therefore, a qualitative descriptive design allows the researcher to describe variations in SRL strategies—metacognitive, motivational, and behavioral—based on actual student performance, reflections, and processes. This approach supports the inductive development of classifications grounded in participants' authentic problem-solving experiences.

3.2. Participants

The participants in this study consisted of 20 students selected through purposive sampling. This method was chosen because the study aimed to explore specific behaviors—self-regulated learning (SRL) strategies during mathematical problem-solving—which require participants who actively engage in such processes. According to Patton (2002), purposive sampling is appropriate in qualitative research when the goal is to obtain in-depth understanding from information-rich cases.

The sample size of 20 was determined based on the principle of data saturation, a common criterion in qualitative research where additional data no longer yield new insights (Guest et al., 2006). During preliminary coding and comparative analysis, the researcher found that patterns of SRL behavior began to repeat after analyzing around 15 participants, and no new themes emerged beyond the 18th subject. Thus, 20 participants were deemed sufficient to ensure both diversity and theoretical saturation in SRL classifications.

Furthermore, the participants were drawn from three different regions (Java, Sumatra, Borneo) to provide heterogeneity in academic background and cultural setting, thereby increasing the contextual richness of the SRL classifications.

3.3. Research Tools

In line with qualitative research traditions, the primary research instrument in this study was the researcher, who functioned as the planner, data collector, analyzer, and interpreter (Creswell & Creswell, 2014). As the central instrument, the researcher played a critical role in observing the students' problem-solving processes, conducting interviews, and interpreting verbal and written data.

To ensure the credibility and objectivity of the findings, several strategies were implemented. First, triangulation was used by collecting data from multiple sources—student worksheets, audiovisual recordings, and interview transcripts—thereby reducing the likelihood of bias from a single data stream (Patton, 2002). Second, peer debriefing was carried out with fellow researchers to validate the coding, categorization, and interpretation of student SRL behaviors. Third, the researcher maintained a reflexive journal throughout the research process to monitor personal assumptions, decisions, and potential biases (Lincoln, Y. S. and Guba, 1985). These steps helped uphold the trustworthiness of the research and reinforced the rigor of qualitative analysis.

In line with qualitative research traditions, the primary research instrument in this study was the researcher, who functioned as the planner, data collector, analyzer, and interpreter (Creswell & Creswell, 2014). As the central instrument, the researcher played a critical role in observing the students' problem-solving processes, conducting interviews, and interpreting verbal and written data. The mathematical problem sheets used in this study were developed specifically to assess students' self-regulated learning strategies within the context of probability. The items were constructed to encourage the use of planning, monitoring, and reflective behaviors in problem-solving.

To ensure content validity, the problems were reviewed by three experts in mathematics education with extensive experience in problem design and SRL research. These experts assessed the alignment of each problem with the research objectives, as well as its capacity to elicit metacognitive, motivational, and behavioral responses. Revisions were made based on their feedback to improve clarity, difficulty level, and cognitive demand. While statistical measures of reliability are not typically applied in qualitative studies, the reliability of the instrument was addressed through piloting, where the problems were tested with a group of students outside the main sample. The pilot helped ensure that the problems were understood as intended and triggered observable SRL behaviors during task engagement.

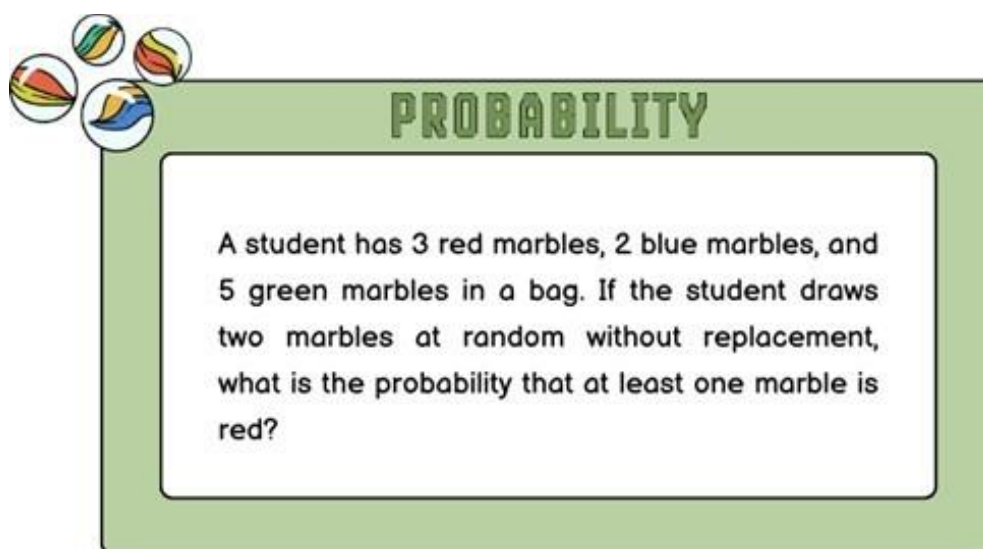


Figure 1. Mathematical Problems

3.4. Data Collection Procedure

The data collection involved three primary techniques: observation, interview, and document analysis (i.e., student work and video recordings). The interviews were conducted in a semi-structured format, allowing the researcher to explore student reasoning processes while maintaining consistency across participants. The interview guide consisted of key questions regarding students' planning strategies, decision-making during problem-solving, and reflections on their motivation and behaviors. Follow-up prompts were used to clarify responses and deepen understanding.

