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Improving Mathematical Creativity Through Self-Regulated Learning in a Problem-Based Learning Model Supported by GeoGebra

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Abstract

Creative thinking is a crucial skill in the 21st century. However, creative thinking abilities are still lacking in Indonesia, with a global creativity index of just 0.202, indicating very low level. This study seeks to evaluate the quality of GeoGebra-assisted Problem-Based Learning in enhancing students' creative thinking skills and to describe students' creative thinking abilities in relation to Self-Regulated Learning. The research method used is a mixed method. The research sample includes students from grades VIII D and VIII E at SMP Negeri 2 Ungaran. The subjects of this study are 6 students categorized by their level of Self-Regulated Learning. Quantitative data analysis involves t-tests and z-tests, qualitative data analysis involves data reduction, presentation, interpretation, and drawing conclusions. The study finds that GeoGebra-assisted Problem-Based Learning effectively enhances creative thinking skills. Students with high, medium, and low Self-Regulated Learning levels showed very good, good, and poor mathematical creative thinking abilities, respectively.
Keywords: Mathematical Creative Thinking; GeoGebra Classroom; Self-Regulated Learning

Abstrak

Berpikir kreatif merupakan kemampuan yang sangat diperlukan di abad 21. Akan tetapi kemampuan berpikir kreatif masih sangat kurang di Indonesia, ditunjukkan dengan indeks kreativitas global Indonesia yaitu 0,202 yang tergolong sangat rendah. Penelitian ini bertujuan untuk mengetahui kualitas *Problem Based Learning* berbantuan GeoGebra terhadap peningkatan kemampuan berpikir kreatif siswa dan mendeskripsikan kemampuan berpikir kreatif siswa berdasarkan *Self-Regulated Learning.* Metode penelitian yang digunakan yaitu *mixed method.* Sampel penelitian yaitu siswa kelas VIII D dan VIII E SMP Negeri 2 Ungaran. Subjek penelitian yaitu 6 siswa berdasarkan tingkat *Self-Regulated Learning.* Analisis data kuantitatif menggunakan uji t dan uji z. Analisis data kualitatif mencakup penyederhanaan data, penyajian, interpretasi, dan penarikan kesimpulan. Hasil penelitian mengindikasikan bahwa Problem Based Learning yang didukung GeoGebra berkualitas dalam meningkatkan kemampuan berpikir kreatif serta kemampuan berpikir kreatif matematis siswa dengan tingkat self-regulated learning tinggi, sedang, dan rendah, masing-masing dengan hasil sangat baik, baik, dan kurang.
Kata Kunci: Berpikir Kreatif Matematis; GeoGebra; *Self-Regulated Learning*

I. INTRODUCTION

Mathematics is one of the fields of science that must be taught in Indonesia from elementary, secondary, to tertiary levels (Rozi, 2023). Mathematics learning is an important teaching and learning activity as a means to learn and develop school mathematics skills so that students are able to implement their learning outcomes and solve problems in their daily lives (Dewi et al., 2022). According to Sumartini (2019), in solving mathematical problems, creative thinking is needed because the creative thinking of each individual at various levels will affect the process of solving mathematical problems.

According to Febrianingsih (2022), creative thinking ability involves being sensitive to problems, generating unique ideas or solutions, and establishing connections during the process of analyzing and solving issues. The solutions devised to address problems are known as creativity or innovation. As the opinion of Suyitno (2020) and Acar et al. (2019), Creativity that leads to new discoveries is often referred to as innovation (Setyaningsih & Kustiana, 2023). Transforming creative ideas into innovations is crucial for achieving a competitive edge (Ranila, Yunianta, & Prihatnani, 2023). So that the creativity produced by each individual can come from himself as a result of the thought process or can also come from the thoughts of others that are developed so that uniqueness arises.

Developing creative thinking skills is essential to address the challenges frequently faced by students today, namely the lack of creativity in thinking which can affect their learning outcomes (Zubaidah et al., 2023). In addition, the mathematics learning process only focuses on behavioral aspects but less emphasis on thinking aspects. This is in accordance with Kadir et al. (2022) that most math learning in the classroom still emphasizes understanding but under develops creative thinking skills. Students are simply taught to solve problems in the same way as exemplified by the teacher.

