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The Intervention of Mathematical Problem-Solving Model on the Systems of Linear Equation Material: Analysing its Impact on Increasing Students' Creative Thinking

Riyan Hidayat [1,*], Erpin Evendi [2]

[1] Department of Science and Technical Education, Universiti Putra Malaysia, Malaysia
[2] Department of Mathematics Education, Universitas Islam Negeri Mataram, Indonesia

*Correspondence: riyan@upm.edu.my

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Students' difficulties in their experiences of the mathematics learning process are when systems of linear equations are integrated with real-world cases in everyday life. Students' logical thinking is not strong enough to solve the problems presented. Finally, ways of creative thinking are needed as a basis for attaining learning competencies in the teaching materials of linear equation systems. On the one hand, an appropriate learning model is needed to encourage students' creative thinking. Therefore, this study aims to intervene in a mathematical problem-solving model on the linear equations system and analyze its impact on improving students' creative thinking abilities. To attain the research aims, a simple experimental method was applied with a one-group pre-post-test design. A valid essay test instrument was employed to measure students' creative thinking in the four aspects of creative thinking (fluency, flexibility, originality, and elaboration). Creative thinking data collected (pre-post-test) were then analyzed descriptively and statistically. The results of the study indicate that the model of solving mathematical problems in the materials of linear equation systems has a significant impact on improving students' creative thinking abilities. This finding becomes a reference in its application in the routine of learning mathematics, not only on linear equation systems but on other calculus materials.

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INTRODUCTION

Creative thinking is the most essential cognitive process dimension employed in solving mathematical problems or generating new ideas (Hadar & Tirosh, 2019). Creative thinking is needed in the process of identifying the nature of objects and their transformation (Perry & Karpova, 2017). In learning mathematics, creative thinking is defined as mathematics creative thinking (MCT) (Suherman & Vidákovich, 2022). Creative thinking or creativity is in line with the basic framework needed in 21st-century learning, which can act as an accelerator so that students are more competent to follow scientific developments. According to the Program for International Student Assessment (PISA), creative thinking is a competency to engage productively in learning, evaluating, and improving ideas that can produce real and practical solutions (OECD, 2017). Therefore, every learning model applied actually strives for action to train and assess students' creativity (Kozlowski et al., 2019).

In the last decade, studies related to mathematics education and learning have encouraged exploratory efforts such as creative thinking, especially to develop a deep understanding of mathematical concepts (Aizikovitsh-Udi & Cheng, 2015). These exploratory efforts are based on the essence of mathematics which is closely related to creative ways of thinking (Grégoire, 2016). Creativity training in mathematics is challenging. However, teaching the cognitive dimension and creative thinking in mathematics is still difficult for teachers. As stated in the results of previous studies, students' creativity in solving mathematical problems was not improved or developed, partly due to inadequate support for learning designs (Krisnawati, 2012).

The supporting design or innovative learning design process is the key to success in achieving learning goals in the 21st century (Prayogi & Verawati, 2020). It has been proven in many studies that innovative learning models or methods oriented towards problem-solving, inquiry, and exploration can train and improve students' thinking performance in the 21st century (Bilad et al., 2022; Prayogi et al., 2018a, 2018b; Prayogi & Asy'ari, 2013; Verawati et al., 2020, 2021). Learning ways that lead each individual in their learning process towards strengthening thinking is a form of aggressiveness in the 21st-century education dimension, and this is a must considering the role of deep-thinking ways that learners need to be able to compete in today's world and future.

Dealing with the researchers' teaching experiences for more than a decade for students taking calculus courses, especially on systems of linear equations, showed students' difficulties in learning, especially if the context of linear equation systems is integrated with real-world cases in everyday life. Students' logical thinking is not strong enough in solving the provided problems. In a similar case, Sadak et al. (2022) recommend the importance of creative thinking to be used in problem-solving in mathematics. It was further explained that creative thinking and problem-solving are two contexts that build each other, where creative thinking can be a way of solving mathematical problems correctly while posing mathematical problems, and solving them can form a higher construct of creative thinking abilities (Sadak et al., 2022).