During the observation process, the researcher used a structured observation sheet that included indicators of self-regulated learning based on three domains: metacognitive (e.g., planning steps, monitoring understanding), motivational (e.g., persistence, effort), and behavioral (e.g., time use, strategy implementation). Observations were made while students worked individually, supported by video recordings for triangulation.

Ethical considerations were addressed through formal approval from the university's ethics committee (Universitas Muhammadiyah Surakarta, 2025). Prior to data collection, students and their guardians were given an informed consent form that explained the purpose of the research, data use, anonymity, voluntary participation, and the right to withdraw at any time. Confidentiality was ensured by anonymizing student data and limiting access to research team members only.

3.5. Data Analysis

The researcher collects, categorizes, and compares data with emerging categories, employing the constant comparative procedure (CCP) as described by (Creswell & Creswell, 2014; Glaser, 1992). CCP is an inductive method of analyzing data in qualitative research, progressing from specific instances to general conclusions, used to generate and classify categories of self-regulated learning. Figure 4 illustrates the application of CCP in data analysis.

Figure 4 demonstrates the use of CCP in this study. In this research, CCP is applied by converting raw data from student answer sheets and audiovisual recordings into aspects of self-regulated learning, including metacognition, motivation, and behavior. The data, gathered from different subjects, sources, or over time, is then categorized into the self-regulated learning categories of connective, visualization, and direct based on the problem-solving methods employed. Throughout this process, the researcher constantly compares the indicators to eliminate redundancy and strengthen the evidence supporting the classification of self-regulated learning.

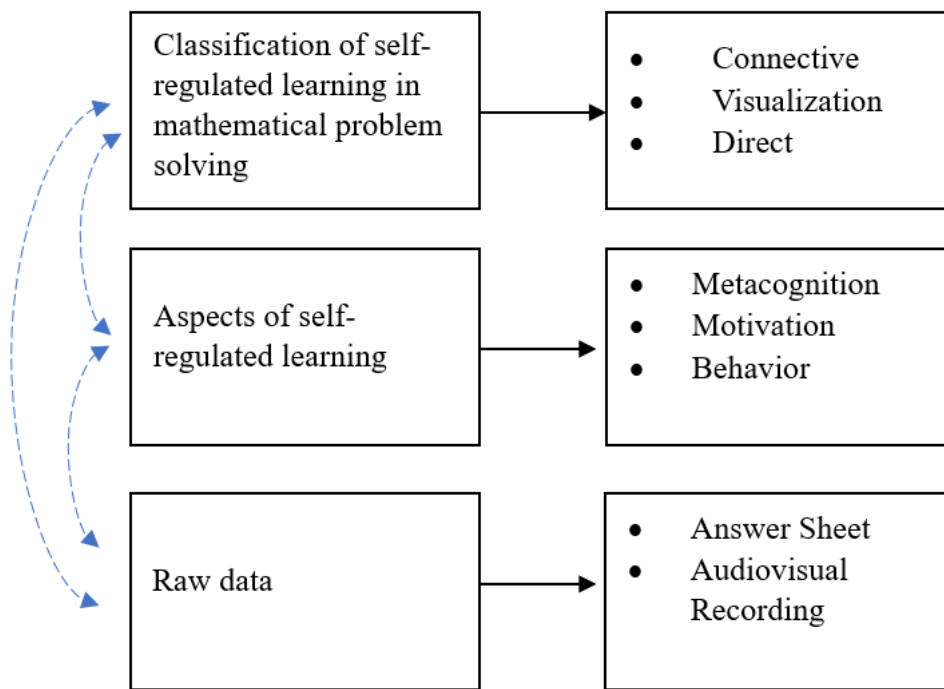


Figure 4. Implementation of CCP in data analysis

4. Results

The results of this study will present data from subjects as they solve problems using self-regulated learning, focusing on how the subjects manage and utilize their learning strategies in addressing mathematical problems. The findings of this study reveal three classifications of self-regulated learning among students in solving mathematical problems: connective, visualization, and direct. Each classification is exemplified by the data from a specific subject: Subject 1 (S-1), who represents the self-regulated learning classification of connective; Subject 2 (S-2), who exemplifies the self-regulated learning classification of visualization; and Subject 3 (S-3), who is categorized under the self-regulated learning classification of direct.

4.1. Classification 1: Connective

The following describes the connective results in classifying self-regulated learning to solve mathematical problems in Figure 5.

