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Performance assessment: Improving metacognitive ability in mathematics learning

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Abstract

This study aims to examine the improvement of metacognitive abilities in learning mathematics through a variety of formative assessments. The study applied an experimental approach with a pre- and post-tests control group design. Six classes of students were chosen by cluster random sampling as the sample, with two classes serve as the experimental group with performance assessments, two classes serve as the comparison group with essay assessments and two additional classes serve as the control group with multiple choice assessments. The instrument to measure metacognitive ability was developed specifically for the pre-and post-tests. The gain score was analyzed using a one-way ANOVA and continued with the Scheffe test. The study discovered that students who participated in learning with formative assessments of performance showed the highest levels of metacognitive skills followed by those who participated in learning with formative assessments of essays and those who participated in learning with formative assessments of multiple-choice questions came in third. These findings lead to the conclusion that formative assessment of performance has a positive effect on improving metacognitive abilities. According to the characteristics of learning mathematics, this situation might happen because the performance evaluation includes activities that are difficult, comprehensive and associated with daily life. In addition, performance assessment also has intrinsic value because it requires students to organize and present material in their own way. It is recommended that mathematics teachers use formative performance assessments in order to enhance cognitive capacities.

Keywords: Ability, Assessment, Formative, Metacognitive, Performance.

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Contents

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Contribution of this paper to the literature
The results of this study enrich the theory to improve metacognitive abilities in learning mathematics one of which is through the application of formative assessment of performance. Performance assessment requires students to focus on processes and products so that they have a complete understanding of the whole problem.

1. Introduction

There are several theoretical and practical applications for mathematics. It is impossible to live in the twenty-first century without the application of mathematics because its methods and reasoning are so widely used in other branches of science and in daily practical life (Cockcroft, 1982).

The modern technological revolution is based on mathematics which is a fundamental component of human understanding (Ernest, 2015; Hafni, Herman, Nurlaelah, & Mustikasari, 2020; Hajeniati & Kaharuddin, 2022). Even the application of mathematics includes fields outside of science and technology such as economics, social sciences and activities of daily life.

The great benefits of mathematics must be accompanied by the difficulty of learning them. There is a general opinion that most students do not like mathematics due to a series of factors related to the material, student attributes and learning environment (Almerino Jr, Etcuban, De Jose, & Almerino, 2019; Cheah, 2020; Martínez-Sierra & García González, 2014).

The National Science Foundation reports that the educational challenge ahead will help students cultivate a love and curiosity for science and math from an early age. How students can learn mathematics effectively and efficiently is an important topic that has to be researched.

Many efforts have been made to improve the quality of mathematics learning. In addition, the factors that influence the learning outcomes of mathematics must be studied properly. The success of students learning in school is largely determined by their metacognitive abilities (Antonio & Prudente, 2022; Chytrý, Říčan, Eisenmann, & Medová, 2020; Martin & Clerc-Georgy, 2015). Metacognitive ability is very influential on problem -solving ability (Avargil, Lavi, & Dori, 2018; Güner & Erbay, 2021). According to the findings of a survey of 179 publications out of 200 variables that influence learning outcomes, metacognitive ability ranks at the top (Langdon et al., 2019; Shen & Liu, 2011).

Metacognitive ability refers to the ability of individuals to understand their own abilities (Flavell, 1979; Kornell, Son, & Terrace, 2007). Metacognitive ability is also interpreted as the ability to think (Magno, 2010; Weil et al., 2013).

Making judgements based on what is known and using strategies for learning to discover what is unknown are examples of metacognitive skills (Astiningsih & Partana, 2019; Schoenfeld, 2016).Thus, metacognitive abilities strongly support student independence in learning for lifelong learning (Matsumoto-Royo, Ramírez-Montoya, & Glaserman-Morales, 2022; Worrall & Bell, 2007).