Creative thinking in mathematics is characterized by creating something new from results, ideas, descriptions, concepts, experiences, and knowledge related to mathematics which includes fluency, flexibility, originality, and elaboration (Suherman & Vidákovich, 2022). These creative thinking processes are developed by the existence of a problem-solving process or stimulus so it has long been stated that the essence of mathematical creativity is problem-solving skills (Ervynck, 2002). In previous studies, the findings present there is a strong relationship between mathematical creativity and problem-solving (Kirisci et al., 2020). Verification of the link between the two has also been investigated, and the close link is the development of creativity or creative mathematical thinking that grows and develops through problem-solving and problem-construction activities (Craft, 2005). Finally, one of the most potential foundations to lead students to think creatively is to apply a problem-solving-oriented way of learning.

Mathematical problem-solving in its development has been modified a lot, and the most familiar today is the selective problem-solving model. The theoretical framework of selective problem-solving is based on Polya's problem-solving model in four stages (Polya, 1945), selective thinking (Davidson & Sternberg, 1984), analogy structure mapping theory (Gentner, 1983), and research on creativity itself (Sak, 2011). The learning steps are: (1) defining the target problem, (2) identifying the source problem, (3) finding the source problem solution, (4) constructing the original analogical problem, (5) solving the original analogical problem, and (6) evaluation (Kirisci et al., 2020).

In the current study, researchers appreciate this problem-solving model as an effort to train students' creative thinking. Specifically, the purpose of this study was to intervene in a mathematical problem-solving model on systems of linear equations and to analyze its impact on improving students' creative thinking skills. Based on these objectives, the research questions is "what is the impact of the mathematical problem-solving model on the system of linear equations on the improvement of students' creative thinking skills?"

METHOD

A simple experimental method with a one-group pre-post-test design (Fraenkel et al., 2012) was conducted to achieve the objectives of this study. The simple design is O1-X-O2, where a sample group is prepared and subjected to a problem-solving model. Before and after the intervention, students as members of the sample group were observed for their ability to think creatively (as pretest O1, and also posttest O2). In the design used, there was no comparison group, so the effect of the intervention model of mathematical problem solving on improving students' creative thinking abilities were only assessed from pretest and posttest scores.

Twentyone students were involved as participants or research samples. They were students taking calculus courses at Mataram State Islamic University. Demographically, the gender ratio between men and women is balanced in terms of number and age (ranging from 17 to 18 years). Participants consistently participated in the pretest, learning process, and posttest activities within two weeks. Mathematics learning materials that are intervened with problem-solving models are systems of linear equations.

Data on students' creative thinking skills were collected using a test instrument in the format of an essay test. Each test instrument has been validated by an expert validator, and the results show that the creative thinking test instrument is valid so it is feasible to use as a data collection instrument in this study. Creative thinking skills measured before and after the problem-solving model intervention were in the four aspects i.e., fluency, flexibility, originality, and elaboration. These aspects are strong indicators for measuring creative thinking in mathematics and have been used in several studies (e.g., Sadak et al., 2022; Singer & Voica, 2015; Suherman & Vidákovich, 2022). The increase in creative thinking skills is counted based on indicators, where the score intervals and categories of creative thinking skills that are measured are: very creative ($X > 3.21$); creative ($2.40 < X \leq 3.21$); quite creative ($1.60 < X \leq 2.40$); less creative ($0.80 < X \leq 1.60$); and not creative ($X \leq 0.80$).

Student creative thinking data were analyzed descriptively and statistically. Analysis of data on improving creative thinking skills (between pre and post-test after intervention) descriptively refers to the n-gain formulation (Hake, 1999). The criteria range from very creative (highest level of creative thinking) to not creative (lowest level of creative thinking). Furthermore, statistical analysis (paired with different sample tests) was carried out to determine the difference in the increase in creative thinking scores in the intervention group ($p < .05$). This was preceded by the Shapiro Wilk normality test ($p > .05$). The conclusion of the test refers to the hypothesis (Ha), that is, there are differences in students' creative thinking abilities before and after the intervention of the mathematical problem-solving model in the material of linear equation systems.

