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Improvement of The Ability of Mathematical Creative Thinking through Pace-Geogebra Learning in Terms of Student Self-Regulated Learning

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ABSTRACT

The ability of mathematical creative thinking is essential for students to possess, but in reality, the level of mathematical creativity in Indonesia remains comparatively low. This study aims to find out if learning with PACE-GeoGebra helps improve students' mathematical creative thinking abilities and to understand how self-regulated learning relates to the improvement of these abilities through PACE-GeoGebra. Quasi-experimental research methodology is employed. The study uses a non-equivalent comparison group design. All of the 10th graders enrolled in one of Cianjur's high schools for the 2024–2025 school year make up the study's population. Two classes—classes X-E and X-F—were chosen as samples from the population using a purposive sampling technique. While the control group employed the standard learning model, the experimental group employed the PACE-GeoGebra learning model. Tests and questionnaires with information on quadratic functions were the tools utilized. Using the two-sample mean equality test, data analysis was done on the average gain index between the two sample classes. The research results show that (1) there is a significant difference in the improvement of mathematical creative thinking abilities between students who use the PACE-GeoGebra approach and students who use conventional learning. (2) There is a correlation between student self-regulated learning and the improvement of mathematical creative thinking skills through PACE-GeoGebra learning.

Keywords: mathematical creative thinking; pace-geogebra; self-regulated learning

INTRODUCTION

Mathematics plays a crucial role in life, particularly in education at schools and universities, as it helps achieve national educational goals and fosters a society that is creative, productive, and innovative (Nurulaeni & Rahma, 2022). One of the mathematical competencies that schools teach is the ability to think creatively about mathematics (Afriansyah et al., 2019). One of the abilities needed to solve difficulties is the capacity for creative thought (Jawad et al., 2021). Thinking creatively entails coming up with fresh concepts, approaching challenges in novel ways, and addressing various problems (Munthe & Hakim, 2022).

It will be simpler for students with mathematical creative thinking abilities to comprehend and resolve challenging math problems since they may come up with original ideas in addition to using formulas (Fathoni & Siswono, 2023). This ability must be fully pursued in mathematics education in addition to being a competency that students must be taught (Septian et al., 2020). In practice, there is still a shortage of mathematical creativity. This aligns with the findings of the 2022 study conducted by the global institution known as the Programme for International Student Assessment (PISA), specifically with reference to the PISA 2022 creative thinking test, which demonstrates cognitive abilities. The exam comprises 32 computer-based, open-ended, human-scored problems intended to assess three aspects of ideation: coming up with original ideas, coming up with diverse ideas, and assessing and refining ideas. According to the Organization for Economic Co-operation and Development (2024), Indonesia's capacity for mathematical creativity is below average among OECD member nations.

One of the reasons for the inadequate capacity for mathematical creativity is the inefficient learning model. This occurs as a result of students becoming passive and only mimicking without understanding due to repetitive, teacher-centered mathematical training (Munthe & Hakim, 2022). Student creativity receives less attention as a result of the ongoing underutilization of the emphasis on cultivating creative thinking abilities in mathematics instruction (Palwa et al., 2024). Furthermore, pupils' capacity for mathematical creativity may be impacted by their level of learning independence. Students who learn on their own will be better equipped to finish assignments since they will have developed the habit of thinking creatively (Simamora et al., 2023). Students with greater autonomy in their education will take greater ownership of it, which will affect their learning results (Septian et al., 2022).

Many earlier studies have looked at ways to improve skills in mathematical creativity, like using the Creative Problem Solving (CPS) method, which was explored by Ikhsan Faturohman and Ekasatya Aldila Afriansyah (2020) to boost mathematical creative thinking skills, and also by using GeoGebra software to see how students' critical thinking skills and learning independence are connected (Ali Asmar and Hafizah Delyana 2020). Accordingly, studies conducted by Rosyana et al. (2023) demonstrate how using the PACE and PACE-GeoGebra learning models helps students become more adept at problem-posing and using their creative thinking abilities in mathematics. The effectiveness of the PACE-GeoGebra paradigm in developing students' mathematical creative thinking abilities while taking their learning freedom into account, however, has not been thoroughly studied.

