



Assessing the Effectiveness of Creative Problem-Solving Learning on Mathematical Creativity and Communication Across Varying Self-Regulation Levels

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Abstract: This study aims to determine which learning model, Creative Problem Solving (CPS) or direct learning, and which level of self-regulated learning, high, medium, or low, is better for increasing mathematical creative thinking and mathematical communication skills. The research method used is quantitative research with a quasi-experimental design. The sampling technique employed cluster random sampling, resulting in the selection of Class VII D, which was assigned the direct instruction model, and Class VII E, which was assigned the CPS model. Data analysis in this study utilized multivariate analysis of variance. The results of the study indicate that, in terms of mathematical creative thinking and mathematical communication skills, the CPS learning model is better than the direct learning model, students with high self-regulated learning are better than students with moderate self-regulated learning, and both are better than students with low self-regulated learning. Additionally, there was no interaction between the learning model and students' self-regulated learning. There are still limited studies discussing the application of the CPS model on mathematical creative thinking and mathematical communication skills from the perspective of self-regulated learning so that this study can contribute to the existing literature on this topic.

Keywords: creative problem solving, self-regulated learning, mathematical creative thinking skill, mathematical communication skill.

▪ INTRODUCTION

Mathematics as an educational subject plays an important role in facing these global developments. Mathematics serves as the foundation for modern technological advancements and plays a vital role in various other fields of science (Nufus et al., 2024). With these developments, a deep understanding of mathematics is essential. Therefore, mathematics education must be understood and mastered by all members of society, especially students from elementary school through university.

In this era of globalization and technological development, the development of 21st-century skills in mathematics has become highly relevant. These skills not only help students understand mathematical concepts but also prepare them to face the challenges of an ever-changing world. One of the 21st-century skills that needs to be developed is creative thinking. Creative thinking skills are important for students to help them solve problems effectively (Suherman & Vidakovich, 2025). In addition to creative thinking skills in mathematics, the development of mathematical communication skills is also significant. According to Lestari et al. (2025), the importance of communication skills is related to students' ability to solve problems they face daily.

The creative thinking skills of seventh-grade students at junior high school in Tasikmadu are still low, as they tend to solve mathematical problems according to what the teacher has taught and are unable to provide new solutions, resulting in less varied answers. When presented with more varied problems, students still struggle to solve them.

Additionally, when answering mathematical problems, their work is often not systematic, making it difficult to understand the solutions.

In addition, the mathematical communication skills of seventh-grade students at junior high school in Tasikmadu are also still low. Most students, when given mathematical problems in story questions, still find it challenging to model the problems into mathematical forms, so the problems are not solved correctly. Students also still find it challenging to convey the results of their work directly or in writing, so it is sometimes difficult to understand. Therefore, efforts are necessary to improve these mathematical creative thinking and communication skills.

Regarding the importance of improving students' creative thinking and mathematical communication skills, one effort that can be made is to increase student activity in the learning process. Febriani et al. (2021) state that to support the improvement of creative thinking and mathematical communication skills, an appropriate learning model is needed. One learning model believed to enhance creative thinking and mathematical communication skills is the Creative Problem-Solving (CPS) Learning Model. This model employs a learning approach that utilizes teaching skills and problem-solving, followed by the development of these skills (Chen & Chen in Murwaningsih & Fauziah, 2020)

In addition to the learning model factor, which is still teacher-centered, other factors influence the improvement of mathematical creative thinking and communication skills, namely, self-regulated learning. Self-regulated learning is an approach in which learners manage their metacognition, motivation, and behavior to achieve their educational goals (Zimmerman, 1990; Wati, 2024). Based on the interviews conducted, in classroom learning, seventh-grade students still depend on teacher guidance in carrying out learning activities. When the teacher delivers the learning, students often ask whether they should take notes on what is being taught or not. This shows that their ability to regulate themselves in learning is still lacking. In addition, students tend only to start learning when the teacher gives them assignments.

