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Metacognitive Self-management in Developing Students' Rigorous Mathematical Thinking Skills

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Abstract.
This study aims to describe the metacognitive self-management of students in developing rigorous mathematical thinking. This study uses a qualitative method with a case study approach. The participants were three students from the third-level mathematics education department, who were selected and made a contract with for real analysis lectures. The first student experienced a significant change from the beginning of the meeting, resulting in the metacognitive self-management process being well-conditioned. He completed the task more confidently than the initial presentation, used several references and sources of information to complete the job, and represented each answer in the form of mathematical symbols. This studentscognitive function appears to be of level-1, with qualitative thinking. For the 2nd student, a change was observed in the learning process and the teacher's motivation and guidance. The results of the interviews showed that the student applied strategies in completing assignments. He answered them systematically, based on experience, and mastered the prerequisite material. This student showed improved thinking skills related to mastery of concepts from new material, analyzing the problems given, being critical and focused when answering, and looking hard to get maximum evaluation results. This 2nd student entered the level of quantitative thinking with precision. Lastly, in the 3rd student, self-management seems stable, but was still lacking in adjusting the understanding of prerequisites with understanding concepts from new material. The development during the learning process shows that he can activate his mathematical knowledge, compose logical proofs of Real Analysis material problems, and build relationships between prerequisite concepts and new material. This type of student enters the level of abstract relational. The results of the study can be a reference for teachers to determine the learning model and the related instruments, so that they can grow the level of mathematical thinking before, during, and after the learning process.

Keywords: Metacognitive, selfmanagement, Mathematical thinking skill

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1. INTRODUCTION

Metacognition is an essential strategy in triggering thinking skills and the depth of students' thinking levels [1]. Through metacognition, students understand problems and how to solve them systematically [2]. In addition, students have independence and are critical of what is written, understand the learning process, and believe that they can complete their assignments [3]. Metacognition provides an overview of the experience in accuracy and perseverance from the intellectual side of students to understand in depth a lesson. Learning motivation and self-discipline are oriented towards learning objectives [4]. There are three forms of metacognition, namely metacognitive skills, metacognitive experience, and metacognitive knowledge [5]. Specifically, metacognitive knowledge specializing in self-regulation oriented to student learning outcomes and skills is divided into several components, including self-management [6]. When a student experiences the learning process, interpreting each flow of teaching and learning activities with experience-based self-ability, it is necessary to manage further cognitive development, then more diagnosed with metacognitive self-management. This component sets explicitly targets that require high analysis, so students need to carry out explorations that raise their creativity for learning success, especially materials that are difficult to understand.

Self-management or self-regulation is the ability of a person to bring up and monitor his thoughts, feelings and behaviour to achieve a specific goal, in this case, the learning goal [7]. Self-management shows the existence of student self-management, which can be seen from three processes of students' abilities, namely to: (a) plan, (b) organize, (c) evaluate learning [8]. Planning undergoes several unique processes, namely analyzing tasks, setting goals, and selecting specific strategies that support learning objectives—regulating the emphasis on systematic and periodic adjustments related to the cognitive activities of students. While evaluating refers to assessing the status of students from the mental side in understanding the learning material both before, during the process, and after learning. These three processes contribute to metacognitive self-management, such as providing a standard so that each individual develops standards used in self-achievement [9]. It can be seen that metacognitive self-management goes beyond the ability to self-assess because it has reached the stage of managing the further development of student's abilities.

Metacognitive self-management has a relationship with the cognitive function of rigour mathematical thinking. The connection lies in the contribution of individual thinking experiences to metacognitive, which is illustrated by the three components of cognitive function, namely conceptual, action, and motivational components [10]. Metacognitive self-management means that the three parts of cognitive function play a role in the rigour of an individual's mathematical thinking ability, which describes the quality of being relentless in the face of challenges and complexities and the motivation and self-discipline to strive in learning goal-oriented learning. Meanwhile, suppose you look at the level of cognitive function for rigour mathematical thinking, namely qualitative, quantitative with precision, and abstract relational [11]. In that case, the quality of a student's review can be built with good self-management. Students can measure how he understands the material presented by the teacher based on experience in learning, and a strong desire to learn something new.