The goal of this study is to see if there is a significant difference in how well students improve their mathematical creative thinking abilities when using the PACE-GeoGebra method compared to traditional learning and to find out if there is a link between students' self-regulated learning and the improvement of their mathematical creative thinking abilities through PACE-GeoGebra teaching. The goal of this research is to help create more relevant and successful teaching strategies for mathematics that will meet both the needs of students and the demands of the modern world.

RESEARCH METHODS

Utilizing a quasi-experimental design and quantitative research methodology, the design chosen was a non-equivalent comparison group. In Table 1, the nonequivalent comparison group design that can be applied to Johnson & Christensen's (2019) study is shown in detail as follows:

Table 1. Design of Nonequivalent Comparison Groups

Class	Pretest	Treatment	Posttest
Experiment	O_1	X_1	O_2
Control	O_1	X_2	O_2

Note:
O_1 = Pretest
O_2 = Posttest
X_1=Treatment with the PACE-GeoGebra learning model
X_2 = Treatment with the conventional learning model

One of Cianjur's high schools conducted this study during the even semester of the 2024–2025 school year. This took place from February 12 to April 16, 2025. The sample consists of 72 students, 36 of whom are in class X-E; of these, 36 are in class X-F, and the experimental class uses the PACE-GeoGebra learning paradigm, which is the control class using the regular learning model. We used the purposive sampling method for sample selection, taking into account the equivalent pretest results and the mathematics teacher's recommendation.

A mathematical creative thinking ability test and a self-regulated learning questionnaire were used as research instruments in this study. Both instruments were deemed appropriate, as the trial results indicated that they met the validity and reliability criteria. The validity coefficients ranged from 0.500 to 0.965, indicating moderate to very high validity. The reliability coefficient was 0.831, categorized as very high, confirming that the instruments are valid and reliable for use in this study. To gather data, pretests and posttests measuring mathematical creative thinking abilities were administered, and following treatment, the experimental class was given a learning independence questionnaire.

A pretest (normality, homogeneity, and two-sample mean equality test) and a posttest (normality and Mann-Whitney test) comprise the mathematics creative thinking ability data analysis technique. The data analysis process uses the normality test and Spearman's Rank-Order Correlation test for the questionnaire. We use IBM SPSS Statistics version 27 software for the instrument test.

RESULTS AND DISCUSSION

Analysis of Pretest Data on Initial Mathematical Creative Thinking Ability

We utilize the pretest acquisition results from the experimental and control classes to assess the students' initial ability in mathematical inventiveness. We conduct a pretest before training to determine whether the experimental and control classes have an equivalent initial ability for mathematical creative thinking. Upon teaching students about quadratic functions, we first assess their capacity for mathematical creativity. Table 2 displays the results of the normality test for the pretest data.

Table 2. Normality Test Results for Pretest Data

Class	Shapiro-Wilk	
	Sig.	Explanation
Experiment	0.286	Normal
Control	0.253	Normal

According to Table 2, the experimental class's Sig. value is 0.286, meaning that it is accepted and the significance value is higher than 0.05. The control class has a significant value of 0.253, signifying its acceptance and surpassing the significance level of 0.05. Therefore, we can argue that both the experimental and control groups sourced their pretest data samples from a normally distributed population. We then conducted a homogeneity of variance test to evaluate the homogeneity of the variance. The results of the homogeneity test are presented in Table 3.

Table 3. The Pretest Data Homogeneity Test Outcomes

Pretest Data	
Sig.	Explanation
0.889	Homogeneous

According to Table 3, a significant value of 0.889, beyond 0.05, indicates the acceptance of H_0 . Consequently, we can assert that we consistently obtained samples from the populations of both classes. We conducted a two-sample mean equality test using the t-test, an independent sample test that assumes equal variances. Table 4 displays the outcomes of the two-sample mean equality test.

