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Self-Regulated Learning for Solving Mathematical Problems: A Systematic Literature Review

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ABSTRACT

Berbagai penelitian telah membahas self-regulated learning maupun kemampuan pemecahan masalah matematika namun secara terpisah. Belum ada kajian systematic literature review yang mengintegrasikan kedua topik tersebut dalam satu kerangka analisis yang komprehensif. Kondisi ini menimbulkan kesenjangan pengetahuan mengenai bagaimana strategi regulasi diri dapat secara efektif mendukung proses pemecahan masalah dalam pembelajaran matematika. Penelitian ini bertujuan untuk memberikan gambaran menyeluruh tentang self-regulation learning untuk menyelesaikan masalah matematika yang meliputi tren penelitian, peran, proses, dan strategi. Systematic literature review ini menggunakan protokol PRISMA dan PICO sebagai panduan pelaksanaannya. Hasil menunjukkan tren penelitian self-regulation dalam memecahkan masalah matematika didominasi oleh pendekatan kualitatif deskriptif, dengan subjek yang bervariasi yaitu siswa, calon guru, dan guru. Dalam memecahkan masalah matematika self-regulation berperan membantu siswa mengelola pikiran, emosi, dan tindakan mereka secara sistematis. Prosesnya, mulai dari perencanaan, pelaksanaan, pemantauan, refleksi, hingga penyesuaian diri. Beberapa strategisnya adalah mendorong siswa untuk merencanakan penyelesaian masalah, mempraktikkan pemantauan diri, mengelola emosi, dan melakukan penyesuaian diri. Implikasi penelitian adalah untuk membantu pendidik memahami kebutuhan spesifik siswa, sehingga strategi self-regulation dapat disesuaikan dengan kemampuan siswa yang beragam.

Various studies have addressed self-regulated learning and mathematical problem-solving skills, but separately. There has not been a systematic literature review has integrated the two topics into a comprehensive analytical framework. This creates a knowledge gap regarding how self-regulation strategies can effectively support problem-solving in mathematics learning. This study aims to provide a comprehensive overview of self-regulation learning for solving mathematical problems, including the research trends, role, process, and strategies. This systematic literature review uses the PRISMA protocol and PICO as its implementation guide. The results show that the trend of self-regulation research in solving mathematical problems is dominated by descriptive qualitative approaches, with varying subjects, namely students, pre-service teachers, and teachers. In solving mathematics problems, self-regulation plays a role in helping students systematically manage their thoughts, emotions, and actions. The process includes planning, implementation, monitoring, reflection, and self-adjustment. Some strategies include encouraging students to plan problem-solving, practice self-monitoring, manage emotions, and make self-adjustments. The implication of the research is to help educators understand the specific needs of students, so that self-regulation strategies can be tailored to the diverse abilities of students.

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INTRODUCTION

Problem-solving refers to students' ability to apply mathematical concepts that they have mastered to solve problems (Muis et al., 2016). Problem-solving is considered a key component in mathematics learning (Hasibuan et al., 2018) and helps students relate the math concepts learned to their application in real life (Verschaffel et al., 2010). Problem-solving is not instilled directly but develops gradually as a thought process. Problem-solving schemes will emerge naturally if students are given the opportunity to develop strategies that are meaningful to them without being forced to memorize procedures. This ability is closely related to the learning process that involves self-regulation (Pape & Smith, 2002). Self-regulation that allows students to actively engage in learning by controlling their planned thoughts, feelings, and actions (Zimmerman, 2005). Problem-solving and self-regulation are complex tasks that require learners to be active and strategic problem solvers (Cleary & Zimmerman, 2004). When solving complex problems, students tend to use self-directed learning strategies (Marcou & Philippou, 2005). Self-regulation can be used as a comprehensive framework to understand how students become active agents in the learning process (Pape et al., 2003). Mathematical problem-solving ability depends on the application of self-regulation strategies, which are theoretically viewed as essential characteristics and contribute significantly to the effectiveness of the problem-solving process (Fadlelmula, 2010). Motivation is an important element in the self-regulation process (Zimmerman, 2005). The stronger a learner's drive to achieve a goal, the greater their efforts in achieving that goal, including in solving math problems.