Learning mathematics is closely related to efforts to improve students' mathematical thinking skills [12]. To develop students' mathematical thinking skills, especially to the abstract relational level of rigorous mathematical thinking, it is necessary to have various supporting components, especially those related to students' initial understanding of the material, their experiences during learning, and control their cognitive abilities further. All the linkages that occur impact students' ability to deal with mathematical problems and confusion in solving these problems. As the main actor who can build students' mathematical thinking skills, the teacher certainly plays a significant role as long as students learn to grow their ability to control their cognitive potential. Several studies related to student self-management have been conducted, concluding that self-management strategies enable students to complete their social and academic tasks [13]. It can be seen from the results of existing research that students can complete these tasks accurately, creatively and prepare critical answers.

Based on the background stated previously, this study aims to describe the metacognitive knowledge of students' self-management in building rigorous mathematical thinking skills. This study focuses on various self-management metacognitive indicators that appear from students, and then it will be adjusted to hands that arise from the ability to think mathematically rigorously. The results of this study can be used as a reference for teachers to determine the learning model and various related instruments in adjusting to the mathematical material to be able to grow the level of mathematical thinking according to the students' conditions and meaningful experiences both before, during, and after the learning process.

2. RESEARCH METHOD

This study uses a qualitative model with a case study approach. Case studies were chosen because this research approach is used to generate an in-depth understanding of complex problems in the context of everyday life [14, 15]. The research subjects were three third-level students from the Department of Mathematics Education who were randomly selected. The research instrument is in interview texts and observation reports during Real Analysis lectures in one semester. The selection of instruments is by the model and approach chosen because it must go through a careful and in-depth analysis not to get lost in adjusting theories and conclusions [16]. Researchers observed the three research subjects for one semester by conducting continuous interviews after 3-4 lecture meetings. Interviews were conducted after each subject made a presentation of the tasks that had been given. Discussions are always associated with the three metacognitive indicators of self-management by continuously providing motivation and enthusiasm for learning. Researchers analyzed every development in the three research subjects, adjusting between self-management metacognitive indicators and rigour mathematical thinking skills. The selection of project-based lecture methods and discussions at each meeting also changes between learning independence, perseverance in completing assignments, accuracy and accuracy in doing projects, and the ability to think mathematically in improving learning outcomes from each meeting.

3. RESULTS AND DISCUSSION

The results of this study are qualitative data. Students as the 1st research subject showed differences from four observations from the effects of presentations, discussions, and analysis of interview texts. Initial data obtained that students go through three stages of self-management, namely planning, organizing, and evaluating, but not yet structured. Students experience confusion in completing assignments in the form of projects whose results must be presented. He is not used to self-study from mathematics in the Real Analysis course, prioritizing the power of experience and reasoning in solving problems. So that it appears that in the initial presentation, when a question and answer session was conducted regarding the depth of the material presented, he answered haltingly or not fluently, expressing many apologies for not being able to answer, and there was a long pause to answer when asked a question. The strategy in solving the problems given as part of the project is not structured systematically. This results in the learning objectives still not being achieved. The assessment in terms of cognitive activity is also

still in the fewer criteria. When students were asked to evaluate the task's process, it seemed that they were still less focused and did not seem to understand as a whole. For this reason, the teacher always provides motivation for enthusiasm in learning, provides assistance in choosing the correct reference, and helps students' difficulties when a solution has not been found.

The next meeting on the 1st subject showed that there were changes that made the self-management process appear well-conditioned, where the given project tasks were completed more creatively and critically. He seemed calmer in presenting project results, giving answers began to look more systematic, but there were still shortcomings in understanding the material. The subject completes the task more confidently than the initial presentation, uses several references and sources of information to complete the job, and better represents each answer in mathematical symbols. It can be seen that when students' self-management began to be implemented better with the help of teachers in guiding students during learning both from an emotional and conceptual perspective, the cognitive function of rigour mathematical thinking began to develop. It is also seen that in subject-1, the mental process that appears is level-1 with qualitative thinking. It turns out that in principle when students are in a position of independent learning, they can find various solutions in completing the given task. However, they still return to the understanding ability of each student.

