Metacognitive Skills in Mathematics Learning: A Systematic Review of Literature

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Abstract

The goal of mathematical learning strategies is to create highly competent skills people with various problem-solving processes. Nonetheless, conceptual grasp remains a difficult issue in mathematics. So, the review article is about metacognitive skills and mathematical problem-solving. This paper aims to determine the impact of metacognitive skills on problem-solving skills in mathematics learning in a metacognitive learning strategy. metacognition skills are an important factor in the problem-solving process in mathematics. The review of thirteen articles related to metacognitive strategy and problem-solving in mathematics learning found that the metacognitive skills regarding planning, monitoring, and evaluation affect the development of a more profound comprehension of the learning process in mathematics, empowering them to become more effective and independent learners in mathematics learning. Additionally, these skills have a significant role in understanding the problem, making a plan, carrying out the plan, and looking backward to the solution in the problem-solving of mathematics learning.

Keywords: metacognition, metacognition skills**,** metacognition learning strategy, problems solving,

Introduction

The learning approach is one of the most essential things contributing to students' competency in mathematics(Abu Bakar & Ismail, 2020). Metacognition is understanding one's thought processes and controlling and monitoring them while performing a task (Rhodes, 2019). The Metacognition approach refers to ‘thinking about thinking’ or ‘learning how to learn’(Beach et al., 2020). it describes methods that assist students as two components involving metacognitive knowledge and metacognitive regulation in comprehending and controlling their learning processes (Stanton et al., 2021). For instance, according to Koriat(2007), metacognition is what learner know about cognition, their cognitive processes, and how to apply this knowledge to modify their information processing and behavioral patterns. Therefore, the regulation of cognition enhances the learners' metacognitive abilities in planning, monitoring, controlling, and assessing cognitive processes(Koriat, 2012). Planning entails selecting the best course of action for the task, while monitoring is being conscious of one's performance while working on a task. Control and assessment entail a comprehensive process review(Schraw & Moshman, 1995).

According to Corte et al.(2011), problem-solving in mathematics can be built up competent through the following five categories of cognitive, affective, and conative components: (1) organizing of the domain-specific knowledge of the contents i.e., facts, symbols, algorithms, concepts, and rules. (2) Heuristic methods i.e., decomposing a problem into subgoals; making the appropriate representation of the problem so that it can make a probability of finding the correct solution. (3) Metacognitive knowledge in which one’s cognitive potential can be developed through learning and efforts in mathematical tasks. (4) Self-regulating skill that embraces skills relating to the metacognitive skills i.e., planning and monitoring, keeping attention, and motivation in problem-solving. (5) positive mathematical-

related effects i.e., positive attitudes and emotions toward mathematics in teaching learning. In problem-solving in mathematics, Polya's four steps, namely, understanding the problem, making a plan, carrying out the plan, and checking out the solution can be used(Riyadi et al., 2020). These steps are aligned with the metacognitive skills planning, monitoring, control, and evaluation(Ader, 2019; Whitebread et al., 2009). Metacognition is an important factor in mathematical problem-solving in which the students can monitor and control their thoughts to approach the problem and choose the strategies to find a solution to the problem (Izzati & Mahmudi, 2018).

Metacognition activities boost the abilities of students in problem-solving skills to enhance their performance in mathematics learning (Izzati & Mahmudi, 2018). The metacognitive intervention in mathematics improves learners' attitudes towards mathematics and serves as a guide, to ensuring the effective teaching and learning of mathematics (Du Toit & Kotze, 2009). In metacognitive activities, it is used different cognitive strategies to hand and possess the motivation and determination to tackle problems and apply these strategies (Quigley & Stringer, 2018). With this strategy, students can monitor and regulate their thinking to solve problems in mathematics (Abu Bakar & Ismail, 2020; Guner & Erbay, 2021). It promotes social metacognition when working in groups and encourages tracking and management of learning(Stanton et al., 2021) In this approach, teachers use strategies like questioning, reflecting, think-aloud, and feedback to help students and themselves express their thoughts clearly (Beach et al., 2020). Moreover, the metacognition process is a crucial component of teaching and learning, in which students draw on past experiences to create a plan, accomplish a goal, choose a strategy, track their progress, and think back on what they have learned (Beach et al., 2020; Mevarech et al., 2017). The student's role in the metacognitive approach students who use metacognitive skills can reflect on their thinking

and embedding the understanding of the learning process improves their control over their learning. Additionally, it allows the development of a person's ability to control their motivation for learning and to practice self-regulation in mathematics(Nilson & Barry, 2013).