Figure 5 is the answer to S-1. The first step taken by S-1 is to analyze the information provided in the question. In the metacognitive aspect, S-1 demonstrates good planning ability by identifying the important components of a problem and relating them to the concept of combination, demonstrating connective ability in mathematics. S-1 counts the total marbles ($3+2+5=10$). The intrinsic motivation is seen in the time of S-1's rigor and diligence in outlining each completion step. Furthermore, S-1 uses combination notation $10C2$ to calculate the number of ways to take two marbles out of 10 marbles. The behavioral aspect can be seen from the neatness and systematic writing at each step of calculating details $10C2 = \frac{10!}{2!(10-2)!} = \frac{10 \times 9}{2 \times 1} = 45$.

Original Version
$n = 3 + 2 + 5 = 10$ - Red Diambil 2 kelereng dari 10: ${}_{10}C_2 = \frac{10!}{2!(10-2)!}$ $= \frac{10 \cdot 9 \cdot 8!}{2 \cdot 1 \cdot 8!}$ $= 45$
Translated Version
$n = 3 + 2 + 5 = 10$ Take 2 marbles out of 10 : ${}_{10}C_2 = \frac{10!}{2!(10-2)!}$ $= \frac{10 \cdot 9 \cdot 8!}{2 \cdot 1 \cdot 8!}$ $= 45$

Figure 5. Connective Classification Answers for Students Part One

Because the red marbles were not taken, the total marbles were 7 with two blue marbles and five red marbles, S-1 then calculated ${}_{7}C_2 = \frac{7!}{2!(7-2)!} = \frac{7 \times 6}{2 \times 1} = 21$. The subject showed high intrinsic motivation by using visualization as a combination formula (${}_{7}C_2$) to describe the possibility of taking the first and second marbles. In the behavioral aspect, the subject showed his organizational ability by developing a solution strategy by calculating the number of red marble combinations that could be taken with the formula ${}_{7}C_2 = 7!/2!(7-2)! = (7 \times 6)/(2 \times 1) = 21$. Thus, the subject shows a structured and directed learning process that involves metacognitive, motivational, and behavioral aspects in solving problems in Figure 6.

Original Version
tidak diambilnya kelereng merah = 7 >> 2 kelereng biru + 5 kelereng merah $= {}_{7}C_2 = \frac{7!}{2!(7-2)!}$ $= \frac{7 \cdot 6 \cdot 5!}{2 \cdot 1 \cdot 5!}$ $= 21$
Translated Version
No red marbles were drawn = 7 >> 2 blue marbles + 5 red marbles $= {}_{7}C_2 = \frac{7!}{2!(7-2)!}$ $= \frac{7 \cdot 6 \cdot 5!}{2 \cdot 1 \cdot 5!}$ $= 21$

Figure 6. Connective Classification Answers for Students Part Two

Lastly in figure 7, metacognitive monitoring at the time of S-1 calculates the chance of taking at least one red marble: $1 - \left(\frac{{}^7C_2}{{}^{10}C_2}\right) = 1 - \left(\frac{21}{45}\right) = \frac{24}{45} = \frac{8}{15} \approx 0,5333$.

In self-regulated learning, S-1 shows excellent metacognitive ability in processing information, as seen in analyzing problems systematically, appropriately using combination strategies, and monitoring each completion step. The motivation aspect can be seen from the thoroughness in solving problems and a strong desire to achieve accurate results. Regarding behavior, S-1 demonstrates effective time management and structured and neat organization of answers. The thought process is structured, and the ability to relate mathematical concepts shows excellent problem-solving metacognition. This is strengthened by strong motivation or self-confidence in facing complex problems, as shown through the consistent completion of the calculation stages in detail. Metacognitive evaluation and reflection are seen when S-1 examines the final result and converts it to decimal form. S-1 self-regulated learning ability, from organizing problem-solving to identifying important information to selecting the right solution strategy. Using the combination method, S-1 successfully connects various mathematical concepts (connected) and demonstrates a good understanding of the concept of chance and the ability to apply it in mathematical problem-solving.

Original Version
diambilnya ~~45~~ setidaknya 1 kelereng Merah $= 1 - \frac{{}^7C_2}{{}^{10}C_2} = \frac{8}{15}$ $= 1 - \frac{21}{45} = 0,5333 \dots$ $= \frac{45}{45} - \frac{21}{45}$ $= \frac{24}{45}$
Translated Version
at least 1 red marble is taken $= 1 - \frac{{}^7C_2}{{}^{10}C_2}$ $= 1 - \frac{21}{45}$ $= \frac{45}{45} - \frac{21}{45}$ $= \frac{24}{45}$ $= \frac{8}{15} = 0,5333 \dots$

Figure 7. Connective Classification Answers for Students Part Three

4.2. Classification 2: Visualization

The following describes the visualization results in self-regulated learning to solve mathematical problems, as shown in Figure 8. Figure 8 is the answer to S-2 on the classification of self-regulated learning solving mathematical problems. To solve the mathematical problem, in the metacognitive aspect, S-2 carried out the planning process by writing down initial information in the form of the number of marbles of each color and the total marbles, showing awareness in regulating their thinking process. Intrinsic motivation can be seen from S-2 using visualization as a tree diagram to illustrate the possibility of picking the first and second marbles. Regarding behavior, S-2 shows organizational ability in developing a solution strategy.

