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ORIGINAL

Enhancing Creative Mathematical Thinking with GeoGebra: A Comparative Study of Secondary School Students

Mejorando el Pensamiento Matemático Creativo con GeoGebra: Un Estudio Comparativo de Estudiantes de Secundaria

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ABSTRACT

Developing students' creative mathematical thinking skills is essential for problem-solving and innovation in mathematics education. GeoGebra, as a dynamic geometry software, has been widely used to support conceptual understanding and visualization. However, limited studies have explored its impact on creative mathematical thinking in schools with different characteristics. This study aims to analyze and provide an overview of the improvement in students' creative mathematical thinking skills using GeoGebra software in schools with different characteristics. This research uses a quasi-experimental method with a pre-test and post-test design without a control group. The sample consists of 90 eleventh-grade students from three high schools in Padang City. Data were collected through tests of creative mathematical thinking skills and classroom observations. Statistical analyses, including Wilcoxon and t-tests, were conducted to measure the significance of changes in students' creative thinking skills. The results indicate that most aspects of creative thinking skills showed significant improvement, particularly in originality and flexibility, although there was a decline in some aspects, namely fluency and elaboration, in these schools. The Wilcoxon and t-test analyses showed a significant difference ($p < 0,05$ %) between students' pre-test and post-test creative mathematical thinking scores. Therefore, there is an improvement in students' creative mathematical thinking skills after learning using GeoGebra. This study demonstrates that integrating GeoGebra into mathematics instruction enhances students' creative mathematical thinking. The results suggest that GeoGebra can be an effective tool for fostering creativity in mathematics education. Future research should focus on addressing the decline in fluency and elaboration to optimize its implementation.

Keywords: Creative Thinking; Comparative Study; GeoGebra; Mathematical Learning.

RESUMEN

Desarrollar las habilidades de pensamiento matemático creativo de los estudiantes es esencial para la resolución de problemas e innovación en la educación matemática. GeoGebra, como un software de geometría dinámica, ha sido ampliamente utilizado para apoyar la comprensión conceptual y la visualización. Sin embargo, hay pocos estudios que hayan explorado su impacto en el pensamiento matemático creativo en escuelas con diferentes características. Este estudio tiene como objetivo analizar y proporcionar una

visión general sobre la mejora en las habilidades de pensamiento matemático creativo de los estudiantes mediante el uso del software GeoGebra en escuelas con características diferentes. Esta investigación utiliza un método cuasi-experimental con un diseño de prueba previa y prueba posterior sin grupo de control. La muestra consiste en 90 estudiantes de undécimo grado de tres escuelas secundarias en la ciudad de Padang. Los datos se recopilaron mediante pruebas de habilidades de pensamiento matemático creativo y observaciones en el aula. Se realizaron análisis estadísticos, incluyendo las pruebas de Wilcoxon y t, para medir la significancia de los cambios en las habilidades de pensamiento creativo de los estudiantes. Los resultados indican que la mayoría de los aspectos de las habilidades de pensamiento creativo mostraron una mejora significativa, particularmente en originalidad y flexibilidad, aunque se observó un descenso en algunos aspectos, como fluidez y elaboración, en estas escuelas. Los análisis de Wilcoxon y la prueba t mostraron una diferencia significativa ($p < 0,05$ %) entre las puntuaciones de las pruebas previas y posteriores de pensamiento matemático creativo de los estudiantes. Por lo tanto, se observa una mejora en las habilidades de pensamiento matemático creativo de los estudiantes después del aprendizaje con GeoGebra. Este estudio demuestra que la integración de GeoGebra en la enseñanza de las matemáticas mejora el pensamiento matemático creativo de los estudiantes. Los resultados sugieren que GeoGebra puede ser una herramienta efectiva para fomentar la creatividad en la educación matemática. Las investigaciones futuras deberían centrarse en abordar el descenso en fluidez y elaboración para optimizar su implementación.

Palabras clave: Pensamiento Creativo; Estudio Comparativo; GeoGebra; Aprendizaje Matemático.