Many of the skills needed for active learning, critical thinking, reflective judgement, problem solving and decision-making are considered to be related to metacognitive abilities which are conceptualized as interconnected competencies for learning and thinking (Dwyer & Walsh, 2020; Kitsantas, Baylor, & Hiller, 2019). Metacognitive abilities develop and contribute to learning performance which is partly independent of intelligence (Dwi Hastuti, Fuster-Guillén, Palacios Garay, Hernández, & Namaziandost, 2022; Van der Stel & Veenman, 2014). Metacognition becomes more explicit, powerful and effective because it increasingly performs under the control of the individual's consciousness (Diehl et al., 2014; Kazemi, Yektayar, & Abad, 2012).

Another study mentions that metacognitive abilities do not need to be studied in isolation (Akben, 2020; Avargil et al., 2018). It can be learned in an integrated manner with other abilities. Mathematics, language, science and other subjects all teach metacognitive abilities. In addition, metacognitive abilities can also be studied at all levels of education.

Metacognitive abilities are general characteristics associated with people across age groups and are not domain-specific (Bellon, Fias, & De Smedt, 2020; Fitzgerald, Arvaneh, & Dockree, 2017).

The development of metacognitive abilities among students is a challenging task (Abdelrahman, 2020; Abdullah, Rahman, & Hamzah, 2017). Many efforts can be made to learn mathematics to improve metacognitive abilities. Other research mentions that metacognitive abilities can be learned through mathematical thinking in the form of training accompanied by active intervention when students work on problems (Amin & Mariani, 2017; Hacker, Kiuhara, & Levin, 2019). Previous researchers attempted to improve metacognitive abilities by using a computational framework designed to enhance learning from examples (Azevedo & Aleven, 2013; Yastibas & Yastibas, 2015). Another researcher tried to increase metacognitive ability with effective assessment (Clark, 2012; Crisp, 2012).

This research tries to increase metacognitive ability in mathematics learning through formative assessment. Teachers can examine how students develop through formative assessment (Granberg, Palm, & Palmberg, 2021; Nilsson, 2013). Formative assessment enables teachers to look at the competencies that have been mastered by students and identify gaps between student competencies and the standard competencies to be achieved (Konopasek, Norcini, & Krupat, 2016; Magno, 2010). Information from formative assessments is used as input to improve subsequent learning (Cañadas, 2021; Setemen, Widiana, & Antara, 2023). Iterative processes allow for continuous quality improvement in learning.

Many studies have been carried out to improve metacognitive abilities through formative assessments (Brady & Forest, 2018; Braund & DeLuca, 2018). Various forms of assessment, ranging from performance assessment to multiple choice can be used in formative assessment (Kulasegaram & Rangachari, 2018). Homework, portfolios and observation sheets are used as formative assessments. The choice of formative assessment is based on its capability to monitor student competence.

Performance evaluation examines students' competencies by evaluating how well they carry out a task that has inherent value (Gall, Gall, & Borg, 2003; Yan, Chiu, & Ko, 2020). Therefore, the performance assessment tasks are

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complex, complete and involve daily life. Performance assessment provides opportunities for teachers to monitor student progress continuously (Turner, 2014; Wragg, 2011).

Students must organise and present content in accordance with the assignment's guidelines for performance evaluation (Negretti, 2012; Orlich, Harder, Callahan, Trevisan, & Brown, 2010). Performance assessment is also an assessment procedure that provides opportunities for students to produce various correct responses to the same assessment and can be used to measure the performance shown by students (Haolader, Ali, & Foysol, 2015; Ngereja, Hussein, & Andersen, 2020).

A performance evaluation is more effective if a teacher wants to measure a student's capacity for doing difficult activities that depend on the application of knowledge and skills in real-world contexts (Moon & Callahan, 2001).

Essay assessment is used when learning outcomes emphasize on the ability to organize and integrate ideas according to the constraints of the problem (Orlich et al., 2010). Students use their ability to organize information to respond to requests for assessment items. The ability to prove or solve problems is very effective when measured by a description assessment.

Descriptive assessments give students an indication of the type of thinking and content used to provide responses (Lam, 2013; McLaren, 2012; Stewart & Houchens, 2014). Responses to essay assessment require a creative combination of many elements to understand a single topic (Liu, Frankel, & Roohr, 2014). However, it is not uncommon for students to feel they have the freedom to express their thoughts and provide a response so the response becomes very varied. If students feel that the teacher is not properly assessing their responses, then they will not bother studying at a higher level for the next exam but will instead go back to memorizing facts (Steele, 1997).