Original Version
Total Kelereng = 3 (Merah) + 2 (Biru) + 5 (Hijau) = 10 Kelereng Peluang terambilnya satu kelereng merah = 2 MM, 1M 1B, 1M 1H
Translated Version
The Total Marbles: 3 (red marbles)+ 2 (blue marbles)+ 5 (green marbles) =10 marbles Probability of taking one red marble = 2 red marbles, 1 red marble, 1 blue marble, 1 red marble, 1 green marble

Figure 8. Student Visualization Classification Answer Part One

In the tree diagram Figure 9, the metacognitive aspect of S-2 shows the monitoring process by illustrating that the first pick can produce red marbles ($\frac{3}{10}$), blue marbles ($\frac{2}{10}$), and green marbles ($\frac{5}{10}$). Then, for each of these possibilities, the behavioral aspect is shown through the consistency and rigor of S-2 during ongoing monitoring by describing the possibility of a second pick with the number of marbles remaining.

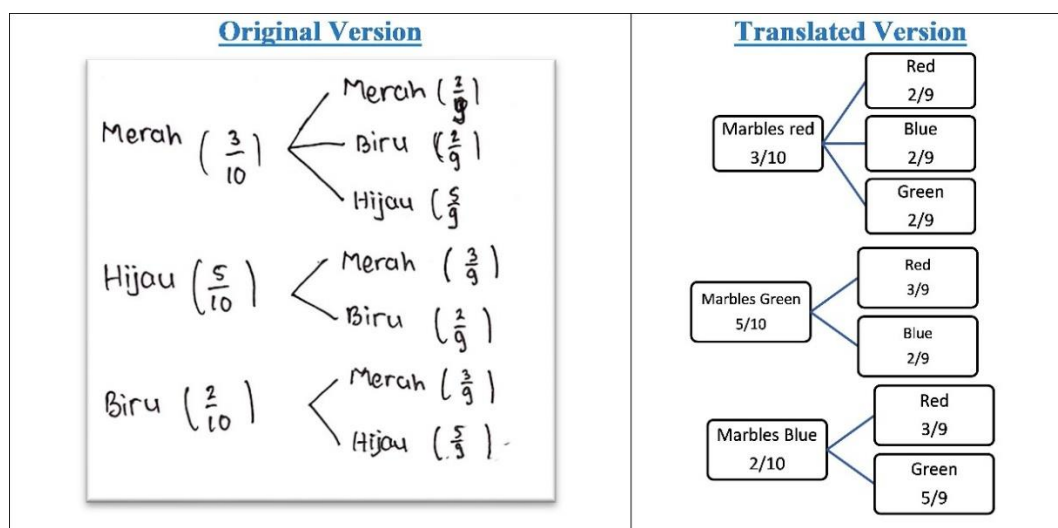


Figure 9. Student Visualization Classification Answer Part Two

S-2 calculates the odds for each combination containing at least one red marble, namely Red-Red (RR), Red-Blue (RB), Red-Green (RG), and Green-Red (GR), which indicate good strategy-setting skills. (RG) Moreover, Green-Red (GR) also shows good strategy-setting skills. As shown in Figure 10, the probabilities for each combination are systematically calculated, demonstrating the student's ability to apply probability concepts effectively.

Original Version	Translated Version
Diperoleh : Peluang (MM) = $\frac{3}{10} \times \frac{2}{9} = \frac{1}{15}$ P (MB) = $\frac{3}{10} \times \frac{2}{9} = \frac{1}{15}$ P (MH) = $\frac{3}{10} \times \frac{5}{9} = \frac{1}{6}$ P (HM) = $\frac{5}{10} \times \frac{3}{9} = \frac{1}{6}$ P (BM) = $\frac{2}{10} \times \frac{3}{9} = \frac{1}{15}$	Obtained: Probability (2 red) = $\frac{3}{10} \times \frac{2}{9} = \frac{1}{15}$ Probability (1 red, 1 blue) = $\frac{3}{10} \times \frac{2}{9} = \frac{1}{15}$ Probability (1 red, 1 green) = $\frac{3}{10} \times \frac{5}{9} = \frac{1}{6}$ Probability (1 green, 1 red) = $\frac{5}{10} \times \frac{3}{9} = \frac{1}{6}$ Probability (1 blue, 1 red) = $\frac{2}{10} \times \frac{3}{9} = \frac{1}{15}$

Figure 10. Student Visualization Classification Answer Part Three

Figure 11 shows S-2 solution process in solving the problem. In solving the problem, Metacognitive S-2 shows the process of cognitive regulation by summing up all the odds that contain at least one red marble: $P(\text{at least one red}) = \frac{1}{15} + \frac{1}{15} + \frac{1}{6} + \frac{1}{6} + \frac{1}{15} = \frac{8}{15}$ or 0,5333. S-2 also shows the process of evaluation and reflection by verifying the results. Aspects of S-2 behavior when performing stacked division to change fractions $\frac{8}{15}$ into a decimal form, indicating $8 \div 15 = 0,5333 \dots$. This shows the ability to self-monitor to check the results of the calculation.