Several studies examine the relationship between the CPS learning model and mathematical creative thinking skills, such as the study by Reza et al. (2024), which states that there is a positive influence of the CPS learning model on students' mathematical creative thinking abilities. Meanwhile, there is also research on the relationship between the CPS learning model and mathematical communication skills conducted by Tambunan (2021), which shows that the CPS learning model can enhance students' mathematical communication skills. Research conducted by Nufus et al. (2024) on the relationship between self-regulated learning and mathematical creative thinking skills also shows that self-regulated learning has a significant correlation with students' mathematical creative thinking abilities. Additionally, the research on the relationship between self-regulated learning and mathematical communication skills, such as the study conducted by Sudia & Muhammad (2020), shows that self-regulated learning can improve students' mathematical communication skills. However, there are still a few studies that specifically discuss the CPS learning model in relation to improving mathematical creative thinking skills and mathematical communication skills by reviewing self-regulated learning. Therefore, this study was conducted to contribute to mathematics education studies on this topic.

This study aims to address this gap by examining three topics: first, which of the CPS learning model and the direct learning model produces better mathematical creative thinking and mathematical communication skills; second, which level of self-regulated learning high, medium, or low produces better mathematical creative thinking and mathematical communication skills, and third, whether there is an interaction between the learning model and self-regulated learning on mathematical creative thinking and mathematical communication skills.

▪ **METHOD**

Participants

This study was conducted at a junior high school in Tasikmadu, Karanganyar, in the seventh grade during the second semester of the 2024/2025 academic year. The population in this study included all seventh-grade students at junior high school in Tasikmadu in the 2024/2025 academic year, consisting of seven classes. From these seven classes, cluster random sampling was used to obtain the research sample, resulting in two classes being selected as the sample: class VII-E as the experimental class and class VII-D as the control class, each consisting of 32 students. The average age of the students in this study was approximately 12 to 13 years old. To ensure equality between the two groups, a balance test was conducted using a t-test with data from the final semester exam scores for mathematics, which resulted in sig. (two-tailed) 0.194 with a significance level of 0.05, meaning that the two samples were balanced.

Research Design and Procedures

This study is classified as quasi-experimental research because the researcher cannot control all external variables that influence the implementation of the experiment (Sugiyono, 2016). The external variables referred to the students' psychological conditions and academic backgrounds. Efforts to minimize the impact of these variables were made by ensuring that both classes were taught by the same teacher, used the same materials, and had equal study time allocations. This type of research was chosen to determine whether there is a relationship between variables by treating the experimental and control groups as comparators.

The research procedure began with the creation of tests of mathematical creative thinking ability, tests of mathematical communication ability, and a self-regulated learning questionnaire. After the tests and questionnaire were created, content validation was conducted with valid results. The validation was carried out by one mathematics education lecturer and one mathematics teacher from a junior high school in Tasikmadu as validators for the test instruments, and one guidance and counseling lecturer as a validator for the questionnaire. The validation assessed aspects of content, construction, and language, and concluded that the instruments were suitable for use in the research. Subsequently, the validated instruments were tested in class VII F, which consisted of 32 students. After data collection, item analysis, reliability tests, and difficulty and discrimination index analyses were conducted. Once the instruments met the required psychometric criteria, they were then administered to the experimental and control classes.

Before collecting research data, the experimental and control groups were first given treatments. Class VII E, as the experimental class, was given the CPS learning model with learning stages in accordance with the learning syntax according to Osborn-

Parnes (Huda, 2014; Wardani & Izzati, 2017), namely objective finding, fact finding, problem finding, idea finding, solution finding, and acceptance finding. In class VII D as the control class was given the direct learning model, which consisted of five phases: stating objectives and preparing students, demonstrating knowledge and skills, guiding training, checking understanding and providing feedback, and providing opportunities for further training. After the treatments were given, the test instruments were distributed and then processed using appropriate data analysis techniques.

Instrument

The instruments used in this study consisted of a self-regulated learning questionnaire, a mathematical creative thinking ability test, and a mathematical communication ability test. The self-regulated learning questionnaire used indicators related to metacognition (planning, goal setting, monitoring, and self-evaluation), motivation (self-confidence and interest in tasks), and behavior (managing and optimizing the learning environment). This questionnaire consists of 46 statements that are developed from these three aspects. After conducting instrument validation, which included content validation, internal consistency testing, and reliability testing, out of the 46 statements, 26 were deemed suitable for use in this study, while the remaining 20 were deemed unsuitable due to an internal consistency index less than 0.3. This questionnaire used a Likert scale with four options: always, often, rarely, and never.