Essay assessment is limited to the scope of the material discussed while responses are limited based on the questions asked. As a result, it is not uncommon for description assessments to be dominated by calculations and the memory of facts. If this condition occurs, then the description assessment does not automatically assess higher-order thinking skills (Lam, 2013; McLaren, 2012; Stewart & Houchens, 2014). There are conditions where the essay assessment is not able to measure higher-level cognitive skills. On the other hand, performance assessment continuously demands the ability to perform complex tasks that require the application of knowledge and skills in real-life situations.

Multiple-choice assessments have dominated formative and summative assessments. The broad scope of material, time constraints and ease of assessment are the reasons for the dominance of multiple-choice assessments (Gyllstad, Vilkaitė, & Schmitt, 2015; McAllister & Guidice, 2012). A student can answer a large number of multiple-choice questions in a limited time. Multiple-choice assessments can also be written in various ways to map different types of thinking (Scully, 2017; Smith, 2017). The diverse assessment items test a variety of materials to explore students' knowledge.

Students do not need to find the proper response when responding to multiple-choice questions. They have to understand the correct choice (Butler, 2018; McKenna, 2019; Towns, 2014). Students who do not understand the material can give the correct answer by guessing. On the other hand, it is extremely challenging for students to respond correctly to a description assessment if they only comprehend a small portion of the content being examined. Description assessment is more effective than multiple-choice assessment in measuring higher-level cognitive skills (Scully, 2017; Smith, 2017).

The theoretical description above indicates that description assessment is still more effective than multiple-choice assessment for enhancing metacognitive ability. It was also described that to measure and train metacognitive abilities, performance assessments were more effective than description assessments. Based on these descriptions, it can be assumed that for formative assessment in mathematics learning, performance assessment produces the highest metacognitive ability followed by description assessment and multiple-choice assessment provides the lowest metacognitive ability.

2. Methods

The study used an experimental approach with a pre- and post- tests control group design in learning mathematics for junior high school students. The study was conducted on students of class VIII to avoid the intervention of historical factors in class VII students and the intensity of preparation for the final exam program for students of class IX. Six classes were selected as samples by using cluster random sampling. Two classes with 66 students became the experimental group that participated in learning with formative assessment in the form of a performance test, two classes with 68 students became the comparison group that participated in learning with formative assessment in the form of a description and two classes with 67 students became the control group that participated in learning with form of formative assessment in the form of multiple choice. A pre-test was conducted to measure the initial metacognitive abilities of the three groups before the experiment. The treatment for each group is given in Table 1.

The instrument for measuring metacognitive ability in mathematics learning is guided by two indicators of metacognitive ability: cognitive knowledge and cognitive regulation. Knowledge consists of three sub-indicators i.e., declarative knowledge, procedural knowledge and conditional knowledge. Meanwhile, the regulation consists of five sub-indicators: planning, regulation or management of information, processing or calculation, control and evaluation.

The instrument was developed in the form of non-routine mathematical problems. Students are asked to solve these problems by answering several questions related to indicators of metacognitive ability. The instrument consists of eight problem items with a reliability coefficient of alpha 0.828.

At the end of the experiment, a post-test was conducted to measure the final metacognitive ability of each group. The gain scores of the three groups were then analyzed using one-way Analysis of Variance (ANOVA) followed by the requirements test including the normality test for data distribution using the Kolmogorov-Smirnov test and the homogeneity test of the variance of the data using the Levene test. If the main effect test with a one-way ANOVA shows a difference in metacognitive ability between the three groups, then proceed with the Scheffe test to test the simple effect. All tests were carried out at a significance level of 0.05.

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Table 1. Differences in treatment for experimental class, comparison class and control class.