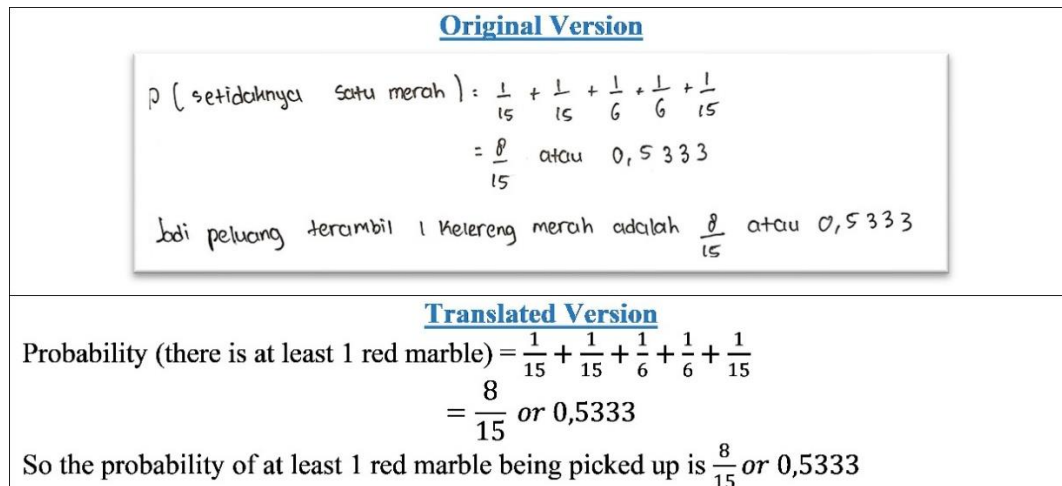


Figure 2. Student Visualization Classification Answer Part Four

Overall, S-2 metacognition can be seen from applying a consistent and systematic solution method to solve this opportunity problem, showing good self-regulated learning ability. S-2 uses a tree diagram to visualize and understand the relationship between the first and second picks based on the information provided. This visualization helps S-2 find a solution to the problem of marble picking opportunities.

4.3. Classification 3: Direct

Figure 12 is the answer to S-3 on the classification of self-regulated learning. To solve the mathematical problem, S-3 shows the metacognitive aspect through the planning process by writing down initial information in the form of the number of marbles of each color (3 red, 2 blue, 5 green). Metacognitive abilities are also evident in how S-3 organizes the completion strategy by writing down the chance formula in a structured manner for at least one red marble: $P(1 \text{ red } 1x) + P(1x \text{ 1red}) + P(2\text{red})$. $= \left(\frac{3}{10} \times \frac{7}{9}\right) + \left(\frac{7}{10} \times \frac{3}{9}\right) + \left(\frac{3}{10} \times \frac{2}{9}\right) = \frac{21}{90} + \frac{21}{90} + \frac{6}{90} = \frac{48}{90}$ and perform fractional conversions $\frac{48}{90}$ into decimal form 0,5333.

From the aspect of motivation, S-3 shows independence and confidence in solving the problem directly by determining the formula of opportunities following the problem's context. The behavioral aspect of S-3 can be seen from the consistent completion of the planned flow. S-3 shows good monitoring and self-evaluation skills by reflecting on their understanding and writing conclusions that reflect the solution to the problem. Thus, S-3 shows good self-regulated learning in solving mathematical problems, integrating metacognitive abilities in planning and implementing strategies, intrinsic motivation in solving problems, and structured and systematic behavior throughout the problem-solving process.

Original Version

PENYELESAIAN:

Kelereng $\rightarrow$ 3M, 2B, 5H

Peluang setidaknya 1 merah $\rightarrow P(1M1x) + P(1x1M) + P(2M)$

$$\Rightarrow P(1M1x) + P(1x1M) + P(2M)$$

$$= \frac{3}{10} \cdot \frac{7}{9} + \frac{7}{10} \cdot \frac{3}{9} + \frac{3}{10} \cdot \frac{2}{9}$$

$$= \frac{21}{90} + \frac{21}{90} + \frac{6}{90}$$

$$= \frac{48}{90} = \frac{8}{15} = 0,5333$$

Jadi peluang terambilnya setidaknya satu kelereng merah adalah 0,5333.