INTRODUCTION

Creative thinking skills are one of the essential competencies that must be developed in 21st-century education.[1,2,3] Creative thinking enables students to face and solve problems innovatively, not only in everyday life but also in academic fields, including mathematics. In mathematics, creative thinking skills encompass the ability to generate various solutions, adapt to different approaches, and find original and detailed solutions.[4,5,6] Therefore, mathematics education in secondary schools should focus on developing students' creative thinking skills to prepare them for the future. However, various studies indicate that Indonesian students' creative mathematical thinking skills are still relatively low. This is evident from the results of the Systematic Literature Review (SLR) research conducted by Iskandar & Juandi, which states that students' creative thinking abilities in Indonesia are lower compared to the eight countries studied.[7] This research is based on the 2018 study by Hans Jellen from the University of Utah, USA, and Klaus Urban from the University of Hannover, Germany. The sample consisted of 50 children aged 10 years in Jakarta. This is due to the fact that Indonesia provides an environment that does not support these children in expressing their creativity, particularly in the family and school environments. Research by Sa'dijah shows that many students are passive during the teaching and learning process, and students' creative thinking abilities are relatively low.[8]

With regards to mathematics, the main topic of Programme for International Student Assessment or PISA 2022, 15-year-old Indonesians scored 366 points as compared to an average of 472 points in OECD countries.[9]

In the global context, creative mathematical thinking skills are increasingly emphasized in educational curricula across various countries. According to the OECD report (2019), countries with the highest PISA scores, such as Singapore, Japan, and Finland, have integrated the development of creative thinking skills into their mathematics curricula. For instance, Singapore, with a PISA score of 569 in mathematics, has implemented the "Mathematical Problem Solving" framework since 1992, which explicitly includes elements of creativity.[10,11,12,13]

An international study by Trends in International Mathematics and Science Study (TIMSS) 2019 shows that countries with high performance in mathematics tend to have a larger proportion of students capable of solving problems that require creative thinking. For example, 54 % of students in Taiwan and 50 % of students in South Korea can solve advanced-level problems requiring creativity, while the international average is only 11 %.[14]

The gap between Indonesia and these high-performing countries further underscores the urgency to enhance the creative mathematical thinking skills of Indonesian students. A study by the Asian Development Bank predicts that without significant improvements in mathematical abilities, particularly in creativity and problem-solving, Indonesia risks falling behind in the global economic competition, which increasingly relies on technological innovation.[15]

Creative mathematical thinking is essential for both solving complex problems and driving innovation and technological advancements.[16] In mathematics education, the use of technology has become an effective method to support the development of creative thinking skills.[17,18,19] One software that is increasingly used in mathematics education is GeoGebra, a visualization-based software that supports direct interaction between students and mathematical concepts, such as geometry, algebra, and calculus, in a dynamic and interactive manner.[20,21,22,23,24,25] GeoGebra software can help students enhance their mathematical abilities [18,26,27,28] by

providing students with more opportunities to visualize geometric concepts, which often helps low-achieving students. Other research indicates that GeoGebra is easy and practical to use in mathematics learning.[29] With GeoGebra, students can construct and explore various mathematical representations, allowing them to delve deeper into different ideas and solutions.[30,31,32]

Many studies have shown that GeoGebra software is an effective tool in the teaching and learning process, especially in geometry.[18,23,33,34] A previous research conducted by Zulnaidi et al has shown that the use of technology, particularly GeoGebra,[35] can help students to better understand mathematical concepts and encourage more creative exploration in problem-solving. Similar findings were reported by Hidayat and Wardat[36] and Malatjie and Machaba.[37] However, there is a lack of research specifically investigating how GeoGebra can enhance secondary students' creative mathematical thinking, especially through comparative studies between schools with with diverse backgrounds. Therefore, further research is needed to determine the extent of GeoGebra's influence on the development of students' creative mathematical thinking skills and to compare the results across various schools.

