

Express Students' Problem Solving Skills from Metacognitive Skills Perspective on Effective Mathematics Learning

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Abstract Measuring the standard of success in mathematics learning is whether students can apply mathematical concepts and solve mathematics problems completely. However, the ability of students in solving mathematics problems is sometimes limited to routine problems and when faced with non-routine and in the form of HOTS applications problems, there is complicatedness and difficulty in determining the solution. Therefore, this study aims to review systematically, which metacognitive skills are applied and practiced when students solve mathematics problems and also to clarify the effect of metacognitive skills on student's learning performance. Studies around 2006 and up to date have been explored based on approaches, methods, and practices of metacognitive skills implemented. A total of 12 articles were selected for analysis. This review shows that metacognitive skills are implied and practiced when students solve mathematics problems, but the metacognitive regulation subcomponents are more likely to affect the completeness of the solution than the metacognitive knowledge aspects. Metacognitive skills also have a positive impact on student learning. So, delivering effective learning is very reasonable and timely, and metacognitive skills are applied based on platforms for metacognitive learning strategy.

Keywords Problem-Solving Skills, Metacognitive Skills, Effective Mathematics Learning, Metacognitive Regulation, Metacognitive Knowledge

1. Introduction

Mathematical competencies are the ability of students to co-ordinate their cognition of mathematical concepts, knowledge, and skills in problem-solving [1-3] and can be

transformed into a wider context [3-5]. The challenge to ensure that the goals are met is the weakness and the level of students' ability to solve mathematical problems, whether routine or non-routine questions [6,7]. Problem-solving skills are the student's ability to regulate and manage cognitive aspects [8]. This ability is based on the stimuli of the internal factor of self and external factors. According to Adnan & Arsad Bahri [9], Menz & Cindy Xin [10] and Stephanou & Mpiontini [10] internal factors are related to existing cognitive settings, experience, and knowledge. If students are accustomed and trained to solve mathematical problems independently (minds-on), then the experience can influence the success [12,13]. The impact of positive experiences and current expertise improved by cognitive coordination will enhance the success of mathematics problem-solving [14,15]. The external factor refers to external stimuli that can induce students' activeness and willingness to solve problems [3,16]. The interests of the issues and problems discussed in the task and the situation delivered of the assignment are also influencing problem-solving skills as an external factor. According to Tzohar-Rozen & Kramarski [17] and Smith & Mancy [8], the appropriateness and attractiveness of the delivery or the solution of problem-solving activities are also factors affecting the problem-solving skills of the students.

To bridge the gap between the internal and external factors discussed, some analyses have shown that metacognitive skills are very significant and can meet the needs of reducing the problem of the low level of mathematics problem-solving skills [3,4,11]. According to Schraw & Moshman [14] and Tzohar-Rozen & Kramarski [17], metacognitive skills are a reference and act like an engine that can leverage student learning. Metacognitive skills are the mastery and implementation of metacognitive components that are metacognitive knowledge and metacognitive regulation [18,19]. Metacognitive

knowledge includes subcomponents which are declarative, procedural and conditional, while metacognitive regulation includes planning, monitoring, and evaluation. According to Schraw & Moshman [14], Tarricone [18] and Du Toit & Du Toit [5] these two components influence learning but will give an impact separately and can move in or follow the order [20,21] and according to Tarricone [18], these metacognitive skills will form taxonomy to metacognition and thinking chronology during the learning process.

Metacognitive knowledge will stimulate emotional, motivational and previous knowledge of students to form problem-solving orientation [2]. This knowledge will create awareness of the good habit of learning, the necessary solution strategies and knowledge about the source of information to solve the problem [22]. The introduction of the activity and the presentation of the task will form an external stimulus which in turn will affect emotion and self-determination. This effect is an adaptation of metacognitive knowledge. Furthermore, to form behaviours and actions to solve the problem is the effect of metacognitive regulation on thinking procedure (process) and determine of solutions by managing, planning, monitoring and evaluating [4,13,14,16]. Just now, it is the metacognitive regulation acting on the internal factor of the learning. Students' skills in planning solutions, setting goals for solving, selecting strategies, acting on strategies, monitoring accuracy and reflecting findings will lead to perfection and accuracy in solving mathematical problems [2,9].