Nevertheless, for effective teaching, educators must possess a foundational understanding of metacognition, and incorporate it into their pedagogical practices in problem-solving in mathematics. The report of the Department of Education of the Government of New South Wales (2020) reported that the UK-based Education Endowment Foundation (2018) offers a seven-step model, for explicit teaching of metacognitive strategy in mathematics learning. According to the report of the Department of Education (2020), this model involves seven steps (1) Prior knowledge activation, (2) explicit strategy instruction, (3) modeling of acquired tactics (4) memorization of strategy, (5) guided practice (6) independent practice, and (7) structured reflection. Therefore, teachers are responsible for organizing, supervising, and modifying their instructional strategies for each metacognitive component of problem-solving in mathematics. Correspondingly, Guner & Erbay(2021) state that students who use metacognitive skills in learning mathematics, with a high level of metacognitive awareness are much better at understanding and using what they read in the problem-solving process. From these strategies, the teaching strategies relate to problem-solving in mathematics through reflective and reflexive actions by strengthening the planning, monitoring, and evaluation.

Methodology

The current study aims to identify the metacognition skills that students acquire in their mathematics learning through metacognitive pedagogy. In addition, the study aims to investigate the impact of metacognitive skills on problem-solving skills in mathematics

learning. As a result, the following research question was formulated to achieve the study's goal.

1. What is the impact of metacognitive skills in the problem-solving process in mathematics learning regarding metacognitive strategy?
2. Which aspect of metacognitive skills is most closely related to problem-solving in mathematics learning?

Next, searching for relevant publications and articles consists of two steps: (1) searching, for articles related to metacognitive pedagogy in mathematics learning to identify the metacognitive skills that students acquire. (2) looking at the articles based on metacognitive learning strategy to determine the metacognitive skills that influence problem-solving skills in mathematics learning. Articles on research were found by searching Google Scholar from 2017 to 2023, published articles on ERIC, Springer Link, ResearchGate, and other open databases using keywords, metacognitive skills, metacognitive pedagogy, and problem-solving skills in mathematics learning. The analysis of the metacognitive skills and their impact on problem-solving mathematics learning is presented in the following table.

Table 1

Analysis of Metacognitive activities and impact on problem-solving process in Mathematics Learning

Authors and Research Title	**Objectives**	**The metacognitive activities**	**Impact on Problem-solving Process Mathematics Learning**
Parbawanto, Sufyani (2023) Improving prospective mathematics teachers' reversible thinking ability through metacognitive-approach teaching, *EURASIA Journal of Mathematics, Science and*	To improve prospective teachers' reversible thinking ability through metacognitive approach teaching.	Analyze the problem in mathematics differently.	Improves reversible thinking at all initial mathematical abilities (IMA).

*Technology Education,19***(6).**			
Vula, E., Avdyli, R., Berisha, V., Saqipi, B., & Elezi, S. (2017) The impact of Metacognitive strategies and Self-regulating process of solving math word problem, *International Electronic Journal of Elementary Education*,*10*(1).	To investigate the impact of metacognitive strategies and self-regulating processes on learners' achievement in solving math word problems	Ability to monitor the learning process Self-evaluation of the learning process by linking prior knowledge. Enhance the ability to select strategies. Enhance responsiveness to feedback on the content. Connect the existing knowledge to new ones.	Enable learners to control their actions, reason, and reflect which influences their success in solving a math word problem.
Ghofur, A., Andawiyah, R., Al Mattari, A. S. (2023). Empowering learners on mathematic subjects by problem-based Learning and metacognitive strategy to improve reflective thinking competence, *International Journal of Education Research and Development 3*(3*)*.	1. Knowing how the implementation of problem-based learning and metacognitive in improves mathematic reflective thinking competence, 2. Analyzing the lack of implementation of problem-based learning and metacognitive in improving mathematic reflective thinking competence, 3. Knowing the advantages of problem-based learning and metacognitive activities for improving mathematic	The application of metacognitive knowledge to the learning of mathematics, including task planning, self-regulation during learning, progress evaluation, comprehension monitoring, and accessing knowledge that one already possesses.	1. Teaching-learning activities should become more active. the students have 2. develop thinking skills, enabling them to find the appropriate ways to solve problems, they face. 3. Developing the thinking process to enable the students to solve mathematical problems 4. Developing the ability to make connections of prior knowledge with cause-and-effect relationships, and make quick and accurate decisions or conclusions to the mathematical problem.