In the mathematical creative thinking ability test instrument, the indicators used were fluency, flexibility, and novelty. The mathematical creative thinking ability test consists of 6 questions developed from the three test indicators used. After conducting content validation and item analysis of the instrument, the six questions were deemed suitable for the study. The scoring guidelines use a 0-4 scoring rubric with different response criteria depending on the question, ranging from 0 for no response to 4 for correct and complete answers based on the indicators.

For the mathematical communication ability test instrument, the indicators used were modeling situations using concrete writing, images, graphs, or algebraic methods, explaining mathematical ideas in writing, and rephrasing a mathematical description in one's own words. This mathematical communication ability test consisted of 3 questions. After conducting content validation and item analysis, the three questions were deemed suitable for use in the study. The scoring guidelines used a 0-4 scoring system with different response criteria depending on the question, ranging from 0 for no response to 4 for correct and complete answers based on the indicators.

Data Analysis

This study has two independent variables and two dependent variables. The first independent variable is the learning model, which consists of the CPS learning model and the direct learning model. The second independent variable is the level of Self-Regulated Learning (SRL), which is divided into three levels: high, medium, and low. The first dependent variable is mathematical creative thinking ability, while the second dependent variable is mathematical communication ability. Therefore, this study used a two-way multivariate analysis of variance with unequal cells because it involved two independent variables, namely learning model and level of self-regulated learning, as well as two dependent variables, namely mathematical creative thinking ability and mathematical communication ability.

The initial data analysis technique used a t-test to see if the two classes are balanced. Next, a prerequisite analysis test was performed with a multivariate normality test by looking at the scatter plot and Mahalanobis distance correlation with chi-square and a univariate normality test with the Kolmogorov-Smirnov test. The homogeneity of the covariance matrix was tested using Box's M test, and the homogeneity of variance was tested using Levene's test based on the mean. After all prerequisites were met, the multivariate analysis of variance hypothesis test was conducted using Wilk's lambda test, followed by a follow-up test with univariate analysis of variance and multiple comparison test using the Scheffé method. All tests were conducted using SPSS 27 with a significance level of 5%.

▪ RESULT AND DISCUSSION

Before conducting data analysis, it is necessary to perform prerequisite tests consisting of multivariate and univariate normality tests as well as multivariate and univariate homogeneity tests. The multivariate normality test was conducted on the five groups: the experimental group, control group, high self-regulated learning group, moderate self-regulated learning group, and low self-regulated learning group. The correlation values of the five groups (r_Q) were greater than the table value ($r_{(table)}$), meaning the data were normally distributed in a multivariate sense. Subsequently, univariate normality tests were conducted based on the variables of mathematical creative thinking ability and mathematical communication ability. For each variable, the five groups tested had significance value higher than 0.050, meaning that the data for each variable was univariate normally distributed.

Multivariate homogeneity testing was conducted on two groups, namely the learning model group and the self-regulated learning group, where in both groups the significance values were higher than 0.050, meaning that the covariance matrices of the two populations were homogeneous. This was followed by univariate homogeneity testing on each variable of mathematical creative thinking ability and mathematical communication ability. For each variable, both groups tested had a significance value higher than 0.050, so meaning that the population variances were homogeneous. Since the assumptions for multivariate analysis of variance were met, a two-way multivariate hypothesis test with unequal cells was conducted, as presented in Table 1.

Table 1. Two-way multivariate analysis of variance test with unequal cells

Group	Sig.	Decision
Learning model	0.005	H_0 rejected
SRL	0.001	H_0 rejected
Interaction	0.991	H_0 accepted

Based on Table 1, it is known that in the learning model factor and the self-regulated learning factor, the $\text{Sig.} > \alpha = 0.050$ so H_{0A} and H_{0B} are rejected. However, in the interaction factor, the P-value is $\geq \alpha$, so H_{AB} is accepted. This means that in the learning model factor and the self-regulated learning factor, there are differences in mathematical creative thinking ability and mathematical communication ability. Meanwhile, in the interaction factor, there is no interaction between the learning model and self-regulated learning in mathematical creative thinking and mathematical communication abilities.