For the second research subject, the three processes that show metacognitive self-management seem to be well structured. However, there are still many doubts when answering every question given by the teacher. Subjects can position themselves to manage the task completion assigned by the teacher in groups according to the experience and understanding of the prerequisite material. This becomes a simple strategy of the subject to achieve learning objectives. He also showed his efforts to find various references and sources of information before presenting a project by asking many teachers questions and searching on the internet and other companion books. This is implied from the interviews conducted at the end of the lesson. Cognitive activity still shows doubts in applying the theorems, axioms, definitions, and properties in the answers to the test questions given. According to him, still not getting used to working on the questions given is a different obstacle in learning, so evaluating is still at the level of Less. The teacher provides motivation and guidance to raise enthusiasm in learning and overcome obstacles encountered by students.

By applying project-based learning to foster independent understanding in students and reflecting at the end of the lesson, it can be seen the changes experienced by students, including students in subject 2. From the 2nd meeting until the end, he seemed

calmer in presenting the project results, focusing on understanding the material he had. It appears that when the interview was conducted, questions related to strategies in completing the task, he answered them systematically, based on experience, and mastered the prerequisite material. The results of the tests given indicate that the subject's thinking ability has increased related to mastery of concepts from new material, can analyze the problems presented, is critical and focused when answering, and looks like a strenuous effort to obtain maximum evaluation results. This 2nd subject is entered at the level of quantitative thinking with precision at rigour mathematical thinking. The development of this thinking ability can be seen from students organizing themselves to adjust their experiences, understandings, and motivations.

In the 3rd research subject, it can be seen from the initial meeting that he could condition himself with the various challenges of the tasks given; self-management seemed stable. However, there were still shortcomings in adjusting the understanding of the prerequisites with understanding the concepts of the new material. Students develop strategies to complete the given project tasks by routinely searching for various literature, including asking questions directly with the teacher. Learning motivation has arisen from the beginning of learning so that the teacher only provides guidance related to understanding the concept of new material. For this reason, at the 2nd meeting until the end, it was seen that self-management was getting better so that students were able to carry out self-evaluation by reflecting individually on the learning outcomes of each meeting and high self-confidence along with the development of learning motivation. Good metacognitive self-management can develop students' cognitive functions. This can be seen from developing the 3rd subject's thinking ability, where he can activate his mathematical knowledge, compile logical proofs of Real Analysis material problems, and build relationships between prerequisite concepts and new material. This type of student enters the level of abstract relational, cognitive function from rigour mathematical thinking.

Based on the research results obtained, students can apply self-management strategies by providing motivation and guidance for the difficulties experienced by the teacher. This is following research conducted by Sears [17], where when students are trained to use self-management, it is necessary to follow up in the form of guidance from the teacher so that the resulting impact is more visible. Because self-management needs to be raised in learning, teacher intervention must run according to the desired effects. The significant influence of self-management needs to be anticipated because the mental condition of students is not the same when entering learning with new materials. They need to make habituation, especially to independent, creative, critical,

and thorough knowledge related to their search for various sources of information, references, and personal problem-solving.

The teacher's selection of the suitable learning model also has a significant impact on the self-management metacognitive knowledge brought by each student. It can be formed well through a process that is not short. After several meetings, only self-management skills can be raised according to the order so that they can build students' mathematical thinking skills. Initially, students who were wrong in applying self-management strategies and the lack of intensity of teachers in guiding students resulted in the minor mastery of learning, cognitive function as part of rigour's mathematical thinking ability did not develop. For this reason, the relationship between choosing the suitable learning model, self-management strategies that are following the level of proficiency of each student, appropriate intervention from the teacher, and patience in maintaining self-management in students can build rigour mathematical thinking skills that have a high level of cognitive function.

4. CONCLUSION

Metacognitive self-management is formed perfectly over time, and the teacher's ability to learn is indicated by providing learning motivation and guidance in solving problems experienced by students. When self-management metacognitive knowledge runs systematically, rigour mathematical thinking skills are built, high-level thinking abilities. In addition, to maintain metacognitive self-management in students, it is necessary to carry out periodic interventions by the teacher.

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