Many aspects can affect the lack of creativity in thinking experienced by students, one of which is learning independence or self-regulated learning (Wong et al., 2019; Zaiyar & Qalbi, 2023). According to van Alten et al. (2020), self-regulated learning is the ability that individuals have in self-regulating or actively regulating metacognition, motivation, and behavior in the learning process that involves strategies and processes in achieving goals (Fitriatien & Mutianingsih, 2020). Active participants who can self-regulate themselves or called self-regulated learners show characteristics in the form of being able to plan, organize, directing and monitoring themselves, and evaluate themselves at levels different from what they learn in depth (Subtikasari & Neviyarni, 2019; Ghassani et al., 2023). The tendency that occurs in secondary school is that students are less able to regulate their own way of learning, which has an impact on the emergence of passive responses during learning (Atiyah & Nuraeni, 2022). In this case, the expected learning objective when developing self-regulated learning is to increase students' creative thinking abilities.

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To enhance students' creative thinking skills related to self-regulated learning in problem-solving, educators can employ various learning models, including the Problem-Based Learning model. Based on research conducted by (Maskur et al., 2020), employing problem-based learning models is believed to improve students' creative thinking skills, especially in addressing mathematical problems.

In the application of learning models, appropriate ways or strategies are needed, one of which is the use of media or learning resources. Utilizing IT (Science and Technology) is one of the strategies that can be implemented in education (Septia & Wahyu, 2023). The application of the Problem-based Learning model in this study is assisted by a digital application, namely GeoGebra Classroom. GeoGebra Classroom is a virtual platform that is one of the newest features of GeoGebra (Puspitasari et al., 2023). As the opinion of Asyura & Dewi (2020) that GeoGebra Classroom makes learning interactive both online and offline, then the use of GeoGebra Classroom is considered more practical and can be used through mobile devices and computers for each student. By implementing GeoGebra-assisted problem-based learning in the classroom, it is anticipated that creative thinking skills related to self-regulated learning will improve. This study aims to evaluate the effectiveness of GeoGebra-assisted problem-based learning in enhancing students' creative thinking abilities and to analyze these skills based on self-regulated learning.

II. METHOD

This research employs a mixed-method approach with a sequential explanatory design. In this design, data is first collected and then analyzed quantitatively. The second stage is to collect and analyze data qualitatively to strengthen and deepen quantitative results (Creswell & Creswell , 2018). The quantitative research design is experimental, involving two groups: an experimental class and a control class. The experimental design used in this study is quasi experimental. Quasi-experimental design includes a control group but cannot fully account for external variables that affect the execution of the experiment (Sugiyono, 2018). Quasi experimental is used with posttest only control group design which is briefly shown in the Table 1.

Table 1
Posttest Only Control Group Design

Group	Treatment	Posttest
Experiment	X_1	O
Control	X_2	O

Keterangan:
X_1 : PBL Assisted by GeoGebra Classroom
X_2 : *Discovery learning*
O : *Posttest Mathematical Creative Thinking*

The population for this study consists of all grade VIII students at SMP Negeri 2 Ungaran for the 2023/2024 academic year. Sampling in this study used random sampling technique. The sampling is based on various considerations, including grade VIII students all get the same curriculum, students as research objects are at the same level and class, and class division is carried out randomly or there is no superior class. Using random sampling, two classes were chosen: class VIII D as the experimental group and class VIII E as the control group. The experimental class

received the GeoGebra-assisted Problem-Based Learning model, while the control class was taught using the Discovery Learning model.

The research variables used in the study were bound variables and independent variables. The learning model applied is an independent variable, and students' mathematical creative thinking ability is a dependent variable. Data collection techniques in this study consisted of tests, psychological scales, and interviews. Test is a data collection technique to measure the ability that researchers want to observe. The ability assessed is mathematical creative thinking. The test for this ability is designed based on the creative thinking indicators established by the researchers, which include fluency, flexibility, originality, and elaboration.

The psychological scale is a data collection technique by providing a series of statements that are used in order to reveal indicators of the subject's behavior (Azwar, 2019). The psychology scale created is used to classify students' self-regulated learning by taking into account the indicators of self-regulated learning set by (Soemarmo & Hendriana, 2014) is: (1) There is an initiative to learn in students without any coercion from other parties; (2) the student's ability to know his learning needs; (3) students are able to design learning goals to be achieved; (4) able to choose learning resources and accuracy in the use of learning resources; (5) students are able to develop learning strategies and evaluate the learning outcomes they have done; (6) students are able to cooperate with other parties; (7) students' ability to construct meaning from the knowledge they acquire; and (8) students are able to exercise self-control in acting.

Interview is a data collection technique that uses open-ended questions in order to obtain in-depth results. According to Creswell (2018), The interview method can be done by face-to-face interviews with participants, by telephone, or in focus group interviews. The interview method is made using an unstructured interview method, which is an interview that uses open-ended questions in order to raise the views and opinions of the research subject (Creswell, 2018).