Table 4. Two-Mean Equality Test Outcomes for Pretest Data

Pretest Data	
Asymp. Sig. (2-tailed)	Explanation
0.644	H_0 accepted

Table 4 indicates a significant value of 0.644, signifying the acceptance of H_0 since the significance value of the pretest data exceeds 0.05. The early mathematical ingenuity of the experimental group is thus comparable to that of the control group. This technique allows the researcher to conduct the study by treating each class differently.

Improvement in Mathematical Creative Thinking Ability (Gain Index)

The gain indexes from the experimental and control classes were utilized to evaluate the enhancement of students' mathematical creative thinking skills. Subsequent to the acquisition of pretest and posttest data, the researcher calculates the gain index value. In the study of quadratic functions, students in both experimental and control groups undergo different interventions, and the gain index is employed to evaluate the enhancement of their mathematical creative thinking abilities. The PACE-Geogebra learning model is implemented in the experimental group, whereas the conventional learning model is utilized in the control group. Table 5 presents the results of the normality test for the gain index data.

Table 5. Gain Index Information Results of Normality Testing

Class	Shapiro-Wilk	
	Sig.	Explanation
Experiment	0.001	Not Normal
Control	0.083	Normal

Table 5 indicates that the significance value for the experimental class is 0.001, which is less than 0.05, whereas the significance value for the control class is 0.083, which exceeds 0.05. The homogeneity test is unnecessary because one of the two pretest data samples lacks a normal distribution; however, the Mann-Whitney nonparametric statistical test is required. Table 6 presents the results of the Mann-Whitney test.

Table 6. Gain Index Data for Mann-Whitney Test Results

Gain Index Data	
Asymp. Sig. (2-tailed)	Explanation
0.001	H_0 declined

Table 6 showed a significance value of 0.001, which indicates that the significance of the gain index data is less than 0.05 and that H_0 it has declined. Consequently, it can be said that students who use the PACE-GeoGebra approach and students who use standard learning methods differ significantly in how well their mathematical creative thinking skills grow. Compared to the group that employed traditional learning, the group using the PACE-GeoGebra approach had a greater improvement in learning outcomes.

The improvement in learning outcomes in the experimental group can occur because the treatment given during the learning process is able to provide a more meaningful learning experience. When students are actively involved through real experimental activities, they do not just passively receive information but also build understanding through direct engagement. One of the learning approaches that aligns with this principle is the PACE model. According to the research by Septian et al. (2020), applying Android-based GeoGebra enhances students' mathematics creative thinking abilities more than traditional learning methods do. GeoGebra helps students learn and solve math problems about quadratic functions, and it becomes easier to understand when pictures or visual aids are included. (Sugiarni et al., 2024).

This conclusion is supported by Rosyana et al. (2023), who state that their research results show that the implementation of the PACE learning model and the GeoGebra-assisted PACE model (PACE-G) has a positive impact on improving students' problem-posing and mathematical creative thinking abilities. In this case, students who received instruction using the PACE-G model showed a higher improvement compared to those who followed the PACE model without technological assistance or conventional learning. Furthermore, the PACE learning model not only enhances students' mathematical proof abilities but also provides a more engaging and enjoyable learning experience compared to conventional learning (Rahman & Yunita, 2018).

The PACE-GeoGebra learning paradigm has demonstrated efficacy in enhancing students' academic performance and mathematical creative thinking ability relative to traditional instructional methods. This learning provides a more meaningful educational experience through the active involvement of students in the thinking and problem-solving process, thereby encouraging trust in one's abilities, curiosity, and high participation. In addition to having a positive impact on students, this model also encourages teachers to be more open to learning innovations and to create a cooperative and student-centered learning environment. In line with the findings of Siregar & Ratnaningsih (2019), students showed a positive attitude toward geometry learning when using PACE-GeoGebra. Therefore, schools are recommended to implement this model in mathematics education and provide training for teachers to be better prepared to integrate GeoGebra into the learning process, especially on topics such as quadratic functions.