	reflective thinking competence.		
Sercenia, J. C., & Prudente, M. S. (2023). Effectiveness of the metacognitive-based pedagogical intervention on mathematics achievement: A meta-analysis, *International Journal of Instruction16*(4).	To examine the effectiveness of the metacognitive-based pedagogical intervention on students' mathematics achievement.	The students use metacognitive activities i.e., planning, monitoring, implementation, evaluation, and concept mapping,	Significantly large and positive effect on students' mathematics achievement.
Daher, W., Anabousy, A. & Jabarin, R. (2018). Metacognition, positioning, and emotions in mathematical activities, *International Journal of Research in Education and Science (IJRES) 4*(1).	To study the linkage of the metacognitive process to the students' positions and emotions To investigate the relationship between the metacognitive process and students' positioning in mathematics activities.	Analyze the level of mathematics. Design and develop the activities in learning. Observe the activities of work making decisions, evaluating, monitoring, and regulating.	1. Metacognitive activity, self-awareness, and self-complexity enhance the problem-solving process in mathematics. 2. establish the relationship between the students' self-assurance and pride in themselves in the problem-solving process.
Toraman, C., Orakei, S., & Aktan, O. (2020). Analysis of the relationships between mathematics achievement, reflective thinking of Problem-solving, and metacognitive awareness, *International Journal of Progressive Education,16*(2).	To investigate the extent to which the student's mathematics achievement was explained by reflective thinking with their problem-solving skills and metacognitive awareness. To examine the relationship between reflecting thinking	Connect the mathematical achievement and problem-solving techniques aligned with Polya's Problem-Solving Model regarding planning, and monitoring. And evaluation.	1. A strong positive significant correlation between students' mathematics achievement, reflective thinking towards problem-solving, and metacognitive awareness. 2. Strongly positive significant correlation between reflective thinking towards problem-solving and

	toward problem-solving skills and metacognitive awareness.		metacognitive awareness.
Syaiful, Huda, N., Mukminin, A., Kamid. (2020). Using a metacognitive learning approach to enhance students' critical thinking skills through mathematics education, *SN Social Science, 31*(2).	describe how the metacognitive learning approach (MLA) helped a university's mathematics lecturer enhance students' Mathematical Critical Thinking Skills (MCTS) through mathematics learning	Metacognitive talk-discussion includes planning, monitoring, and evaluating the problem or the problem-solving process	1. Enhance the mathematical critical thinking skills in problem-solving in mathematics. 2. Optimizing the involvement of students' activity to create an effective learning atmosphere.
Li, W., Liu, CY. & Tseng, J.C.R. (2023). Effects of the interaction between metacognition teaching and students' learning achievement on students' computational thinking, critical thinking, and metacognition in collaborative programming learning. *Education and Information Technology, 28*.	To examine the effect of the metacognition-based collaborative programming approach (M-CPA) on students' learning achievement. To evaluate the effectiveness of the method for students with different levels of learning achievement	Engaging students in collaborative activities, such as group discussions, encourages them to share and compare their metacognitive approaches.	Improve students' problem-solving leading to deeper understanding and enhanced metacognitive awareness.
Murphy, D.H., Hoover, K.M. & Castel, A.D. (2022). Strategic metacognition: Self-paced study time and responsible remembering, *Memory and Cognition,51*.	examined the metacognitive control processes involved in responsible remembering by evaluating how information importance affects	Making decisions with better informed, resulting in learning. Recall the prior important information in current ones.	1. Better informed in strategic studying. 2. Greater recall of information with the most severe consequences for forgetting.