Therefore, simply by developing the student's metacognitive skills, mathematical problem-solving skills can be improved. However, specific research on how exactly this metacognitive skill affects the mathematical problem-solving skills and the details of the metacognitive components and subcomponents is a need. According to Stephanou & Mpiontini [11], Tony Karnain et.al [12], Menz & Cindy Xin [10], Smith & Mancy [8] and Cera, Mancini & Antonietti [23] metacognitive studies need to be continued to ensure metacognitive skills and strategies learning that applying metacognitive skills can contribute knowledge and ideas to generate intervention to learning, especially in scope of mathematical problem-solving. Tarricone [18] has outlined the metacognitive hierarchy and its existence based on one's thinking ability. However, in-depth studies of metacognitive skills as students solve mathematical problems are lacking. The discussion and relevance of mathematical problem solving and metacognitive skills also need to be clarified and proven by pieces of evidence [20]. More previous studies have focused on the correlation of mathematical problem

solving to either metacognitive knowledge or metacognitive regulation, such as Desoete & Roeyers [24], Kazemi, Fadaee & Bayat [7], Abdullah,

Rahman & Hamzah [6], Van Der Stel, Veenman, Deelen & Haenan [15], but do not in detail focus on how these metacognitive skills work and act during mathematical problem-solving steps.

2. Methodology

This review is to determine which metacognitive skills are applied and practiced when students solve mathematics problems and to study the effect of metacognitive skills on student's mathematical learning performance. To achieve the objectives, the research questions were created as follows:

1. What are metacognitive skills that students applied during the mathematical problems solving task
2. What is the effect of metacognitive skills on the student's learning performance

The procedures and designs of this study are in the form of surveys by conducting systematic review based on the implementation of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) proposed by Moher et al [25], on studies that deal with the effectiveness and influences of metacognitive on mathematical problems or mathematics learning in general. The journal or article must meet the requirements of this study to be selected which must show statistically evidenced and implied metacognitive inventory that has been recognized. Articles are selected after going through the steps such as Identification, Screening, Eligibility and Included.

Search through databases such as Google Scholar, Researchgate, ERIC, SpringerLink, Elsevier, and some other databases, begins with keywords such as mathematical problem-solving skills and metacognitive skills separately and then they are combined into metacognitive skills in mathematical problem solving to prevent journals and non-focused articles from being displayed. However, the journals and articles found are quite limited and the keywords subsequently changed to be more general by using metacognitive in mathematical learning. 'Snowballing' methods are also applied to increase the number of journals and articles funding [2], but the main requirements remain. 12 qualified and selected articles will be analyzed. The following table shows an analysis of the application of metacognitive skills and their effect on students' learning.

Table 1. Analysis of Application Aspect and Effect of Metacognitive Skills in Mathematics Learning