Experimental class	Comparison class	Control class
Learning with formative assessment in the form of a performance test.	Learning with formative assessment in the form of description.	Learning with formative assessment in the form of multiple choice.
Submission of the material to be discussed along with the learning objectives.	Submission of the material to be discussed along with the learning objectives.	Submission of the material to be discussed along with the learning objectives.
Recall the previous material.	Recall the previous material.	Recall the previous material.
The use of worksheets with exercises in the form of performance tests helps students develop their cooperative learning skills.	The use of worksheets with exercises in the form of performance tests helps students develop their cooperative learning skills.	The use of worksheets with exercises in the form of performance tests helps students develop their cooperative learning skills.
The teacher observes student behavior and provides reinforcement during discussions and presentations.	The teacher observes student behavior and provides reinforcement during discussions and presentations.	The teacher observes student behavior and provides reinforcement during discussions and presentations.
The teacher provides a formative assessment in the form of a performance test.	The teacher provides a formative assessment in the form of a description.	The teacher provides a formative assessment in the form of multiple choice.
Students do the assessment.	Students do the assessment.	Students do the assessment.
The teacher provides feedback in the form of completing the assessment.	The teacher provides feedback in the form of completing the assessment.	The teacher provides feedback in the form of completing the assessment.
Students look at each other's solutions.	Students look at each other's solutions	Students look at each other's solutions.
The teacher and students conclude the learning material.	The teacher and students conclude the learning material.	The teacher and students conclude the learning material.

3. Results and Discussion

3.1. Result

The normality test for metacognitive ability data yielded a Kolmogorov-Smirnov statistic of 0.103 with a significance of 0.91 in the experimental group, 0.101 with a significance of 0.193 in the comparison group and 0.105 with a significance of 0.081. The metacognitive ability data in the three treatment groups were normally distributed. The homogeneity of variance test resulted in Levene's statistic of 0.104 with a significance of 0.901. This means that the metacognitive ability data from the three treatment groups is homogeneous. Thus, hypothesis testing with a one-way ANOVA is feasible to continue. The summary of the results of the ANOVA test on the mean difference in metacognitive abilities for the three treatment groups is shown in Table 2.

Table 2. The summary of the one-way ANOVA test.

Source	Sum of square	Df	Mean square	F	Sig.
Between group	1922.408	2	961.204	23.042	0.000
Within group	7758.904	186	41.715		
Total	6641656.000	189			

The value of F=23,042 with sig 0.000 in Table 2 shows that there is a difference in metacognitive ability between students who take performance assessment, formative assessment in the form of description and formative assessment in the form of multiple choice. Therefore, a post-hoc test is needed to obtain multiple comparisons. The sample size of each cell is different, so the post-hoc test was carried out using the Schefft test and the results obtained are listed in Table 3.

Table 3. Multiple comparisons with the Schefft test.

(I) Group	(J) Group	Mean difference (I-J)	Standard error	Sig.
Performance	Essay	3.07	1.151	0.031
Performance	Multiple choice	7.73	1.146	0.000
Essay	Multiple choice	4.66	1.155	0.000

The multiple comparisons in Table 3 show that each group has significantly different metacognitive abilities. The mean difference between the performance assessment and description assessment groups is 3.07 with a significance of 0.031 between the performance assessment and multiple-choice assessment groups is 7.73 with a significance of 0.000 and between the description and multiple-choice assessment groups is 4.66 with a significance of 0.000. The results of the data analysis showed that the metacognitive ability of students who participated in learning with formative assessment in the form of performance was better than the metacognitive ability of students who participated in learning with formative assessment in the form of description or multiple choices.

4. Discussion

There are two objectives of performance assessment: response and simulation formats (Shavelson, Zlatkin-Troitschanskaia, Beck, Schmidt, & Marino, 2019). Response formats imply that performance assessment requires students to perform a task or performance such as solving math problems, formulating hypotheses and programming, designing or translating text. Meanwhile, the focus on simulation implies that performance assessment is based on product or behavioral assessments that are arranged in such a way as to simulate real everyday life. Therefore, performance assessments have a greater chance of successfully measuring complex abilities and skills.