As such, this study seeks to compare the creative mathematical thinking skills of students in three different secondary schools, using GeoGebra as a teaching tool. Through this research, it is expected to find empirical evidence on the impact of using GeoGebra on aspects of creative mathematical thinking, such as fluency, flexibility, originality, and elaboration. In assessing creative mathematical thinking skills, particularly in the context of using GeoGebra, a comprehensive creativity framework developed by Guilford and Torrance will be utilized.[38,39] Furthermore, this research also aims to analyze and obtain an overview of the enhancement of students' creative mathematical thinking skills through the use of GeoGebra software in three high schools in Padang City, Indonesia.

METHOD

This study uses a quasi-experimental method with a pre-test and post-test design without a control group. The study aims to measure the impact of GeoGebra-based learning on students' creative mathematical thinking skills in three different high schools.

Participants and Sampling

The research was conducted in three high schools in Padang City, Indonesia, selected based on their different characteristics in terms of student demographics and learning environments. The sample consisted of 90 eleventh-grade students, with 30 students from each school, selected using a purposive sampling technique to ensure representation across different school types. The selected students had prior experience using GeoGebra in basic mathematical problem-solving but had not previously undergone structured learning with GeoGebra.

Reseach Instruments

Table 1. Rubric for Assessing Creative Thinking Skills

Aspect	Score 1 (Poor)	Score 2 (Fair)	Score 3 (Good)	Score 4 (Excellent)
Fluency	– Provides only one solution. – Ideas are very limited or irrelevant.	– Provides 2 solutions, but with limited variety. – Most ideas are relevant to the problem.	– Provides 3 or more solutions relevant to the problem. – Most solutions are logical and show variety.	– Provides 4 or more highly relevant and varied solutions. – All solutions are logical, varied, and in-depth.
Flexibility	– Uses the same approach or strategy to solve the problem. – Shows no variation in thinking.	– Uses more than one approach, but with limited variety. – Some strategy adjustments are made.	– Uses various relevant approaches. – Shows flexible thinking in changing strategies when needed.	– Uses diverse and creative approaches. – Shows flexibility in switching between several highly relevant strategies.
Originality	– Solutions are very common and show no originality. – Mimics or repeats usual solutions.	– Some elements of originality, but most solutions are common.	– Shows fairly original and unusual ideas in problem-solving. – Most solutions contain innovative aspects.	– Solutions are very original and different from the usual. – Shows high creativity with innovative and unusual solutions.
Elaboration	– Solutions are given without adequate explanation or detail. – No further development of ideas.	– Solutions are given with minimal explanation. – Ideas are not well developed.	– Solutions are given with good and structured explanations. – There is idea development showing deep understanding.	– Solutions are very detailed and well explained. – Idea development is excellent and shows comprehensive understanding

Source: adapted from Guilford (1967)

This study used a creative mathematical thinking skills test, administered twice as a pre-test and post-test. The questions were designed to allow students to use their mathematical abilities to solve problems. The test items used are valid and reliable. Students' answers were then assessed using a rubric for evaluating creative mathematical thinking skills, as shown in table 1.

Procedure

1. Pre-Test: Students completed an initial test to assess their creative mathematical thinking skills before the intervention.
2. GeoGebra-Based Learning Implementation: Teachers integrated GeoGebra into mathematics lessons over six weeks, with three sessions per week, each lasting 90 minutes. The learning activities involved guided explorations, problem-solving tasks, and student-led investigations using GeoGebra.
3. Post-Test: After the intervention, students completed the same test to evaluate their improvement in creative mathematical thinking skills.
4. Data Collection and Analysis: Student responses were assessed using a rubric-based evaluation, and statistical analyses (Wilcoxon and t-tests) were conducted to determine the significance of the observed differences.

Data Analysis

The collected data were analyzed using descriptive and inferential statistical methods:

1. Descriptive statistics: Used to summarize the students' scores and identify overall trends in creative thinking improvement.
2. Inferential statistics: The Wilcoxon matched-pairs test was used for non-normally distributed data, while a paired t-test was applied to normally distributed data to determine whether the changes in students' creative thinking skills were statistically significant ($p < 0,05$ % was considered significant).