Author(s)	Research Objective(s)	Application aspect of MS	Effect of MS
Kazemi, Fadaee & Bayat [7] A Subtle View to Metacognitive Aspect of Mathematical Problems Solving Procedia Social and Behavioral Sciences 8 (2010) 420–426	i. To assess the role of metacognitive skills in mathematical problems solving	ii. Starting with planning the task iii. Clarifying task and activities requirements iv. Always reviewing on progress v. Always checking the error vi. Detecting new development	vii. High mathematics problem-solving performance viii. Students are cautious to understand the relationships between the facts in a problem ix. Students are checking for accuracy x. Students monitor the process of problem-solving step by step
Nongtodu & Bhutia [26] Metacognition And Its Relation With Academic Achievement Among College-Going Students Of Meghalaya International Journal of Education and Psychological Research (IJEPR) Volume 6, Issue 2, June 2017	i. To study the metacognition among college-going students of Meghalaya ii. To explore whether metacognition is related to academic achievement, gender, streams of discipline and locale	i. Looking at the problems orientation ii. Planning the task iii. Monitoring and testing the strategies' used iv. Repairing while meet the confuse v. Evaluating and reflecting	i. Students visualize the thinking processes such as self-concept of knowledge, self-intelligence, self-memory, attention ii. Students build positive study habits
Desoete & Roeyers [24] Metacognitive Macroevaluations In Mathematical Problem Solving Learning and Instruction 16 (2006) 12e25	i. To understand the functioning of the task-specific or micro-metacognitive skills on mathematical problem solving	i. Planning and working according to the plan ii. Changing the plan iii. Reflecting in advance on how difficult this exercise will be	i. Students more alert with accuracy ii. Students more focus on working and solutions
Phi [3] Developing Students' Metacognitive Skills In Mathematics Classroom Annals. Computer Science Series. 15th Tome 1st Fasc. – 2017	i. To present the importance of metacognition to the learning of mathematics employed metacognitive skills in the process of solving mathematics problems ii. To build a theoretical model of metacognition in Mathematics within the context of problem-solving among the junior Mathematics major students of Le Hong Phong high school, Dong Nai province, Vietnam	i. Making reflections on what went on their minds and what they thought about	i. Students become comfortable with strategies ii. Students employ the strategies automatically to learning tasks iii. Students more focusing on their attention, deriving meaning iv. Students make adjustments if something goes wrong

<p>Smith & Mancy [8] Exploring The Relationship Between Metacognitive And Collaborative Talk During Group Mathematical Problem-Solving – What Do We Mean By Collaborative Metacognition? Research in Mathematics Education 20:1, 14-36</p>	<p>i. To enhance understanding of the relationship between collaborative talk and metacognitive talk during group mathematical problem-solving.</p>	<p>i. Using the metacognitive skill of monitoring the interactions of peers ii. Displaying metacognitive knowledge about the problem and presenting a strategy iii. Questioning another’s thinking and inviting them to justify their answer iv. Displaying metacognitive monitoring by seeking clarification v. Inviting the others in the group to engage in discussion regarding their strategy use</p>	<p>i. Students with much more advanced metacognitive process patterns are more involved in discussions and subsequent solutions. ii. During the problem-solving exercise, students with higher metacognitive awareness have more influence</p>
<p>Van der Stel, Veenman, Deelen & Haenen [15] The Increasing Role Of Metacognitive Skills In Math: A Cross-Sectional Study From A Developmental Perspective ZDM Mathematics Education (2010) 42:219–229</p>	<p>i. To investigate the development of metacognitive skillfulness during math performance in particular ii. To investigate the relation between metacognitive skills, intellectual ability, and learning performance in math from a developmental perspective</p>	<p>i. Estimating the answer ii. Sketching the problem to represent the problem iii. Designing a step-by-step action plan, instead of working by trial and error iv. Monitoring action plan v. Checking an answer by recalculating vi. Paraphrasing the problem vii. Concluding while referring to the problem statement</p>	<p>i. Students become more selective in their orientation activities over the years, resulting in fewer, but perhaps better, orientation activities ii. Students increase the number of their elaboration activities iii. Students seem to experience a problem in abstracting knowledge</p>
<p>Su, Ricci & Mnatsakanian [27] Mathematical Teaching Strategies: Pathways to Critical Thinking and Metacognition International Journal of Research in Education and Science, Volume 2, Issue 1, Winter 2016</p>	<p>i. To indicate the necessity of applying critical thinking and provide an example of how critical thinking, creativity and flexibility in finding such ways help students to better understand the concepts of number sense</p>	<p>i. Identifying possible conclusions and selecting logical conclusions ii. Describing how a solution was presented iii. Identifying scenarios and evaluating iv. Selecting problem-solving strategies v. Indicating how those solutions can be applied to more advanced math problems</p>	<p>i. Students become confident critical thinkers ii. Developing critical thinking and reasoning allows students to think about how they utilize their discipline of mathematical skills iii. Ensuring students to think about their method of thinking iv. Developing the ability to analyze, prepare and strategize is described as key aspects of organizational achievement, decision-making, and life choices v. Metacognition helps students to recognize that math is logical reasoning on solutions to problems</p>