Learning tools used include teaching modules for experimental classes and control classes and student worksheets in the form of GeoGebra Classroom for experimental classes. Before the device is used in both sample classes, it is first validated to experts, namely mathematics lecturers and mathematics teachers. The results of revisions from experts are carried out to improve the learning tools to be used.

The initial data used in this study were odd midterm summative scores of classes VIII D and VIII E. The data were tested for normality, homogeneity, and average similarity to determine the initial ability of the two sample classes to be the same or not. Once it is confirmed that the abilities of the two sample classes are similar, different treatments are applied to each. The experimental class undergoes Problem-Based Learning with GeoGebra assistance, while the control class uses Discovery Learning.

At the end of the learning process, students take a mathematical creative thinking ability test to assess the outcomes

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of the different treatments. The test is given to both sample classes with the same questions, which is 5 questions with an allocation of 80 minutes. The question has previously been tested in class VIII C and has been valid, reliable, and has been considered for its distinguishing power and level of difficulty. Additionally, the results of the mathematical creative thinking ability test are assessed for normality, homogeneity test, due diligence, average and proportion difference test, and influence test of bound variables and independent variables.

III. RESULT AND DISCUSSION

A. Result: Quality of GeoGebra-Assisted Problem-Based Learning in Enhancing Mathematical Creative Thinking Skills

The quality of GeoGebra-Assisted Problem-Based Learning in enhancing mathematical creative thinking skills is measured through three stages: planning, implementation, and evaluation, as explained below.

At the planning stage, the preparation of teaching materials and research instruments is carried out by researcher. Before learning tools are used and mathematical creative thinking skills problems are given to students, they are first validated to mathematics lecturers and mathematics teachers. The results were obtained in the form of an average validation score for teaching modules of 4.83 with very good criteria, an average score for GeoGebra Classroom learning media of 4.70 with very good criteria, and an average validation score for mathematical creative thinking skills questions of 4.89 with very good criteria. Since the teaching materials and research instruments have been validated as "very good," the planning stage of the learning process is considered high-quality.

At the implementation stage, creative thinking skills questions that have been validated and revised according to the advice of experts, are tested in the trial class, namely class VIII C. The results of the trial test are analyzed, producing data that the five question items tested are valid, reliable, have the appropriate distinguishing power and level of difficulty so that all question items can be used. Furthermore, learning was carried out with different treatments in both sample classes. The experimental class used Problem-Based Learning with GeoGebra assistance, while the control class employed Discovery Learning.

After the learning tools were used, student response questionnaires were administered during the second and fourth meetings in a class using GeoGebra-Assisted Problem-Based Learning, with 34 students participating. The average scores for the questionnaires were 80.47 in the second meeting and 82.12 in the fourth meeting. These averages indicate that student responses to the learning process were categorized as good. Additionally, student responses improved from the second to the fourth meeting, demonstrating a positive reaction to the GeoGebra-Assisted Problem-Based Learning model. Since student responses to the learning process were positive and the scores showed an upward trend, the

implementation stage of the learning process is considered high-quality.

At the evaluation stage, A mathematical creative thinking ability test was administered to both sample classes. The results were initially analyzed using prerequisite tests, including normality tests and homogeneity tests of the two research samples with the help of SPSS 25. In the normality test, the significance value of the experimental class is obtained $0.200 > 0.05$ and control classes $0.136 > 0.05$ so that H_0 received or final mathematical creative thinking ability (posttest) test score data in both samples came from normally distributed populations. In the homogeneity test, a significance value is obtained $0.598 > 0.05$ so that H_0 accepted or final mathematical creative thinking ability (posttest) test score data in both samples have the same variance (homogeneous).

The following is the descriptive statistics of mathematical creative thinking skills for the material on straight line equations in the experimental class VIII D and the control class VIII E, as shown in Table 2.

Table 2
Descriptive Statistics of Mathematical Creative Thinking Ability Test Results

Statistics	Experiment Class	Control Class
Multiple Students	34	34
Highest Score	95	95
Lowest Score	56	57
Average	78.62	74,53
Variance	68.122	63.590
Standard Deviation	8.254	7.974
Completeness	94.11%	79.41%

Due diligence based on Actual Due Limits was carried out using the One Sample T Test average value of both research samples with the help of SPSS 25. Obtained $t_{value} = 5.9468 > 1.6924 = \mathrm{t}_{\mathrm{table}}$, so H_0 rejected. This means that the average mathematical creative thinking ability of students in Problem Based Learning assisted by GeoGebra Classroom is more than the actual complete limit (BTA).