Translated Version

Marbels $\rightarrow$ 3 red, 2 blue, 5 green

Probability of at least 1 red marble $\rightarrow P(1 \text{ red}, 1x) + P(1x, 1 \text{ red}) + P(2 \text{ red})$

$$\rightarrow P(1 \text{ red}, 1x) + P(1x, 1 \text{ red}) + P(2 \text{ red})$$

$$= \frac{3}{10} \times \frac{7}{9} + \frac{7}{10} \times \frac{3}{9} + \frac{3}{10} \times \frac{2}{9}$$

$$= \frac{21}{90} + \frac{21}{90} + \frac{6}{90}$$

$$= \frac{48}{90} = 0,5333$$

So, the probability of drawing at least one red marble is 0.5333...

Figure 3. Student Direct Classification Answer

5. Discussion

The results of this study indicate that the subjects tend to use self-regulated learning (SRL) strategies when solving mathematical problems. These three classifications demonstrate that students engage significantly in independent learning while solving probability problems. Self-regulated learning refers to an active process in which individuals manage their learning process by planning, monitoring, controlling, and evaluating their progress in a structured manner to achieve specific learning goals. This process incorporates a range of strategies, including cognitive, motivational, and behavioral approaches (Pintrich, 2004)

In the metacognitive aspect, students display planning skills by recording preliminary information, such as the number and type of marbles, relevant to the probability problem. This aligns with B. J. Zimmerman's (2000) theory, which posits that self-regulated learning involves self-planning and self-regulation, enabling students to determine problem-solving strategies independently. The context of self-regulated learning proves to be particularly effective in helping students understand and solve mathematical problems through systematic and structured approaches. One day, students also employ their self-regulated learning into using technology in mathematics learning (Kholid et al., 2023).

The findings suggest that students effectively solve problems by leveraging aspects of self-regulated learning. SRL plays a critical role in assisting students in managing their learning processes using a combination of cognitive, metacognitive, motivational, and behavioral strategies (B. Zimmerman, 1990). The metacognitive component of self-regulated learning includes activities such as planning, goal setting, organizing, self-monitoring, and self-evaluation, all of which occur at various stages throughout the learning process. Motivation within SRL is evident when students exhibit high self-efficacy, a sense of self-connection, and intrinsic interest in the task. The behavioral aspect of SRL involves students' efforts to select, organize, and create an environment that optimizes learning. While SRL encourages independent planning and regulation of problem-solving strategies, students

often struggle to fully comprehend the purpose of the problem, limiting their ability to effectively apply their ideas and prior experiences. Despite these challenges, students apply various methods to solve problems, which results in the same solution, indicating that they employ SRL strategies to address mathematical problems.

In the first classification, Subject 1 (S-1) solves problems by identifying key components and relating them to the concept of combinations, demonstrating the ability to connect different mathematical concepts. S-1 applies combination strategies and careful planning, such as identifying problem components and calculating combinations. The metacognitive aspect is evident through strong analytical and planning skills, while intrinsic motivation drives S-1 to be meticulous and diligent throughout the problem-solving process. According to (Fauzi & Widjajanti, 2018), SRL involves planning, monitoring, control, and reflection—components clearly present in S-1's approach. This is further supported by S-1's strong motivation and self-confidence, which enables them to persist through complex problems, ensuring consistent and detailed calculation. Metacognitive evaluation and reflection are demonstrated when S-1 examines the final result and converts it into decimal form. S-1's SRL abilities are evident from organizing the problem-solving steps, identifying important information, and selecting the appropriate strategy, which successfully connects various mathematical concepts to apply the concept of probability in problem-solving.

In the second classification, Subject 2 (S-2) solves the problem using a different method, but the solution is ultimately the same. S-2 utilizes a tree diagram to visualize the relationships between elements in the problem, helping them to monitor and organize the problem-solving process systematically. This visualization strategy aids in reviewing each step, which is a form of cognitive regulation in SRL, reflecting a high level of cognitive awareness (Boekaerts et al., 2000). S-2's intrinsic motivation is evident in their choice to use tree diagrams as a tool for understanding the problem's possible outcomes more concretely. (Mayer, 2009) supports this approach, suggesting that visual representations help students understand abstract concepts by making them more tangible. Additionally, S-2 demonstrates behavioral SRL through their ability to organize and maintain consistency in the problem-solving process, as evidenced by the structured and precise tree diagrams. S-2's rigorous approach and self-monitoring, such as verifying the final results through stacked division, are indicative of effective cognitive awareness. This aligns with (Bayuningsih et al., 2017), who assert that visualization in SRL enhances students' ability to connect and understand concepts, strengthening their problem-solving skills.

In the third classification, Subject 3 (S-3) approaches the problem directly, employing a straightforward strategy by establishing the relevant probability formula. This direct approach demonstrates S-3's metacognitive ability to plan and execute a structured strategy. Their high motivation and confidence facilitate consistent problem-solving, and their self-evaluation is reflected in their thorough approach to checking their work. According to Özcan (2016), metacognition in SRL is crucial for setting and implementing effective strategies, and S-3's ability to do so leads to successful outcomes in solving mathematical problems.