Based on these conclusions, further univariate analysis of variance tests will be conducted on the learning model factor and the self-regulated learning factor.

In the learning model factor, H_{0A} is rejected, so further tests will be conducted on each variable. This multivariate analysis of variance test uses a univariate analysis of variance test, also known as a two-way ANOVA with unequal cells. The results of the ANOVA test for the learning model factor are presented in Table 2.

Table 2. Univariate analysis of variance test of learning model factors

Variable	Sig.	Decision
Mathematical Creative Thinking Skills	0.008	H_0 rejected
Mathematical Communication Skills	0.005	H_0 rejected

Based on Table 2, it is known that in the second learning model factor, the Sig. $> \alpha = 0,050$, so H_0 for the variables of mathematical creative thinking ability and mathematical communication ability are rejected. Thus, it can be concluded that there is a significant difference in mathematical creative thinking ability and mathematical communication ability produced by the CPS learning model and the direct learning model.

Since H_0 for the learning model factor is rejected, a multiple comparison test will be conducted. Because the learning model factor consists of only two options, the CPS learning model and the direct learning model, this multiple comparison test was conducted by examining the marginal means of the two groups. The results of the marginal mean calculations are presented in Figure 1.

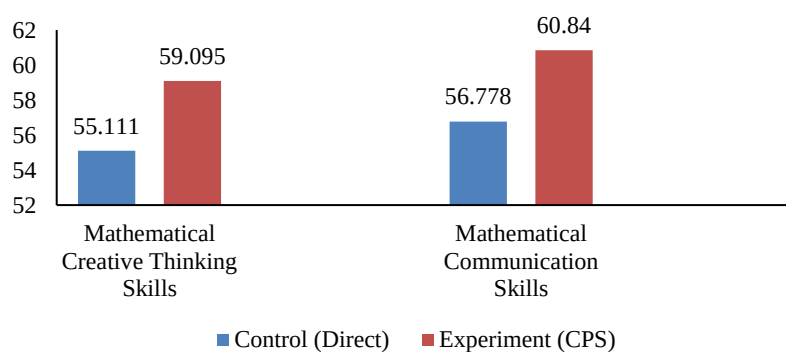


Figure 1. Results of marginal average calculations for learning model factors

Based on Figure 1, it is known that in the mathematical creative thinking ability and mathematical communication ability variables, the marginal average in the experimental class using the CPS learning model is higher than the marginal average in the control class using the direct learning model. Furthermore, from the results of the univariate analysis of variance in Table 2, which shows significant differences in both variables resulting from the learning model factor, and the results of the multiple comparison test in Figure 1, it can be concluded that students exposed to the CPS learning model perform better in mathematical creative thinking ability and mathematical communication ability.

than students exposed to the direct learning model. These figures indicate that the CPS model contributes more effectively to improving both abilities. The consistent increase in the mean scores for both variables suggests that the CPS approach is more effective in encouraging students to think creatively and communicate their mathematical ideas more clearly and structurally. Furthermore, a follow-up univariate analysis of variance test will be conducted for the self-regulated learning factor presented in Table 3.

Table 3. Univariate analysis of variance test for self-regulated learning factors

Variable	Sig.	Decision
Mathematical Creative Thinking Skills	0.001	H_0 rejected
Mathematical Communication Skills	0.001	H_0 rejected

Based on Table 3, it is known that in the self-regulated learning factor, both Sig. $> \alpha = 0.050$, so H_0 for the variables of mathematical creative thinking ability and mathematical communication ability are rejected. Thus, it can be concluded that there are significant differences in mathematical creative thinking ability and mathematical communication ability among students with high, medium, and low self-regulated learning. Since H_0 is related to the self-regulated learning factor, a multiple comparison test is necessary, as presented in Table 4.