	one's allocation of study time and subsequent recall		
Rajadurai R. & Ganapathy H. (2023). Effect of use of metacognitive instructional strategies in promoting mathematical problem-solving competence amongst undergraduate students in facing competitive examination, *Cogent Social Sciences, 9*(1).	look closely into the use of metacognitive instructional strategies by undergraduate students.	Analyze the task, setting objectives. active in the preparation of instructional materials. Evaluating the task, and then reflecting on it.	Increase the mathematical problem-solving competence.
Giiner, P. & Erbay, H. N. (2021). Metacognitive skills and problem-solving. *International Journal of Research in Education and Science (IJRES), 7*(3),	To investigate the metacognitive strategies in problems used in problem-solving.	Identify the problem, determine the appropriate strategy, monitor the effectiveness of the chosen strategy, control the accuracy of the solution, and regulate the problem-solving process	Helps to solve the problem correctly by using appropriate strategies, mathematical notations, and logical reasons
Lestari, W., Pratama, L. D., & Jailani. (2018). Metacognitive skills in mathematics problem-solving, *Jurnal Inovasi Pendidikan Matematika, 6*(3),	To describe the level of metacognitive skills of students in solving problem-solving regarding reflective use, strategic use, aware use, and tacit use	Students demonstrate effective metacognitive practices by thinking clearly during problem-solving tasks and showing the activities of planning, monitoring, and evaluating their learning processes.	1. The students can identify what was known in the problem. 2. Determining to solve strategies using rules, and monitoring carefully. 3. Students can perform, plan intermediate results, 4. Enable to correct mistakes and reflect on the achievement of the objectives.

Based on the result of Table 1, it can be concluded that the metacognitive skills i.e., planning, Monitoring, and evaluation acquired from metacognitive pedagogy impact the different aspects of students' problem-solving- skills i.e., understanding the problem, making a plan, carrying out the plan, and looking backward to the solution in mathematics learning. A total of thirteen articles are selected, and meet the requirements of the study to be discussed.

Discussion

Considering the two objectives of the review, the first step is to determine the impact of metacognitive skills on problem-solving skills in mathematics learning in metacognitive learning strategy. And secondly the relation of the metacognitive activities to the problem-solving skills in learning mathematics. So, the discussion part of the review is based on the following two research questions.

The Impact of Metacognitive Skills Implied in Problem-Solving

The impacts of implementation of Metacognitive activities can be seen from the two points of view. The first is to determine the effect of metacognitive skills in problem-solving in mathematics learning, and the second is to evaluate the metacognitive skills in the problems. Based on the activities of metacognitive skills involved directly in metacognitive pedagogy, The researcher listed the metacognitive activities based on metacognitive skills (planning, monitoring. and evaluating) that directly implied the problem-solving process in mathematics. Table 2 as shown below shows the metacognitive activities' impact on understanding the problem, making a plan, carrying out the plan, and checking out the solution of the problem-solving process in mathematics based on Table 1.

Table 2

The impact of metacognitive activities on problem-solving

Metacognitive Activities	Impact on the student's problem-solving process	References
Planning	Simplify the problem with the help of drawing a diagram or sketching a simple object form, and stating what is to find mathematically. perform reading and writing of what is known, determine solving strategies, and plan intermediate results.	(Ader, 2019; Whitebread et al., 2009), (Izzati & Mahmudi, 2018), (Stanton et al., 2021), (Beach et al., 2020; Mevarech et al., 2017), Government of New South Wales (2020), (Rhodes,2019). Parbawanto & Sufyani (2023)
Monitoring	Projecting the problem into a picture, or table, or writing a small note, etc. facilitates problem-solving. students for completion of the problem. Using rules for solving. Monitoring the problem carefully to find the correct mistake. Develop the skill of arguments for appropriate strategies to get solutions. Check and correct the mistake.	(Ader, 2019; Whitebread et al., 2009), (Izzati & Mahmudi, 2018), (Abu Bakar & Ismail, 2020; Guner & Erbay, 2021). (Beach et al., 2020), (Beach et al., 2020; Mevarech et al., 2017), (Government of New South Wales,2020), (Rhodes,2019), (Ghofur et al. 2023).