The Correlation Between Self-Regulated Learning and PACE-Geogebra Learning-Based Mathematical Creative Thinking Capabilities

The self-regulated learning questionnaire in the experimental class (X-E) supplied the necessary data to analyze the correlation between students' self-regulated learning. The objective is to evaluate how students' self-regulated learning relates to the PACE-Geogebra method. Table 7 presents the results of the normality test for the questionnaire data.

Table 7. Results from the Normality Test Regarding the Correlation Between Mathematical Creative Thinking Ability and Self-Regulated Learning

Class	Shapiro-Wilk	
	Sig.	Explanation
Self-Regulated Learning	0.415	Normal
Mathematical Creative Thinking	0.004	Not Normal

Table 7 shows that the Sig. value for mathematics creative thinking ability is 0.004, which indicates a significance value below 0.05, while the Sig. value for self-regulated learning is 0.415, which indicates a significance value more than 0.05. Spearman's rank-order correlation test was used since one of the sample data was not regularly distributed. Table 8 displays the Spearman's Rank-Order Correlation test findings.

Table 8. Results of Spearman's Rank-Order Correlation Test

Spearman's rho		
Correlation Coefficient	Number of Students	Sig (2-tailed)
0.622	25	0.001

Based on the Spearman's Rank-Order Correlation in Table 8, a Sig value of 0.001 < 0.05 was found, indicating that it is denied. This indicates a connection between the development of mathematical creative thinking abilities through PACE-GeoGebra learning and students' self-regulated learning. The correlation coefficient value of 0.622 indicates a direct relationship between the two variables. Therefore, the capacity for mathematical creativity tends to expand in tandem with self-regulated learning. Atiyah & Nuraeni (2022) assert that pupils who demonstrate strong self-regulated learning tend to possess advanced mathematical creative thinking abilities.

This correlation can occur because students who possess self-regulated learning usually have high initiative, are able to manage their time and learning strategies effectively, and do not rely entirely on the teacher. Asmar & Delyana (2020) declare that self-regulated learning occurs when a person takes the initiative to learn, establishes learning objectives and strategies, and assesses or considers their learning actions. Self-regulated learning makes students more accountable for their education, which in turn affects their learning results (Septian et al., 2022).

This principle is emphasized by Yanti Riyanti and Wahyudi (2021), who state that self-regulated learning includes not always relying on others, being progressive, being resilient, having the initiative to learn, having self-control, being able to make decisions, being responsible, and having self-affirmation. According to the study, the parts of self-regulated learning (SRL) affect how well students can think creatively in math, including their fluency, flexibility, elaboration, and novelty. This evidence suggests that SRL can help students become more proficient in mathematical creative thinking.

A high degree of learning freedom allows students to take initiative, manage their time, and create efficient learning strategies without entirely depending on their teachers, which tends to improve their mathematical creative thinking skills. It is therefore advised that students actively create goals, manage their time, and look for extra learning materials to cultivate an attitude of independent study. Students can develop their capacity for mathematical creativity as well as their comprehension of mathematical ideas by increasing their learning independence.

CONCLUSION

The research and discussion findings suggest that there are substantial differences in the ability of pupils who use PACE-GeoGebra learning to develop their mathematical creative thinking abilities compared to those who use conventional learning. Compared to students who utilize the standard learning model, individuals who use the PACE-GeoGebra learning model improve their mathematical creativity. Additionally, a correlation exists between students' self-regulated learning and the enhancement of mathematical creative thinking abilities through PACE-GeoGebra.

In an attempt to enhance students' mathematics creative thinking abilities, educators should implement the PACE-GeoGebra model as an alternate teaching approach. Teachers are encouraged to give students advance instructions on how to utilize GeoGebra media to boost the application's efficacy and make students more ready and focused when engaging in the learning process. More research using a larger range of objects is required to produce more comprehensive and general findings, as there is currently little research on the application of the PACE-GeoGebra learning model to foster mathematical creative thinking abilities.

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