RESULTS

This study began with designing a learning plan using GeoGebra for eleventh-grade high school students. Students were then given an initial test to assess their creative mathematical thinking skills. The designed learning plan was implemented by the teacher. Subsequently, a reflection on the learning process using GeoGebra was conducted. After implementing the learning design with GeoGebra, students took a final test to evaluate their creative mathematical thinking skills. The results of the creative mathematical thinking skills of eleventh-grade high school students based on the indicators of creative thinking skills are presented in table 2.

Table 2. Pretest and Posttest Results of Mathematical Creative Thinking Ability of High School Students in Padang City, Indonesia

School	Pre-Test				Post-Test			
	Fluency	Flexibility	Originality	Elaboration	Fluency	Flexibility	Originality	Elaboration
SMAN 3 Padang	55	60	40	65	80	70	75	80
SMA Pertiwi 1 Padang	60	25	20	45	75	60	50	20
SMA Adabiah Padang	25	25	30	20	17	60	50	50

Source: Data collected from the research study conducted in three high schools in Padang City, Indonesia (2024)

Based on table 2, it is evident that the post-test scores of students' mathematical creative thinking skills have increased compared to the pre-test scores across all indicators. This indicates that learning using GeoGebra is effective in enhancing students' mathematical creative thinking skills. Posttest scores for three indicators of mathematical creative thinking skills—fluency, flexibility, and originality—have increased after learning using GeoGebra as a medium. However, there is a decrease in the posttest score for the elaboration indicator. Meanwhile mathematical creative thinking skills of SMA Adabiah Padang students have improved in three indicators; flexibility, originality, and elaboration; after learning using GeoGebra as a medium. However, there is a decrease in the post-test score for the fluency indicator.

Based on data from the three schools, there is an overall improvement in students' mathematical creative thinking skills after learning using GeoGebra. The pre-test and post-test results show improvements in almost all indicators of creative thinking skills, namely fluency, flexibility, originality, and elaboration.

The most significant improvements are seen in the aspects of originality and flexibility, indicating that after the learning process, students are better able to generate unique ideas and think from various perspectives. However, there are some decreases in the aspects of fluency and elaboration in certain schools, specifically:

- At SMA Adabiah Padang, there is an 8 % decrease in the fluency aspect (from 25 % in the pretest to

17 % in the posttest).

- At SMA Pertiwi 1 Padang, the elaboration indicator shows the most significant decrease, by 25 % (from 45 % in the pretest to 20 % in the posttest).

Although there were declines in some indicators at these schools, most aspects of creative thinking skills showed significant improvement, particularly in originality and flexibility. This improvement indicates that the learning process using GeoGebra effectively developed students' creative mathematical thinking skills, especially in terms of originality and flexible thinking. This aligns with the research by Howenwarter and Jones which highlights the enhancement of students' visualization and mathematical exploration abilities, contributing to the improvement in fluency and originality aspects of creative thinking.[40] This finding concurs with a study by Birgin and Uzun that revealed that learning utilizing GeoGebra in geometry exploration impacts the enhancement of students' creative thinking skills, particularly in originality and flexibility, i.e. interactive tools help students visualize mathematical problems differently, strengthening a deeper understanding of concepts.[41]

Table 3. Description of Pretest and Posttest Results of Students' Creative Thinking Skills

	N	Minimum	Maximum	Mean	Std. Deviation
Pretest SMAN 3	30	40	80	62,83	10,933
Posttest SMAN 3	30	60	90	71,13	9,733
Pretest SMA Pertiwi	30	35	82	57,97	12,050
Posttest SMA Pertiwi	30	60	85	69,80	6,764
Pretest SMA Adabiah	30	30	80	61,70	12,809
Posttest SMA Adabiah	30	55	83	69,87	7,006
Valid N (listwise)	30				

Source: Data collected from the research study conducted in three high schools in Padang City, Indonesia (2024)

Based on the data in table 3, the average post-test results at each school are higher than the average pre-test results, with the standard deviation of the post-test being lower than that of the pretest. These results indicate that the creative thinking skills in the post-test results are closer to the mean value compared to the pre-test. Thus, the average post-test scores are higher than the average pre-test scores.