Classical due diligence is performed using formula of z test with a percentage of classical learning completeness 75%, $x = 32$ and $n = 34$. Obtained a value of $z_{value} = 2.574$, compared to the $z_{\frac{1}{2}-0,05} = 1.645$ value, so $z_{value} > z_{\frac{1}{2}-0,05}$. It can be concluded that over 75% of students in the GeoGebra-assisted Problem-Based Learning classroom have achieved a satisfactory level of mathematical creative thinking skills.

The average difference test was conducted using SPSS 25 to determine if there was a significant difference in mathematical creative thinking ability between the experimental and control classes. Obtained $t_{value} = 2.077 > 1.668 = \mathrm{t}_{\mathrm{table}}$, so H_0 rejected, this means that The average level of mathematical creative thinking ability among students participating in Problem-Based Learning with GeoGebra assistance is higher compared to the mathematical creative thinking ability of students engaged in Discovery Learning.

The two-proportion difference test was carried out with a completeness proportion z test which aimed To assess whether there was a difference in the proportion of completeness in mathematical creative thinking ability between the experimental class and the control class. 32 students completed in the experimental class and 27 students in the control class, obtained $z_{value} = 1,789$ value. When compared to

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$z_{\frac{1}{2}-0,05} = 1,645$ value, so $z_{hitung} > z_{\frac{1}{2}-0,05}$ therefore H_0 is rejected. This indicates that the proportion of students achieving proficiency in mathematical creative thinking skills is higher in the Problem-Based Learning model with GeoGebra assistance compared to those in Discovery Learning. The test results reveal that students in the experimental class demonstrated significantly better outcomes in creative thinking abilities than those in the control class, the evaluation stage of the learning process is considered high-quality.

B. Result: Description of Mathematical Creative Thinking Skills Based on Self-Regulated Learning

In this research, qualitative data analysis was performed on information gathered from mathematical creative thinking tests and interviews with the research subjects. Prior to administering the mathematical creative thinking test in the experimental class, students completed a Self-Regulated Learning questionnaire. This questionnaire, consisting of 20 statements with 5 response options, aimed to categorize students into low, medium, or high Self-Regulated Learning levels.

Below are the results of the Self-Regulated Learning questionnaire analysis for the experimental class that utilized the GeoGebra-Assisted Problem-Based Learning model.

Table 3.
Results of the Self-Regulated Learning Questionnaire Analysis

Self-Regulated Learning Category	Number of Students	Percentage
High	8	23.53%
Medium	23	67.65%
Low	3	8.82%

Two students were selected from each Self-Regulated Learning category to serve as research subjects. Their test results and interviews were analyzed to provide a description of mathematical creative thinking skills in each category. Based on this analysis, the conclusions regarding the mathematical creative thinking abilities of subjects in high, medium, and low categories are summarized in Table 4.

Table 4.
Mathematical Creative Thinking Ability for Each Research Subject

Self-Regulated Learning Category	Indicator of Mathematical Creative Thinking Ability			
	Fluency	Flexibility	Elaboration	Originality
High (ST-1 and ST-2)	Yes	Yes	Yes	Yes
Medium (SS-1 and SS-2)	Yes	No	Yes	Yes
Low (SR-1 and SR-2)	Yes	No	No	Yes

The results revealed that subjects with high Self-Regulated Learning (SRL) excelled in all indicators of mathematical creative thinking ability—fluency, flexibility, elaboration, and originality. In contrast, subjects with medium Self-Regulated Learning (SRL) demonstrated proficiency in fluency, elaboration, and originality, but not in flexibility, while the flexibility indicators have not been mastered. Furthermore, subjects with low Self-Regulated Learning (SRL) only mastered the indicators of mathematical creative thinking ability, namely fluency and originality, while the indicators of flexibility and elaboration have not been mastered well or are still lacking.

C. Discussion: Quality of GeoGebra-Assisted Problem-Based Learning in Enhancing Mathematical Creative Thinking Skills

The quality of learning is an important factor to consider when implementing the learning process. The quality of learning means that the harmony between the learning activities carried out is going well and the output produced must also have a good level. The quality of learning can affect the learning process and student learning outcomes as well (Yusrianto & Hajeniati, 2022). The quality of learning is measured at the stage of planning, implementation, and evaluation of learning. These stages are in line with research from Khardita et al., (2023).