RESULTS AND DISCUSSION

Studies have been conducted that intervene in mathematical problem-solving models on linear equation systems and analyze their impact on improving students' creative thinking skills. The summary of the results of the descriptive analysis of students' creative thinking skills from the intervention group is presented in Figure 1. This is based on the parameters of the four indicators of creative thinking i.e., fluency, flexibility, originality, and elaboration.

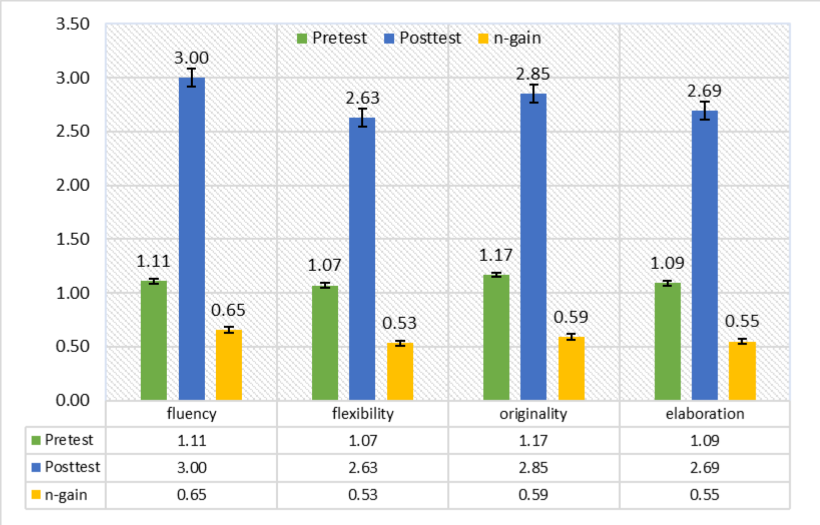

Figure 1. Descriptive analysis results of students' creative thinking skills

Figure 1 shows the results of the measurement of creative thinking from the intervention group. The highest improvement of creative thinking was found in the fluency indicator with an n-gain of 0.65, followed by the originality indicator with an n-gain of 0.59, elaboration with an n-gain of 0.55, and finally flexibility with an n-gain of 0.53. The n-gain criterion for all indicators of creative thinking is moderate. It means that there is no increase in scores on the high or low criteria calculated according to the n-gain criteria (Hake, 1999).

The results in Figure 1 show that the criteria for creative thinking from the pretest to the posttest of all indicators of creative thinking are 'less creative' ($0.80 < X \leq 1.60$) to 'creative' ($2.40 < X \leq 3.21$). The average pretest, posttest, and n-gain scores of all creative thinking indicators were respectively 1.11 (not creative), 2.79 (creative), and n-gain 0.58 (moderate). The results of the descriptive analysis of the n-gain calculation of students' creative thinking abilities completely are presented in Figure 2.

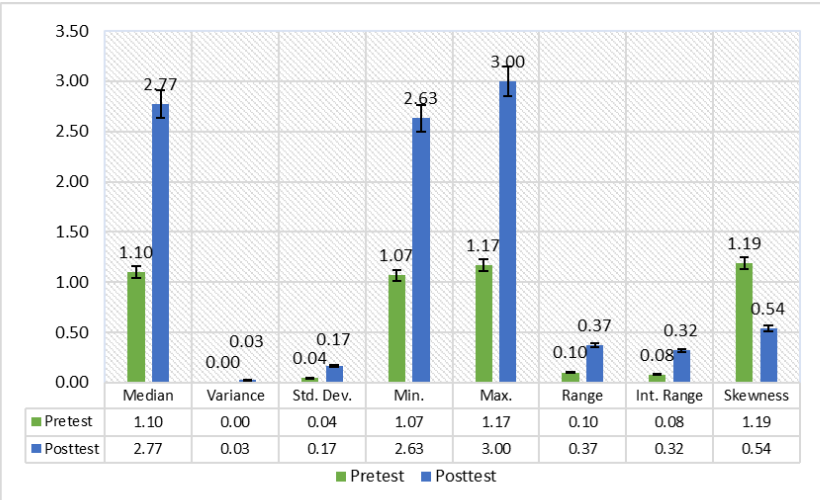

Figure 2. Pre-post-test descriptive analysis results of creative thinking from n gain average

Furthermore, statistical tests are carried out to increase creative thinking scores from the pretest to the posttest. The test uses the paired-t test which meets the data normality requirements. The results of the normality test and the paired-t test of the average scores on the four indicators of creative thinking are presented in Table 1 and Table 2.