<p>Shaw [28] The Effects Of Metacognitive Awareness On The Development Of Mathematical Problem-Solving Skills In Fourth-Grade Homework Assignments Education and Educational Psychology, Spring 5-2008</p>	<p>i. To investigate the effects of metacognitive awareness on the development of problem-solving skills when metacognitive awareness practice was included as a part of mathematical problem-solving skills for homework assignments of fourth-grade students.</p>	<p>i. Awareness of how much learning can be controlled ii. Working constantly to choose suitable strategies iii. Monitoring the strategy used throughout the learning process iv. Tending to continue in a job or task until they are satisfied with it V. Attributing success to students ' efforts</p>	<p>i. Ensuring that students are mindful of themselves, the task and the strategies that are available when entering a learning activity</p>
<p>Tony Karnain, et. al [12] Exploring the Metacognitive Skills of Secondary School Students' Use During Problem Posing Jurnal Teknologi (Social Sciences) 67:1 (2014) 27–32</p>	<p>i. To explore students' use of metacognitive skills during problem-posing activities</p>	<p>i. Making good sense of the task, extracting the information given, and being aware of the purpose ii. Seeking any examples used in the past, and mapping a solution iii. Linking and identifying the previous strategies that are relevant to the current problem iv. Monitoring with screened for errors, justifying their judgments and making revisions to correct wrong turns v. Alluding to the need to revise their approach vi. Always checking the answers being right or wrong</p>	<p>i. Students are proposing alternate solutions and reflecting on what new things they learned by attempting the problem.</p>

<p>Tzohar-Rozen & Kramarski [17] Metacognition, Motivation, and Emotions: Contribution of Self-Regulated Learning to Solving Mathematical Problems Global Education Review, 1 (4). 76-95.</p>	<p>i. To develop, examine, and compare two SRL interventions dealing with two components of self-regulation: metacognitive regulation (MC) and motivational-emotional regulation (ME)</p>	<p>i. Planning and allocating resources for learning ii. Monitoring their knowledge and skills iii. Reviewing their performance levels during learning acquisition at different points iv. Planning includes finding the right strategies and allocating resources that affect performance v. Monitoring relations to the awareness of students of their understanding and quality of performance while carrying out tasks vi. Evaluation referring to assessing the outcomes and methods of learning.</p>	<p>i. Ability to transfer the skills they had learned to a new task ii. The goal of metacognitive regulation is to enhance learning skills by providing learners with structured and explicit feedback as they think and reflect on their tasks</p>
<p>Abdullah, Rahman & Hamzah [6] Metacognitive Skills of Malaysian Students in Non-Routine Mathematical Problem Solving Bolema, Rio Claro (SP), v. 31, n. 57, p. 310 - 322, abr. 2017</p>	<p>i. To identify students' metacognitive skills and the impact of such skills on non-routine mathematical problem solving</p>	<p>i. Translating information into an understandable form ii. Considering alternative solutions iii. Revising the steps for the solution</p>	<p>i. Metacognitive skill awareness can boost interest in the learning process</p>
<p>Amin & Sukestiyarno [13] Analysis Metacognitive Skills On Learning Mathematics In High School International Journal of Education and Research Vol. 3 No. 3 March 2015</p>	<p>i. To extend the metacognitive awareness of high school students when answering a series of questions metacognitive on mathematics learning ii. To see the influence of metacognitive awareness of the cognitive skills and metacognitive skills iii. To study the relationship between cognitive skills and metacognitive skills</p>	<p>i. Understanding what the problem is about-the planning process solutions and choosing the right strategy and the stage of deciding whether it makes sense or not ii. Managing and process information by organizing, outlining, summarizing, selective focus iii. Drawings or diagrams to enhance their understanding iv. Mapping the concepts to help to understand v. Making a summary of what they learned.</p>	<p>i. Increasing the ability to recall information and the ability to judge for themselves on their ability to understand something ii. The student has sufficient ability to perform self-assessment of learning or to assess the strategies it uses iii. The student has sufficient capability of controlling thinking or learning, and building a meaningful theory on their cognition iv. The student has a good ability to plan, set goal, and allocate resources before learning</p>