To assess the overall improvement in students' creative thinking skills, further statistical testing is required to validate the results. Before conducting statistical tests, the data used must meet the requirement of being normally distributed to ensure the validity of the conclusions.[42] The results of the normality test for the pretest and posttest data of the creative mathematical thinking skills of eleventh-grade students in table 4.

Table 4. Normality Test of Pretest and Posttest Data for Creative Thinking Skills

	Tests of Normality					
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	Df	Sig.
Pretest SMAN 3	,111	30	,200*	,968	30	,489
Posttest SMAN 3	,213	30	,001	,888	30	,004
Pretest SMA Pertiwi	,120	30	,200*	,967	30	,465
Posttest SMA Pertiwi	,188	30	,008	,927	30	,041
Pretest SMA Adabiah	,214	30	,001	,900	30	,009
Posttest SMA Adabiah	,174	30	,021	,954	30	,211

Source: Data collected from the research study conducted in three high schools in Padang City, Indonesia (2024)

Based on table 4, The post-test data for SMAN 3 Padang and SMA Pertiwi 1 Padang did not meet the normality assumption ($p < 0,05$), so the Wilcoxon Matched-Pairs Test was used for analysis. In contrast, SMA Adabiah's post-test data were normally distributed ($p > 0,05$), allowing for a paired-samples t-test. Thus, the data were analyzed parametrically using the paired-samples t-test. The results of the analysis can be seen in table 5.

Table 5. Results of Wilcoxon Matched-Pairs and Paired Samples T-Test at Three Schools

School	Statistical Test	N	Mean Rank / Mean	Sum of Ranks / Std. Dev.	Z / t	Sig. (2-tailed) / p-value	Conclusion
SMAN 3 Padang	Wilcoxon Matched-Pairs	30	Mean Rank = 14,38	Sum of Ranks = 435,00	-4,316	0,000	Significant
SMA Pertiwi 1 Padang	Wilcoxon Matched-Pairs	30	Mean Rank = 14,50	Sum of Ranks = 406,00	-4,628	0,000	Significant
SMA Adabiah Padang	Paired-Samples T-Test	30	Mean = 8,167	Std. Dev. = 7,183	6,228	0,000	Significant

Source: Data collected from the research study conducted in three high schools in Padang City, Indonesia (2024)

Based on table 5, all three schools showed similalr results. The p-value of 0,000 indicates that the difference between the pretest and posttest is very significant. This value is much smaller than the common significance threshold (0,05), which means the null hypothesis (no difference between pre-test and post-test can be rejected. In other words, the use of GeoGebra as a learning tool has led to a significant improvement in students' creative thinking abilities.

The inferential analyses shows that there is a significant improvement in the post-test results compared to the pre-test. The mean difference of 8,167-14,50 indicates a substantial increase in skills or outcomes after learning using GeoGebra, and the very low significance value (0,000) ensures that this difference is not due to chance but is statistically significant.

The pretest and posttest data results of the creative thinking skills of eleventh-grade students can be seen in table 6.

Table 6. Paired Samples Test of Students' Creative Mathematical Thinking Skills

Test	School	Sig (2-tailed)
Wilcoxon Test	Pretest - Posttest SMAN 3	0,000
Wilcoxon Test	Pretest - Posttest SMA Pertiwi 1	0,000
T-test	Pretest - Posttest SMA Adabiah	0,000

Source: Data collected from the research study conducted in three high schools in Padang City, Indonesia (2024)

Based on the inferential analyses in table 6, the p-value is < 0,05, indicating a significant difference between the pre-test and post-test scores of the creative mathematical thinking skills of eleventh-grade high school students in the three schools. Thus, there is an improvement in the creative mathematical thinking skills of students taught using GeoGebra.