Self-regulation has become an increasingly important skill for learners in the modern educational environment. Research shows that self-regulation learning can improve academic success, especially in the context of online and blended learning (Dent & Koenka, 2016). These findings underscore the importance of self-regulation in adjusting to a dynamic learning environment. Self-regulation is a thought process that is triggered independently by students through the use of metacognition, motivation, and active behavior (Zimmerman, 1986). In practice, self-regulation encompasses a self-centered learning process, in which students evaluate their learning effectiveness and respond to the feedback received. Learners are required to design their learning paths, set goals, choose the right strategies, monitor progress, reflect on achievements, and adjust their approach when necessary (Carter et al., 2020). Thus, self-regulation plays a key role in the success of the learning process and the academic achievement of students. Including in learning mathematics, an optimal learning process is needed to achieve optimal learning outcomes. When students learn subjects with complex concepts in their learning development, the learning process plays an important role (Khiat, 2022).

Self-regulation is seen as an important foundation in the learning process because it can increase students' motivation and encourage reflection on their learning experiences, which ultimately supports learning achievement (Michalsky & Schechter, 2013). By implementing self-regulation, students can build a deeper understanding of complex material or problems during learning activities (Tian et al., 2018). In addition, behaviors and attitudes that are in harmony with self-regulation also affect students' confidence (Artino & Jones, 2012). Self-regulation as the main indicator of educational achievement such as academic achievement and emotional stability of students (Diamond et al., 2007). Self-regulation as the ability to control thoughts, feelings, and actions to achieve goals (Zimmerman, 2008). Individuals who have good self-regulation are able to maintain optimal balance of emotions, behaviors, cognition, and motivation (Bandura, 1991).

Various studies using the Systematic Literature Review (SLR) approach related to self-regulated learning have been conducted in various learning contexts. For example, the SLR conducted by (Ainulluluah et al., 2022) focused on SRL in online learning based on flipped classrooms supported by interactive e-books and highlighted the importance of student self-regulation in a digital environment. Furthermore, (Simón-Grábalos et al., 2025) through their SLR showed that the integration of self-regulation strategies directly into the lecture process can support the adaptation and learning success of first-year students. Meanwhile, (Ceron et al., 2021) through an SLR on self-regulation in the context of Massive Open Online Courses (MOOC) emphasized how self-regulation plays a role in reducing dropout rates by strengthening self-regulatory control. However, these three reviews focused on SRL as

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a general learning strategy, rather than on how SRL is applied and functions in the context of mathematical problem-solving, which demands more complex cognitive processes. In fact, solving mathematical problems requires not only mastery of concepts, but also the ability of students to analysis the statement, search for resolution strategies, strategy(ies) execution, and solution process control during problem solving (Caballero-Carrasco et al., 2021).

Therefore, this SLR provides a unique contribution by mapping the development of self-regulation research in mathematical problem solving, identifying its contribution to students' problem-solving abilities, outlining the self-regulation processes involved, and determining learning strategies that can be used to optimize these abilities. Thus, this SLR is expected to contribute both theoretically and practically to the development of mathematical problem-solving learning oriented towards students' self-regulation. To fill the identified research gap and confirm the unique contribution of this study, the research questions proposed are as follows:

RQ1: How are research trends on self-regulation in mathematical problem solving evolving?
RQ2: What contribution does self-regulation make to students' mathematical problem-solving abilities?
RQ3: What self-regulation processes are involved in mathematical problem-solving?
RQ4: What strategies can be implemented to optimize mathematical problem-solving through a self-regulation approach?