3. Finding and Discussion

Twelve qualifying studies have been reviewed and the findings will be discussed based on the research questions.

3.1. What Are Metacognitive Skills That Students Applied during the Mathematical Problem-Solving Task?

Based on the findings of the study, it is found that the aspects of metacognitive skills are applied and always practiced while solving mathematical problems. However, there are more aspects of metacognitive skills practiced. The following is an interpretation of findings according to the basic steps in solving mathematical problems.

Based on the results of **Table 2**, it can be concluded that, while solving mathematical problems, students will practice metacognitive skills according to appropriate chronology. However, this study can explain that the practice of metacognitive skills is specific, that the metacognitive knowledge aspect is applied at the initial stage of problem-solving and so metacognitive regulation aspects will take over the entire process and subsequent actions. This coincides with the fact by Tariccone [18] who explains that metacognitive regulation is a secondary cluster in the thinking taxonomy and is an intermittent act of thinking. This is illustrated by Schraw & Moshman [14], Shaw [28] and Desoete & Roeyers [24] who said that knowledge and regulations can move together but will have different effects.

Table 2. A Meta-analysis of Metacognitive Skills Involved during Problem Solving Activities

Problem Solving Steps / Skills	Metacognitive Skills Aspect Involved	Reported Researcher(s)
<p>Understand the problem</p> <ul style="list-style-type: none"> i. Clarifying the problem ii. Looking at problem orientation iii. Seeking any example used in the past iv. Translating the problem statement to own words 	<ul style="list-style-type: none"> Declarative Procedural Planning 	Kazemi, Fadaee & Bayat [7], Nongtodu & Bhutia [26], Desoete & Roeyers [24], Tony Karnain et. al [12], Abdullah, Rahman & Hamzah [6], Amin & Sukestiyarno [13]
<p>Devise a plan</p> <ul style="list-style-type: none"> i. Planning the work ii. Sketching problems iii. Setting the goals iv. Designing the steps v. Paraphrasing the problem vi. Identify possible conclusion/answer vii. Setting the possible strategies viii. Relating to previous solutions/tasks ix. Mapping the plan 	<ul style="list-style-type: none"> Conditional Planning Monitoring 	Kazemi, Fadaee & Bayat [7], Nongtodu & Bhutia [26], Desoete & Roeyers [24], Phi [3], Smith & Mancy [8], Van der Stel, Veenman, Deelen & Haenen [15], Su, Ricci & Mnatsakanian [27], Tzohar-Rozen & Kramarski [17], Amin & Sukestiyarno [13]
<p>Carry out of the plan</p> <ul style="list-style-type: none"> i. Operating the plan ii. Testing the strategies iii. Working on selected strategies iv. Reviewing on progress v. Repairing when meet the confuse vi. On the alternative way if need 	<ul style="list-style-type: none"> Planning Monitoring Evaluating 	Kazemi, Fadaee & Bayat [7], Nongtodu & Bhutia [26], Desoete & Roeyers [24], Smith & Mancy [8], Su, Ricci & Mnatsakanian [27], Shaw [28], Abdullah, Rahman & Hamzah [6], Amin & Sukestiyarno [13]
<p>Look back/Reflection</p> <ul style="list-style-type: none"> i. Evaluating ii. Reflecting iii. Detecting new develop iv. Reflecting in advance on how difficult v. Recalculating the solutions 	<ul style="list-style-type: none"> Monitoring Evaluating 	Kazemi, Fadaee & Bayat [7], Nongtodu & Bhutia [26], Desoete & Roeyers [24], Phi [3], Van der Stel, Veenman, Deelen & Haenen [15], Tony Karnain et. al [12], Amin & Sukestiyarno [13]