The impacts of applying Metacognitive activities can be seen in the four aspects of the problem-solving process in mathematics i.e., understanding the problem, making a plan, carrying out the plan, and checking out the solution of the problem-solving process in mathematics. Reviewed articles showed that metacognitive activities planning, monitoring, and evaluation in problem-solving are mostly effective in the problem-solving process to identifying the problem, determining the appropriate strategy, monitoring the effectiveness of the chosen strategies, controlling the accuracy of the solution, and regulating the problem-

solving process (e.g., Giiner, P. & Erbay, H. N. (2021); Syaiful et al. (2020).; Li et al. (2023)). It also affects the selection of appropriate methods, notations, and logical reasons to increase the competence in problem-solving skills of the students in mathematics (e.g., Rajadurai R. & Ganapathy H. (2023); Giiner, P. & Erbay, H. N. (2021); Abu Bakar & Ismail, 2020; Guner & Erbay, 2021)). It means the application of metacognitive pedagogy greatly enriches the ability of students' problem-solving skills to identify the given information in the problem and consider which ways should be appropriated to solve the problem, determine whether they got closer to the solution, review the solution, and try a different approach. The results of these review situations are in line with the report of the Department of Education of the Government of New South Wales (2020). From most of the review articles, hence the metacognitive activities enable learners to control their actions, reason, and reflect which influences their success in solving a math problem and analyzing the problem in mathematics differently.

The Aspects of Metacognitive Skills Most Closely Related to Problem-Solving

Planning

The planning phase is the first stage of metacognitive activities that includes understanding the problem, attempting to restate it, determining familiarity with whether it has been solved before, recognizing the information provided in the problem, and deciding which approaches to take in the problem-solving. So, the planning activities are mostly close to problem-solving in mathematics learning. Studies by Ader (2019); Giiner & Erbay (2021); Lestari et al.(2018); (Koriat, 2012); Stanton et al.(2021); and Quigley & Stringer (2018) described that the students' activities in metacognitive the crucial phase in learning mathematics regarding the this pedagogy.

Monitoring

In this phase, the students' activities focus on checking the solution, detecting the error if a mistake is seen, executing the appropriate strategy, reviewing the solution, and moving in a different direction if they do not get the required solution. The researcher Rajadurai & Ganapathy (2023).; Murphy et al. (2022); Syaiful, Huda, N., Mukminin, A., Kamid. (2020); Daher et al. (2018) expressed that it most important phase in learning mathematics concerning problem-solving in mathematics learning.

Evaluation

This step is about evaluating the result or performance and rule-following procedures related to learning tasks.in this phase, the students are encouraged to see the effectiveness of their learning strategies and are allowed to make decisions about the task. As described in the study by Marantika (2021); Rajadurai & Ganapathy (2023). Lestari et al. (2018); Beach et al.(2020), Government of New South Wales(2020); and Ghofur et al. (2023), this aspect is also important for making decisions and seeing the accuracy of the result in problem problem-solving process in mathematics learning.

Conclusion

In conclusion, most of the reviewed articles inform that metacognition skills in the teaching and learning of mathematics assist students in examining and controlling their problem-solving processes. These skills are essential in aiding students to develop a more profound comprehension of the learning process in mathematics, empowering them to become more effective and independent learners. By integrating the metacognitive skills of planning, monitoring, and evaluation methods to solve problems, students can enhance their capacity to establish objectives, monitor their advancement, and adapt their learning approaches as necessary during mathematical problem-solving. Self-awareness in metacognitive activities not only fosters essential problem-solving processes and critical

thinking abilities but also enriches performance in mathematics. Therefore, in mathematics learning, employing metacognitive activities students are encouraged to tackle problems independently. Here, students are needed to possess solid background knowledge, which facilitates their ability to identify the connections between mathematical concepts and real-world situations. This approach can also alter students' perceptions toward mathematics, transforming it from being seen as difficult to recognizing its usefulness in addressing problems in their daily lives.

Additional research could be conducted to further improve the results of this study. This could include evaluating the impact on other subjects. Besides this, further study can be conducted on exploring the students' motivation or attitudes towards learning after participating in activities.

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