METHOD

This study uses the Systematic Literature Review method to track, identify, and review various relevant studies to answer research questions. The development of the framework began with a systematic literature search (Wolgemuth et al., 2017). The search source is focused on the Scopus electronic database. Journal articles are searched directly through Scopus database. The selection of the Scopus database is based on its multidisciplinary nature, so that it covers literature from various disciplines that are relevant to the research topic.

In this systematic literature review, the PICO (Population, Intervention, Comparison, Outcome) framework is used to clarify the focus and analysis of the direction of literature selection with the research objectives (Miller & Forrest, 2001). The population component refers to the research subjects, namely students involved in mathematics learning from various levels of education, prospective teachers, and teachers. The intervention component includes the application of self-regulated learning in mathematics learning to support the problem-solving process. Meanwhile, comparison refers to the comparison of two or more mathematics learning processes that do not apply self-regulated learning to assess the improvement of mathematics learning outcomes. The outcome component focuses on improving students' mathematical problem-solving abilities.

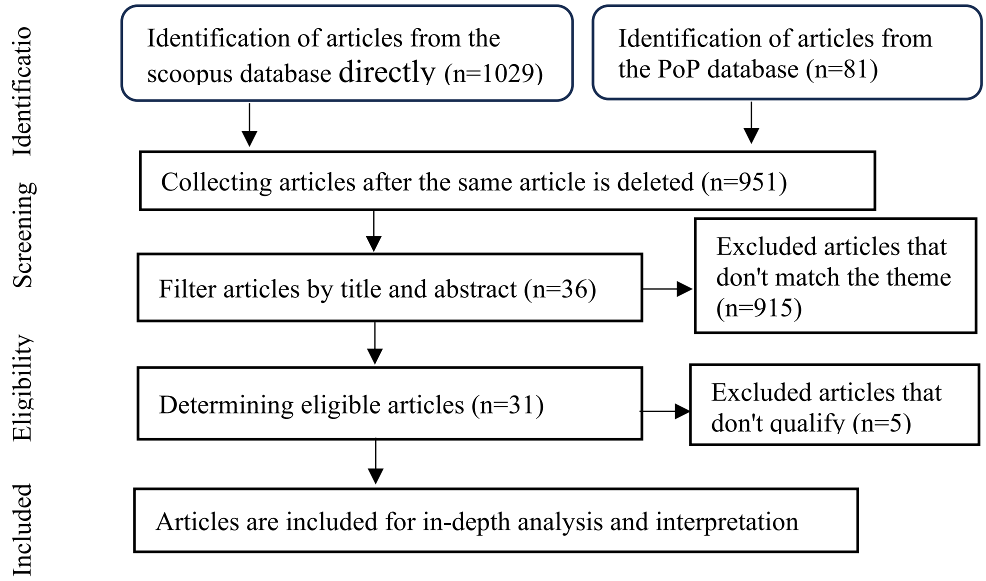

Figure 1. Research flowchart

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The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyzes) protocol was used in this study, which refers to four stages, namely identification, screening, eligibility, and included (Moher et al., 2009). The search process is carried out using the keywords "self-regulation" OR "problem solving ability" OR "mathematics" with article limits from 2019 to 2024. Then the collected literature will be sorted according to criteria: explicitly discussing self-regulation and mathematical problem-solving, in English, open access, published in a peer-reviewed journal, contained a complete description of the research method, presented findings clearly, supported by adequate data, and constituted empirical research.

The identification stage to obtain search results with predetermined keywords obtained 1110 articles. In the screening stage, which is filtering articles by looking at the suitability of the title and abstract of the article, obtained 36 articles. The Eligibility stage, to determine articles according to the specified inclusion criteria. In the included stage, obtained 31 articles that meet the criteria. The flowchart of the article search in this study is as shown in Figure 1.

RESULTS AND DISCUSSION

There are 31 articles that can be collected according to the inclusion criteria. Between 2019 and 2024, articles that promote self-regulation in solving mathematical problems.

Table 2. Overview of studies included in analysis.