DISCUSSION

The research results show differences in the percentage of achievement in aspects of creative thinking skills after learning with GeoGebra at each school. However, overall, learning with GeoGebra can improve students' creative thinking skills. Therefore, learning utilizing GeoGebra as a teaching medium can be used to enhance students' creative mathematical thinking skills.[31,36,43] This is also consistent with the research conducted by Christmas et al. which shows that GeoGebra can enable students to learn independently and explore mathematical concepts.[44]

The findings from the study indicate that students actively participated in the learning process using GeoGebra. Students were able to develop their creative ideas because GeoGebra can visualize lesson materials that require images, such as in the topic of three-dimensional shapes. Students can view every angle of a three-dimensional shape by rotating the image in GeoGebra, see the nets of the shapes that can be opened and closed, and determine the surface area and volume of the shapes. This helps students better understand the concepts of the material being studied. By using GeoGebra, students become more creative in solving the problems given by the teacher. Research conducted by Freeman et al shows that the use of GeoGebra applications in mathematics education can enhance students' ability to express their ideas.[45] Similar results were found in the study by Mujiasih et al, which revealed that students were able to integrate their existing knowledge with information obtained through GeoGebra, thus facilitating them in effectively communicating mathematical ideas.[46]

Through active interaction with GeoGebra's features and interactive tools, students have the opportunity to actively engage and manipulate objects, graphs, and mathematical equations. This hands-on approach has facilitated a deeper understanding of abstract concepts by allowing students to visualize and interact with

these concepts dynamically and comprehensively. The visual representations offered by GeoGebra have played a crucial role in enhancing students' understanding and intuition regarding mathematical relationships.

Additionally, GeoGebra's collaborative features have enabled students to engage in peer interactions and discussions, fostering a cooperative learning environment. Through collaboration, students can express and exchange ideas, receive valuable feedback from peers, and participate in mathematical learning. Hamzah and Hidayat have shown that the use of GeoGebra software positively impacts various aspects of mathematics education.[43] Their review revealed that integrating GeoGebra into teaching can improve academic performance, conceptual understanding, motivation, visualization skills, engagement levels, interest in mathematics, critical thinking, creative thinking, mathematical reasoning, and problem-solving abilities.[47,48,49,50]

This study shows that students actively engage in learning by paying attention and asking questions to teachers and peers while using GeoGebra. The findings support previous research indicating that students actively participate in class because they learn using GeoGebra.[30,51] GeoGebra provides a dynamic and interactive learning environment where students can explore mathematical concepts through hands-on exploration. They can manipulate objects, graphs, and equations in real-time, allowing them to engage with the material and deepen their understanding actively. Thus, by understanding concepts through GeoGebra, students' creative thinking skills will develop.

However, this study has several limitations. First, the research was conducted without a control group, making it difficult to compare the effectiveness of GeoGebra-based learning with traditional instructional methods. Second, the sample size was limited to three schools within a single city, which may not fully represent diverse educational settings. Third, the study only measured short-term improvements in creative mathematical thinking skills, whereas long-term effects remain unknown. Future studies should consider including a control group, expanding the sample to different regions, and conducting longitudinal research to assess the sustainability of GeoGebra's impact on students' creative thinking abilities.

CONCLUSIONS

Based on the research findings, it can be concluded that learning using GeoGebra as a medium can enhance students' creative thinking skills. In terms of the aspects of creative thinking ability, there are differences in the percentage of achievement of creative thinking aspects after learning with GeoGebra in each school. However, overall, learning that utilizes GeoGebra can improve students' creative thinking skills, as seen from the analysis of students' pretest and posttest results. Therefore, learning by utilizing GeoGebra as a learning medium can be used to enhance students' mathematical creative thinking abilities.

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FINANCING

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CONFLICT OF INTEREST

None.

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