Table 1. Results of normality test data, p>0.05

Groups	Shapiro-Wilk		
	Statistic	df	Sig.
Pretest	.927	4	.577
Posttest	.948	4	.701

Table 2. Results of the paired-t test, p<0.05

		Mean	t	df	Sig.
Pair 1	Pretest	1.1100	-29.532	4	.000
	Posttest	2.7920			

The results of the normality test using the Shapiro-Wilk presented that the data were normally distributed, so the statistical analysis used the paired-t test, p<0.05. The results of the paired-t test show that the sig value (0.000) <0.05. It means the hypothesis (Ha) is accepted, that is, there are differences in students' creative thinking abilities before and after the intervention of mathematical problem-solving models in material systems of linear equations.

Descriptive analysis and statistics convincingly show that the intervention of the mathematical problem-solving model in the material of linear equation systems had a significant impact on increasing students' creative thinking skills. In general, these results are important findings to support the achievement of core competencies in learning mathematics in the 21st century. This finding is in line with the results of previous studies that informed problem-solving constructs in mathematics learning can develop students' creativity (Xia et al., 2008). Submitting mathematical problems and solving them can form a higher construct of creative thinking skills (Sadak et al., 2022). In several mathematics teaching programs that use a problem construction approach, the results show the programs can foster students' creativity in mathematics (Cai et al., 2013). In a study nearly twenty years ago, Lesh and Doerr (2003) devised a model of eliciting activities to enhance students' mathematical creativity, in which students solve challenging mathematical problems by developing creative mathematical models based on real-life problems.

The increase in students' creative thinking skills is inseparable from the six-step intervention of the mathematical problem-solving model, the learning phases are defining the target problem, identifying the source problem, finding the source problem solution, constructing the original analogical problem, solving the original analogical problem, and evaluation (Kirisci et al., 2020). The effects of this model are calculated thoroughly on the four aspects of creative thinking that have been successfully improved (fluency, flexibility, originality, and elaboration). In its intervention, this model focuses on creative analogy problem-solving tasks, especially those related to materials of linear equation systems integrated with real-world contexts in everyday life. The results of this intervention model have convincingly demonstrated its efficacy in increasing students' creative thinking abilities. These results are supported by previous studies which found that students' creative thinking capacities (fluency, flexibility, originality) can be developed by giving creative problem-solving assignments in teaching mathematics (Sadak et al., 2022). Mathematical creativity can be developed with cognitive flexibility in learning interventions that encourage students to pose and solve real problems (Singer & Voica, 2015).

The results of the current study are also in line with research findings presented by Tandiseru (2015) who examined the effectiveness of heuristic mathematics learning models with problem-solving steps on the development of students' mathematical creativity. The result informs that the learning model has a significant effect on developing students' mathematical creativity (Tandiseru, 2015). Many other studies show how powerful a learning model based on problem-solving is in that it can help students improve their creative thinking.

Finally, based on the findings from this study as well as the results of relevant studies, the problem-solving model can be applied in routine mathematics learning so that students' creative thinking skills can continue to develop.

CONCLUSION

Studies have been conducted that intervene in the mathematical problem-solving model on systems of linear equations and analyze their impact on improving students' creative thinking skills. The results of the study indicate that the model of solving mathematical problems in the materials of linear equation systems has a significant impact on increasing students' creative thinking abilities. An increase in creative thinking skills was found in all indicators measured by the criteria of not being creative (at the pretest) and being creative (at the posttest) after the learning intervention. Even though this study was conducted in one group without any comparison group, the research findings serve as empirical evidence of the impact of the mathematical problem-solving model on increasing students' creative thinking abilities. This finding becomes a reference in its application in the routine of learning mathematics in class, especially in improving students' creative thinking abilities.

RECOMMENDATION

Future research is important to examine the impact of the problem-solving model on creative thinking in different materials.

Author Contributions

The authors have sufficiently contributed to the study, and have read and agreed to the published version of the manuscript.

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Declaration of Interest

The authors declare no conflict of interest.

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