No.	Citation	Types of Research	Research Subject
1	(Harding et al., 2019)	Correlation	Secondary school students
2	(Cahyani et al., 2019)	Correlation	Secondary school students
3	(Hughes et al., 2019)	Experiment	Secondary school students
4	(Losenno et al., 2020)	Mixed methods	Primary school students
5	(Salangsang & Subia, 2020)	Descriptive qualitative	Primary school students
6	(El-Adl & Alkharusi, 2011)	Descriptive qualitative	Secondary school students
7	(Shodiqin et al., 2021)	Descriptive qualitative	Pre-service teachers
8	(Oudman et al., 2022)	Descriptive qualitative	Primary school students
9	(Yigletu et al., 2023)	Experiment	Pre-service teachers
10	(Häsä et al., 2024)	Descriptive qualitative	College student
11	(Hallarte et al., 2024)	Correlation	Secondary school students
12	(Huang et al., 2024)	Experiment	Primary school students
13	(Chimmalee & Anupan, 2024)	Experiment	College student
14	(Hidajat, 2022)	Experiment	Secondary school students
15	(Landa et al., 2024)	Correlation	Pre-service teachers
16	(Tachie, 2019)	Descriptive qualitative	Secondary school students and teachers
17	(Caballero-Carrasco et al., 2021)	Mixed methods	Pre-service teachers
18	(Seferian et al., 2021)	Experiment	Primary school students
19	(Říčan et al., 2022)	Descriptive qualitative	Primary school students
20	(Zhidkikh et al., 2023)	Experiment	Secondary school students
21	(Mauer et al., 2023)	Experiment	Primary school students
22	(Gürel et al., 2022)	Descriptive qualitative	Teacher
23	(Lyakhova & Joubert, 2022)	Descriptive qualitative	Secondary school students
24	(Lahdenperä et al., 2022)	Mixed methods	College student
25	(Malaspina & Ampudia, 2022)	Correlation	Preschool students
26	(Castilho et al., 2022)	Descriptive qualitative	College student
27	(Arcoverde et al., 2022)	Descriptive qualitative	Pre-service teachers
28	(Purnomo et al., 2024)	Descriptive qualitative	Primary school students
29	(Göller et al., 2024)	Descriptive qualitative	College student
30	(Arvatz & Dori, 2024)	Experiment	Secondary school students
31	(Peteros, 2024)	Correlation	Pre-service teachers

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Research trends on self-regulation in mathematical problem-solving evolving

The majority of the research was conducted on subjects of high school students. In the type of research, descriptive qualitative research places the most research carried out. The following are the results of self-regulation research trends in solving mathematical problems.

Table 2. Distribution of research trends on self-regulation in solving mathematical problems

Types and Subjects of Research	Preschool students	Primary school students	Secondary school students	College students	Pre-service teachers	Teachers
Experiment		3	4	1	1	
Correlation	1		3		2	
Descriptive qualitative		4	3	3	2	2
Mixed methods		1		1	1	

Based on the data in Table 2, it shows the trend of self-regulation research in solving mathematical problems more using a descriptive qualitative approach. This approach dominates almost all subject levels, such as elementary school, high school, college students, prospective teachers, and teachers. This suggests that researchers tend to explore individual thought processes, strategies, and reflections in organizing themselves when solving mathematical problems. This research allows for an in-depth understanding of the process of self-regulation in mathematical problem solving. Students use self-regulation to solve math problems (Salangsang & Subia, 2020).

The trend of self-regulation research in solving mathematical problems is an important topic across educational levels, with diverse research approaches according to the cognitive level and role of each subject. For example, high school students are considered to have more mature self-regulation skills so that they can be researched both in terms of the effectiveness of learning strategies and the relationship between self-regulation and mathematics learning outcomes. Combining information about self-regulation tactics and strategies used by students with predictive learning analysis can provide a solid foundation for implementing meaningful interventions to enhance learning and support students who are struggling (Zhidkikh et al., 2023). On the other hand, there is a direct relationship between the interaction between teachers and students and parental support for self-regulation in learning mathematics (Hallarte et al., 2024).