In addition to cognitive and behavioral dimensions, self-regulated learning also plays a critical role in shaping students' affective characteristics, such as mathematics anxiety and self-efficacy. (Dent & Koenka, 2016; Özcan, 2016) have demonstrated that students with higher SRL tend to report lower levels of math anxiety and greater confidence in their ability to solve problems. These affective variables are not merely by-products but integral to the SRL cycle, influencing students' persistence, emotional regulation, and willingness to engage with complex tasks.

Although this study did not directly measure anxiety or self-efficacy, qualitative observations revealed behavioral markers such as hesitation, avoidance, or persistence that may indicate differing levels of affective engagement. For instance, students in the direct classification appeared more

confident but were prone to over-simplification, while connective learners showed signs of high self-monitoring but sometimes expressed doubt when facing complex conceptual tasks. These patterns suggest that future studies should explicitly examine how SRL interacts with affective variables to influence problem-solving performance more holistically.

This study highlights the significant influence of SRL on students' ability to solve mathematical problems. Students with higher SRL are better able to organize and control their learning processes, leading to improved math performance. These findings are consistent with previous research, which suggests that SRL enhances students' mathematical problem-solving skills through planning, monitoring, and reflection. (Darr & Fisher, 2005) further emphasize that SRL enables students to express their thoughts and observe the cognitive processes of others, ultimately improving their understanding of mathematics.

While the findings align with prior research that emphasizes the importance of self-regulated learning in mathematical problem-solving (Fauzi & Widjajanti, 2018; Özcan, 2016), they also highlight nuances that are not fully addressed in earlier studies. For example, unlike studies that portray SRL as a linear or uniform process (B. J. Zimmerman, 2000), this research reveals that students adopt markedly different SRL strategies—connective, visualization, or direct—even when given the same task. This suggests that SRL is not a one-size-fits-all construct but may vary based on students' prior knowledge, cognitive style, or cultural background.

Interestingly, while visualization is often considered an effective strategy (Mayer, 2009), it did not always lead to accurate or efficient solutions in this study—some students relied heavily on diagrams but made errors in probability logic. It may strengthen students' logical ability (Satriani & Masduki, 2023). This finding partially contrasts with literature that treats visualization as universally beneficial. Similarly, students classified under the direct approach achieved fast solutions but sometimes lacked conceptual clarity, echoing concerns in past research about the limits of procedural fluency (Rittle-Johnson & Schneider, 2014)

These differences illustrate that SRL classifications are dynamic and context-dependent. Therefore, while prior literature generally affirms SRL's benefits, this study provides a more granular understanding of how different SRL types may succeed or struggle depending on task complexity, content domain, and learner profile. A comparative analysis of the three SRL classifications reveals distinct learning preferences and cognitive approaches. Students in the connective classification demonstrate strength in integrating multiple mathematical concepts and show deep metacognitive awareness. This type of regulation often leads to well-structured and accurate solutions, but it may require longer processing time and strong prior knowledge.

Visualization learners, on the other hand, utilize diagrams or graphic representations to clarify relationships and problem pathways. This method is particularly effective for students who struggle with abstract reasoning, as it provides concrete visual anchors. However, its effectiveness depends on the student's ability to construct accurate visual models, and it may not always lead to the most efficient solution. In contrast, the direct classification reflects a pragmatic and goal-oriented approach. These students quickly apply formulas or algorithms based on surface-level recognition of problem types. While this approach can be time-efficient and confidence-boosting, it often lacks conceptual depth and flexibility when dealing with unfamiliar problems.

Each classification thus has distinct strengths and limitations. The connective type excels in conceptual depth, visualization supports strategic clarity, and direct approaches promote procedural fluency. Understanding these differences allows educators to tailor instruction and support based on students' SRL tendencies, helping them to strengthen weaker dimensions while leveraging their natural strengths.

6. Conclusion

The study identifies three classifications of self-regulated learning (SRL) strategies in solving mathematical problems: connective, visualization, and direct. All classifications share the use of key SRL aspects, such as metacognition, motivation, and behavior, but differ in the methods subjects employ to address mathematical problems. In Classification I, subjects using a connective approach exhibit the ability to integrate various mathematical concepts to find solutions, with careful planning, analysis, and high intrinsic motivation, aligning with SRL stages like planning, monitoring, control, and reflection. In Classification II, subjects utilizing a visualization approach rely on tools like tree diagrams to organize and comprehend information, demonstrating effective use of visual aids and high cognitive awareness through cognitive regulation and self-evaluation. Finally, in Classification III, students applying a direct approach solve problems by formulating relevant opportunity formulas and systematically applying them, showcasing strong metacognitive skills, including consistent planning and self-evaluation.