Researchers such as Hasbullah [4], Phi [3], Shaw [28], Nongtodu & Bhutia [26], Desoete & Roeyers [24] and Su, Ricci & Mnatsakanian [27] discussed that regulation aspects play a role in and influence the student's mathematical competence. According to Moos & Ringdals [20], metacognitive regulation begins once the mathematical task is given. It begins with understanding the problem, which involves metacognitive knowledge. For the next, metacognitive regulation will continue the cognitive process by setting goals, designing, selecting strategies, using strategies and concluding by reflecting on such actions [3,26]. To understand that needs to ensure that accuracy and completeness in solving mathematical problems require the ability of students to plan, monitor and evaluate their thinking and learning activities.

3.2. What Is the Effect of Metacognitive Skills on the Student's Learning Performance?

Furthermore, the findings show that students who can practice and develop metacognitive skills will ensure that they can master the learning. The effect of metacognitive skills can be seen from two points of view which is the mastery of student concepts and the students' mathematical competencies. The following researchers report that metacognitive skills have a significant relationship with the mastery of the students, especially in solving mathematical problems. The studies conducted by Phi [3], Nongtodu & Bhutia [26], Desoete & Roeyers [24] and Tzohar-Rozen & Kramaski [17] show that there is a positive relationship between metacognitive skills, grades and achievements through the strategies implemented. This is because according to Schraw & Moshman [14] and Du Toit & Du Toit [5], metacognitive knowledge and regulations drive students to set the learning goals, plan, select strategies, monitor learning processes, and evaluate their learning outcomes. Through this metacognitive skill, thinking efficiency will increase and thus this skill will affect the students' understanding of the concept in parallel with studies of Du Toit & Kotze [22], Smith [16] and Warner & Kaur [1].

As reported by Kazemi, Fadaee & Bayat [7], Nongtodu & Bhutia [26], Desoete & Roeyers [24], Tzohar-Rozen & Kramaski [17] and Tony Karnain et. al [12] students who are given enough metacognitive skills training will always understand the relationships among the facts in a problem, allocate resources before learning, check themselves for accuracy, visualize the thinking processes such as self-concept of knowledge, self-intelligence, self-memory, attention, make adjustments if something goes wrong and so on. Thus, this result clearly shows that the student's mathematical competency has increased. Metacognitive knowledge opens up students' interest and emotional spaces towards looking at more specific problem orientation [17], while metacognitive regulation moves the hands-on and mind-on aspect of students to drive and build

new knowledge when success in problem-solving achieved [3]. Metacognitive skills play a lot of roles in ensuring students can master mathematics and have better mathematical problem-solving skills.

4. Conclusions and Recommendation

To implement effective mathematical learning, metacognitive skills need to be provided with training and applied to improve students' performance and thinking skills which in turn lead to the mastery of mathematical concepts. Therefore, teachers and responsible parties need to provide a learning medium that can create a conducive learning environment that provides opportunities for students to develop metacognitive skills. This is because metacognitive skills can be affected and influence the mastery of the mathematical concept of the students. As a suggestion, the stakeholders or researchers will come up with an approach that implements metacognitive skills to transform conventional teaching practices into active learning practices that provide more opportunities for students to manage their learning naturally and on their own needs for examples, through knowledge, experience, and metacognitive regulation.

Through the literature discussed, some researchers suggest the need for an approach that implements knowledge of metacognitive skills to be in line with the technological developments and the transformation of the current curriculum. In fact, it generates learning kits, modules, models and applications to ensure students get real compatibility. It can be concluded that metacognitive skills are not only important to influence mathematical mastery, but also can affect the formation of students' attitudes and behavior towards mathematical subjects. This study should also have a continuing study on the impact of metacognitive skills and how to produce metacognitive learning strategies.

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