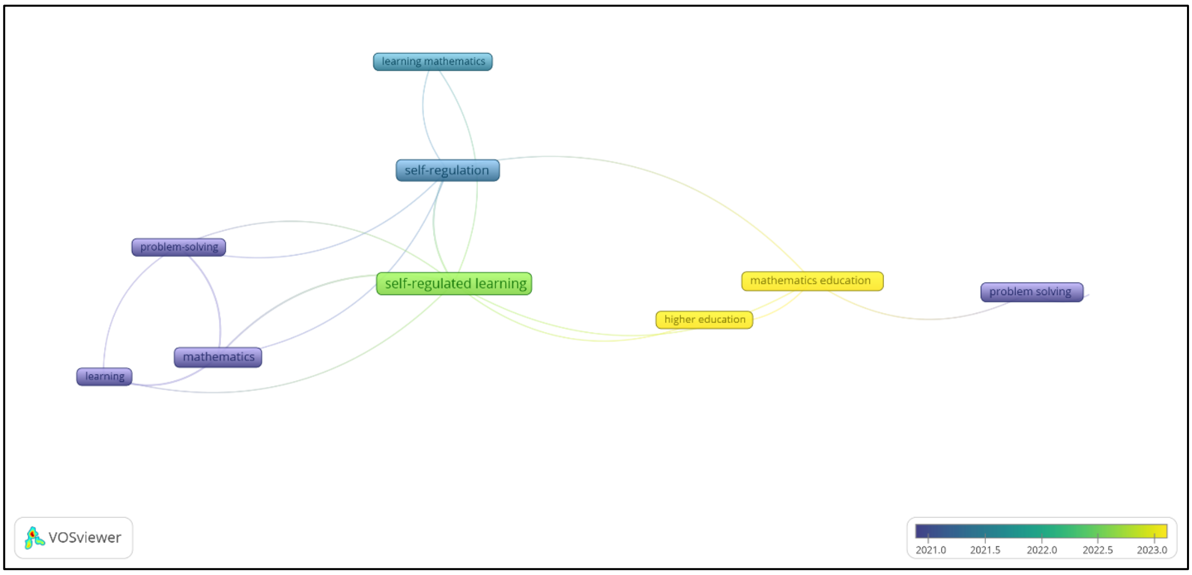

Figure 2. Visualization image of research trends from VOSviewer

The visualization image of research trends from VOSviewer in Figure 2 shows that research topics related to self-regulation in mathematics are in a strategic position that connects various other key concepts such as problem solving, learning, higher education, and creativity. This shows that self-regulation can be the basis that researchers use in understanding and developing mathematical problem-solving skills. Self-regulation and self-assessment skills help them in solving math problems (Tachie, 2019).

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In the newer clusters (in yellow), keywords such as mathematics education and higher education appeared, indicating that in recent years, there has been an increase in interest in the implementation of self-regulation in the context of mathematics education at the university level. This reflects the expansion of the research focus from students in schools to students and prospective teachers, with the aim of strengthening their competence in thinking independently and reflective in dealing with mathematical problems. One of the goals of the prospective teacher education program should be to develop self-regulation skills in learning, so that prospective teacher students are able to become the main drivers in their own learning process and are able to instill these skills in their students in the future (Arcoverde et al., 2022).