7. Pedagogical Recommendation

The practical implication of this study lies in helping teachers recognize the diversity of SRL strategies used by students—connective, visualization, and direct—and tailor their instruction accordingly. Rather than adopting a one-size-fits-all approach, teachers are encouraged to teach and model multiple SRL strategies explicitly. For example, (1) to support connective learners, teachers can provide structured problem-solving frameworks and encourage concept mapping to help students connect mathematical ideas, (2) to assist visualization-oriented students, the use of visual aids such as tree diagrams, manipulatives, or digital drawing tools (e.g., GeoGebra) can help students represent and organize problem information, and (3) for students who adopt a direct approach, teachers should guide them in reflecting on their solution path. In terms of tools, teachers can incorporate SRL scaffolding templates (e.g., planning sheets, self-monitoring checklists, or reflection journals) into problem-solving tasks. Think-aloud protocols and peer modeling may also enhance metacognitive awareness. Professional development workshops on SRL-focused instruction can equip educators to integrate these strategies in a structured yet flexible way. By making SRL processes visible, guided, and adaptable to student profiles, mathematics instruction can more effectively promote independent and reflective learners and identifying when and why procedural shortcuts work—or fail.

8. Future Research Roadmap

Following a thorough literature review conducted in 2025, researchers have concentrated on the categorization of self-regulated learning in mathematical problem-solving. The results of this review are intended to direct future research initiatives. The research agenda for 2026 is set to explore the degree of self-regulated learning in mathematical problem-solving. In 2027, the emphasis will shift towards the development of technology-based tools to enhance self-regulated learning. The research plan for 2028 will focus on designing instructional models aimed at promoting self-regulated learning. Ultimately, by 2029, the objective is to create a marketing strategy for a ready-to-use self-regulated learning model. In parallel, numerous literature reviews on self-regulated learning have been undertaken, with plans to continue exploring this subject in the years ahead. Figure 13 illustrates the trajectory of this research.

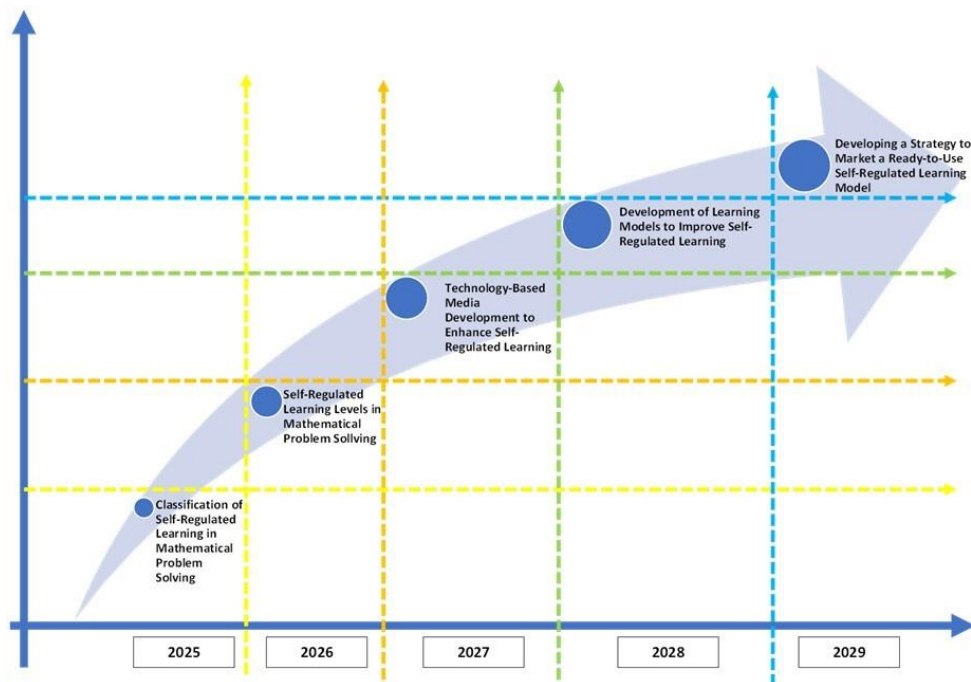


Figure 4. Research Roadmap

9. Implication

The theoretical implication of this study lies in the classification of students' self-regulated learning processes in mathematical problem-solving, emphasizing the differences in their capacity to plan, monitor, and assess their learning. On a practical level, students can refine their learning strategies based on their self-regulatory tendencies, while educators can provide differentiated instruction to aid students in fostering independent problem-solving abilities.

10. Limitation

This study is confined to students within Indonesia. If participants from various regions with diverse educational backgrounds had been included, a more extensive classification of self-regulated learning in mathematical problem-solving could have been achieved.

Declarations

Author Contributions. All authors have read and approved the published version of the article.

Conflicts of Interest. The authors declare no conflict of interest.

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Ethical Approval. This study discovered how students' SRL for mathematical problem-solving. They voluntarily agreed to participate by signing informed consent forms. Their participation does not put them in a dangerous condition and is not physically or mentally harmful. The researchers ensured the confidentiality of the participants' identities throughout the data collection and presentation process, by ethical considerations and guidelines set by the Committee on Publication Ethics (COPE). This study was approved by the Ethics Committee of Universitas Muhammadiyah Surakarta year 2025.

Data Availability Statement. The data that supports the findings of this study are confidential and are bound by the human ethics application.

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