Students may refine their methods and be better equipped to solve problems efficiently and creatively if they are aware of the techniques used in problem solving (Hargrove, 2013; Kertih, Widiana, & Antara, 2023). Students' metacognitive skills improve if they are asked to use techniques while studying (Medina, Castleberry, & Persky,

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2017; Widiana, Triyono, Sudirtha, Adijaya, & Wulandari, 2023).Understanding the techniques used to solve problems is similar to realizing the importance of one's own thinking process. The goal of metacognitive development is to think deeply to develop meaning (Afflerbach, Cho, Kim, Crassas, & Doyle, 2013). Furthermore, metacognitive competence helps individuals recognize the limitations of their abilities (Braffman & Kirsch, 1999; Kruger & Dunning, 1999).

Metacognitive ability consists of metacognitive knowledge and metacognitive regulation (Fabio & Antonietti, 2012; Herlanti et al., 2017; Schmidmaier et al., 2013). Metacognitive knowledge includes three areas: declarative knowledge, procedural knowledge and conditional knowledge. On the other hand, metacognitive regulation covers five areas: setting goals, organizing information, monitoring learning strategies, correcting errors and evaluating the effectiveness of strategies after the learning process. Analysis of performance and effectiveness of strategy selection is well-trained in performance assessment which strengthens the finding that formative assessment of performance forms produces better metacognitive abilities than formative assessment of essays or multiple-choice tests.

Numerous inputs on performing assessments are summarized in prior research which suggests a kind of formative assessment that covers a wider range of assignments, such as performance evaluations, rather than only multiple-choice tests, short answer questions or essay tests. Formative assessment provides a more comprehensive picture of student learning progress than test-based assessments. Research on mathematics learning found that formative assessment of performance can also improve learning outcomes compared to formative assessment of traditional forms of testing (McLaughlin & Yan, 2017; Torrance, 2012).

Performance assessment can increase self-confidence (Lochbaum et al., 2022) because it is more natural and direct. Therefore, performance assessment evaluates learning that has applications in everyday life. It requires students to analyze problems, plan solutions and reflect on the solutions is often called the ability to regulate their own learning. The ability to self-regulate learning can improve metacognitive abilities which include observing, evaluating and regulating cognitive activities (Nash-Ditzel, 2010; Whitebread et al., 2009).

Performance assessment requires students to apply their knowledge and skills from several fields to complete an activity or task (Chung, 2014). Performance assessment focuses on what students need to know, understand and can do (Moon & Callahan, 2001). In other words, performance assessment includes an evaluation of the behavior or product of a behavior. In solving mathematical problems, the competence of students can be evaluated through the work process and the resulting solutions. Behavior-based strategies can improve metacognition in mathematics learning (Desoete & De Craene, 2019). In addition, performance assessment can also involve self-evaluation and peer assessment to affect cognitive and metacognitive abilities (Panahandeh & Asl, 2014; Pantiwati & Husamah, 2017).

The metacognitive system acts as the main manager of the cognitive and behavioral processes of the individual concerned (Roebers, 2017). Metacognition determines which knowledge should be learned next and how to learn that knowledge. Performance assessment provides opportunities for students to demonstrate their abilities, strengths, interests and motivation (Moallem, 2019; Rowe, Mazzotti, Hirano, & Alverson, 2015). The results of previous studies show that performance evaluation may be used to enhance higher-order thinking abilities and comprehension of facts, ideas and metacognitive skills (Shukla & Dungsungnoen, 2016; Widana, 2017).

5. Conclusion

Formative assessment in learning mathematics has a significant effect on the metacognitive abilities of students. Performance formative assessment resulted in the highest metacognitive abilities followed by description formative assessment and the lowest multiple-choice formative assessment. Performance assessment incorporates cognitive tasks for planning, implementing, monitoring and evaluating processes and products. These activities are very relevant to developing metacognitive abilities. Meanwhile, the description assessment emphasis on the ability to structure and combine concepts but it is only applicable to the present problems. Responses are limited based on the questions asked. Indeed, there is a match in the response to the description assessment with the procedure for fostering metacognitive abilities. But there are still limitations, so the increase in metacognitive abilities is not optimal. On the other hand, the lowest level of metacognitive skill develops through multiple-choice tests since students have an opportunity to get the questions if they don't fully grasp the idea. Students can find the correct answer only by matching the problem with the available answer choices and guessing.

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