At the planning stage, an assessment of learning tools and research instruments was carried out by validators. Based on the validation results by expert validators, the average score for all teaching materials was categorized as very good. Therefore, the developed teaching materials are deemed suitable for use in the study. Additionally, the validation results for the research instruments showed that the average score for all instruments was also categorized as very good, making them appropriate for the research. Thus, it can be concluded that the planning stage of the learning process is of high quality, as both the teaching materials and research instruments used are valid and categorized as very good.

At the implementation stage, learning is carried out with the Problem Based Learning model assisted by GeoGebra. The use of GeoGebra Classroom in Problem-Based Learning can enhance learning outcomes. This statement aligns with Puspasari (2022), who found that Problem-Based Learning with GeoGebra Classroom significantly affects students' learning results. GeoGebra-assisted Problem-Based Learning positively impacts students by increasing their engagement in learning activities, challenging them to solve real-life problems, and boosting their confidence and participation during group discussions.

Quality assessment of the learning process was also conducted by administering a student response questionnaire to gauge their reactions to the GeoGebra-Assisted Problem-Based Learning model. The results showed that the average score from the questionnaires was categorized as good and exhibited improvement. This indicates that students responded positively to the learning model. According to the student responses, the GeoGebra-Assisted Problem-Based Learning was perceived as a new and enjoyable learning experience. Students had not previously encountered this model and felt that their understanding of straight-line equations improved. They were able to study independently using GeoGebra Classroom and even review the material outside of class time. Based on the results of observation of teacher activities or the implementation of learning and students' responses to learning, It can be concluded that the implementation stage of learning with GeoGebra-assisted Problem-Based Learning in the classroom is of high quality.

At the evaluation stage, quantitative data analysis of students in the experimental and control classes was carried out. The average mathematical

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creative thinking ability of students who experienced the GeoGebra-Assisted Problem-Based Learning model exceeded the Actual Completion Limit 70.2 and exceeded classical completeness 75%. In addition, on average, Students who received instruction through the GeoGebra-Assisted Problem-Based Learning model demonstrated significantly better mathematical creative thinking abilities compared to those taught using the Discovery Learning model.

D. Discussion: Description of Mathematical Creative Thinking Skills Based on Self-Regulated Learning

From these results in the Table 4, it was known that subjects with high Self-Regulated Learning (SRL) mastered all indicators of mathematical creative thinking ability, namely fluency, flexibility, elaboration, and originality. It is characterized by subjects with high SRL being able to work on problems with their own ideas, being able to present detailed problem solving, being able to solve problems in various ways and solutions. It can be concluded that students with high Self-Regulated Learning have excellent mathematical creative thinking skills.

The subjects with medium Self-Regulated Learning (SRL) are mastering the indicators of mathematical creative thinking ability, namely fluency, elaboration, and originality, while the flexibility indicators have not been mastered. It is characterized by subjects with high SRL being able to work on problems with their own ideas, able to present detailed problem solving, able to solve problems with varied solutions, but not yet able to present problem solving with different variations.

The subjects with low Self-Regulated Learning (SRL) only mastered the indicators of mathematical creative thinking ability, namely fluency and originality, while the indicators of flexibility and elaboration have not been mastered well or are still lacking. It is characterized by subjects with low SRL being able to work on problems with their own ideas, able to solve problems with varied solutions, but unable to present problem solving in detail and in order and varied ways of solving. From the description of the mathematical creative thinking ability, it can be said that the student's mathematical creative thinking ability is comparable to its Self-Regulated Learning. This is in line with research from Agustina et al. (2023), that students' mathematical creative thinking skills are comparable to their Self-Regulated Learning.

IV. CONCLUSION

Based on the research on Mathematical Creative Thinking Ability in relation to Self-Regulated Learning within the GeoGebra-Assisted Problem-Based Learning model, it was concluded that GeoGebra-assisted Problem-Based Learning was of high quality for enhancing students' mathematical creative thinking abilities, as evaluated through three stages of learning, namely the planning stage, the implementation stage, and the evaluation stage. Second, the creative thinking ability possessed by students is comparable to their Self-Regulated Learning (SRL). Students with high SRL have the best mathematical creative thinking skills from other SRL levels, characterized by mastery of all

indicators of mathematical creative thinking ability.

The advice that can be given is that in carrying out Problem Based Learning, teachers and students must prepare infrastructure facilities well which include computers or smartphone, internet connections, and google accounts so that progress during learning is not lost even though there are obstacles to the internet connection. Furthermore, teachers should provide additional exercises related to straight-line equation material for students with low Self-Regulated Learning to optimize their mathematical creative thinking skills, especially in flexibility and elaboration indicators.

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