The contribution of self-regulation to students' ability to solve mathematical problems

Self-regulation has an important role in solving math problems because it helps students manage their thoughts, emotions, and actions during the problem-solving process. Students use self-regulation to solve math problems (Salangsang & Subia, 2020; Tachie, 2019). Self-regulation can affect student learning outcomes (Losenno et al., 2020), probabilistic level of thinking (Shodiqin et al., 2021), learning approach (Häsä et al., 2024), Problem Solving Performance of Math Story Problems (Huang et al., 2024), the pinnacle of the troubleshooting process (Landa et al., 2024), prediction of learning outcomes (Mauer et al., 2023; Říčan et al., 2022), predict student engagement in online math learning (Purnomo et al., 2024). With this ability, students can plan strategies effectively, such as setting clear goals and choosing the right method of completion. Additionally, self-regulation allows students to monitor the progress of the steps taken, evaluate whether their solution is going as planned, and adjust strategies if needed. In the face of challenges, self-regulation helps students manage their emotions, such as coping with frustration or anxiety, so that they remain calm and focused on solutions. This ability also allows students to manage their time well and maintain consistency in their efforts to solve problems, even when facing complex problems. Students who achieve higher self-regulation are also higher (Harding et al., 2019; Oudman et al., 2022).

After solving problems, self-regulation helps students reflect on the process and the results obtained, ensure the answers are correct, and learn from possible mistakes. Thus, self-regulation not only makes the problem-solving process more effective, but also increases students' independence, confidence, and critical thinking skills. Self-regulation of mathematics can increase motivation (Seferian et al., 2021). Self-regulation can also improve the learning outcomes of students with disabilities (Hughes et al., 2019).

In addition, self-regulation allows students to manage their time efficiently, allocate energy optimally, and maintain consistency in solving problems, even when the problems at hand are very difficult. Self-regulation strategies were reported to be stronger by students who took online courses than those who attended in-person classes.(Lyakhova & Joubert, 2022). They are also able to maintain flexibility, such as switching approaches if the initial method doesn't work, without losing their spirit. After solving problems, self-regulation helps students reflect on the processes that have been carried out, examine the results carefully, and ensure that the answers obtained are reasonable. If there are mistakes, they can learn from them to improve their problem-solving skills in the future. There is a positive relationship between self-regulation and academic performance in mathematics (El-Adl & Alkharusi, 2011).

Furthermore, self-regulation not only supports success in solving math problems, but also builds independence, confidence, and critical thinking skills that are essential for dealing with other challenges in life. This ability also helps students to stay motivated and have a positive approach to mathematics learning, thus forming a strong foundation for achieving academic and non-academic success in the future. Self-regulation is related to mathematical performance (Peteros, 2024).

The self-regulation processes involved in the mathematical problem-solving process

Self-regulation skills in children and parenting patterns are important predictive factors in supporting the early development of mathematical abilities (Malaspina &ampudia, 2022). The process of self-regulation in solving math problems involves a series of stages that help students manage their thoughts, emotions, and actions effectively. The first stage is planning, where students read the questions carefully to understand the problem thoroughly. At this stage, they identify important information, determine the goals they want to achieve, and choose an appropriate completion strategy, such as using

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a diagram, table, or specific algebraic method. Planning also includes setting goals (Losenno et al., 2020).

Next is execution stage, where students begin to implement pre-planned strategies. They follow systematic steps and use relevant mathematical knowledge, such as specific formulas or concepts. In this process, self-regulation helps students stay focused, consistent, and motivated, even when facing obstacles. Students also manage their emotions to maintain concentration and avoid frustration that can interfere with logical thinking processes. Self-regulation of learning Mathematics can be determined together from the role of classroom management and mastery goals (Cahyani et al., 2019).

After the execution, students enter monitoring stage. At this stage, they monitor the progress of their work to ensure the steps taken are in accordance with the plan. If there are errors or impasses, students can immediately identify problems and adjust strategies. This monitoring process includes evaluating the logic and accuracy of intermediate results to ensure that the solution is moving in the right direction. Teachers' monitoring and control behavior (self-regulation process) is influenced by the goals they set (Gürel et al., 2022).

When a solution has been found, students proceed to reflection and evaluation stage. They re-examine the entire process and make sure that the final answer is appropriate and reasonable. If there is a mistake, students analyze the cause and learn from the experience to improve their abilities in the future. This reflection also helps students assess the effectiveness of the strategies used. Learning objects with feedback have an effect on Self-regulation in learning mathematical concepts (Castilho et al., 2022). Self-regulation has implications for practice assessment, and the potential for problem-solving, especially when it comes to learning maths with peers (Göller et al., 2024).

The final stage is self-adjustment, where students adjust based on previous evaluations. They can develop new, more effective strategies for future use, while also evaluating how their emotions, motivations, and concentration affect the problem-solving process. This process is dynamic, and students may return to previous stages if they encounter obstacles. By following this process of self-regulation, students can not only solve math problems more effectively but also build cognitive and emotional skills that support lifelong learning. Students' self-regulation skills consist of factors such as goal setting, elaboration, seeking help, reflection on actions, and reflection for actions (Arvatz & Dori, 2024).

Strategies applied to optimize mathematical problem solving through a self-regulation approach

To improve mathematical problem-solving through self-regulation, steps that can be taken include several strategic approaches. There is a direct relationship between the interaction between teachers and students and parental support for self-regulation in learning mathematics (Hallarte et al., 2024). First, students need to be taught to plan well before starting to solve problems, such as understanding problems, setting goals, and choosing the right strategy. The application of creative cooperative learning methods has a positive effect on students' self-regulation skills in mathematics (Hidajat, 2022). Research by (Chimmalee & Anupan, 2024) explained that the Predict-Discuss-Explain-Observe-Discuss-Explain (PDEODE) strategy has a positive effect and can be adopted as an approach to reflect on student self-regulation. Teachers can help by providing explicit guidance on how to identify important information and create a work plan.

Second, students need to be trained to monitor their progress during the problem-solving process. They can be taught to ask themselves questions, such as "Is my move right?" or "Does this solution make sense?" This monitoring helps students realize if they are off track or make mistakes. Research by (Lahdenperä et al., 2022) report a student-centered learning environment that supports undergraduate mathematics students to implement self-regulation.

Third, it is important to train students in managing their emotions, especially when facing difficult issues or feeling frustrated. Emotion control has a positive impact on the development of mathematical problem-solving and not only fosters learning, emotional and cognitive self-regulation but also life skills. (Caballero-Carrasco et al., 2021) Teachers can provide mindfulness exercises or simple relaxation strategies to help students stay calm and focused. Fourth, students need to be taught to reflect on their processes and results after solving problems. They can analyze what works, what doesn't, and why it happens, so they can learn from experience.

Finally, teachers should encourage students to self-adjust based on their reflections, such as trying new strategies or improving their way of thinking. With consistency in practicing these steps, students

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can develop strong self-regulation skills, which will increase their effectiveness in solving math problems. Integrating self-regulation strategies used by students with predictive learning analytics can be a foundation for improving learning and addressing learning difficulties (Zhidkikh et al., 2023). Therefore, one goal of preservice teacher education programs should be to encourage the development of self-regulated learning skills, enabling them to actively participate in their own learning process and instill these skills in the students they will teach in the future (Arcoverde et al., 2022). In the field of mathematics, there is an increase in the self-regulation of prospective teachers after taking a course on basic algebraic concepts (Yigletu et al., 2023).

CONCLUSIONS

Research on self-regulation in mathematics problem-solving is dominated by qualitative descriptive approaches with various subjects, ranging from students, pre-service teachers, and teachers' problems. Self-regulation has been shown to have an important contribution in mathematics problem-solving, as it helps students systematically manage their thoughts, emotions, and actions. In the problem-solving process, self-regulation involves several stages, starting from planning, execution, monitoring, reflection and evaluation, and self-adjustment. To optimize mathematical problem solving through self-regulation, several learning strategies that can be applied include encouraging students to plan problem solving, practice self-monitoring, manage emotions, and make self-adjustments. Further research needs to be conducted longitudinally to observe the development of self-regulation in solving mathematical problems over time.

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