Table 4. Multiple comparison test of self-regulated learning factors

Variable	SRL	SRL	Sig.	Decision
Mathematical Creative Thinking Skills	High	Medium	0.001	H_0 rejected
		Low	0.001	H_0 rejected
	Medium	High	0.001	H_0 rejected
		Low	0.001	H_0 rejected
	Low	High	0.001	H_0 rejected
		Medium	0.001	H_0 rejected
Mathematical Communication Skills	High	Medium	0.001	H_0 rejected
		Low	0.001	H_0 rejected
	Medium	High	0.001	H_0 rejected
		Low	0.001	H_0 rejected
	Low	High	0.001	H_0 rejected
		Medium	0.001	H_0 rejected

Based on Table 4, it is known that the Sig. $> \alpha = 0,050$, so H_0 for the overall comparison of self-regulated learning from the variables of mathematical creative thinking ability and mathematical communication ability is rejected. This means that there is a significant difference in the influence caused by each level of student self-regulated learning on mathematical creative thinking ability and mathematical communication ability. The marginal means of each group are presented in Figure 2.

Based on the results of the univariate analysis of variance in Table 4, which shows significant differences in both variables produced by the self-regulated learning factor. Then, based on the multiple comparison test in Table 5 and the marginal mean values in

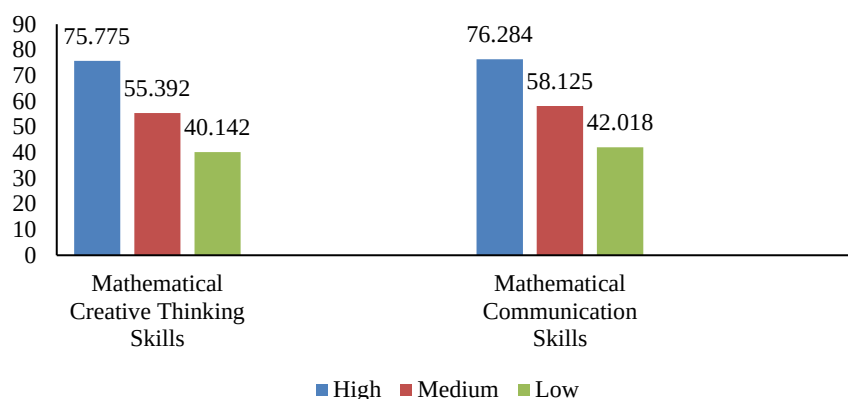


Figure 2. Results of marginal average calculations for self-regulated learning factors

Figure 2, it can be concluded that students with high self-regulated learning have better mathematical creative thinking and mathematical communication skills than students with moderate and low self-regulated learning, and students with moderate self-regulated learning have better mathematical creative thinking and mathematical communication skills than students with low self-regulated learning. These findings indicate that the higher the students' ability to regulate themselves in learning, which includes planning, monitoring, and evaluating the learning process, the better their ability to think creatively and communicate mathematical ideas effectively.

The implementation of the CPS model in mathematics learning was carried out through six main stages, namely objective finding, fact finding, problem finding, idea finding, solution finding, and acceptance finding. During the objective finding stage, students with high self-regulated learning are more independent and faster in identifying problems. Students with moderate self-regulated learning could identify problems but still need the teacher's clarification, while students with low self-regulated learning still need the teacher's guidance and direction. In the fact-finding stage, students with high self-regulated learning could identify problem information critically and independently. Students with moderate self-regulated learning still needed confirmation from the teacher. In contrast, students with low self-regulated learning tended to take notes without assessing the relevance of the information and were very dependent on guidance. At the problem-finding stage, students' ability to formulate problems independently begins to emerge, especially among students with moderate and high self-regulated learning, who begin to show flexibility in viewing problems from various perspectives.

Furthermore, at the idea finding stage, students with high and moderate self-regulated learning could generate many ideas to solve problems. However, they still needed guidance so that these ideas would lead to the desired solution. In contrast, students with low self-regulated learning were still passive and found it difficult to express ideas used to solve problems. Often, the ideas they presented were not related to the problem at hand. At the solution-finding stage, students with high self-regulated learning could analyze and select solutions well and demonstrated the ability to connect solution strategies with mathematical concepts. Students with moderate self-regulated learning were able to evaluate ideas but still needed help from teachers or friends. Meanwhile, students with low self-regulated learning certainly still needed guidance in

evaluating ideas to solve problems. Finally, at the acceptance finding stage, students with high self-regulated learning were able to implement ideas coherently and creatively. They are confident in explaining the steps to solve the problem. Students with moderate self-regulated learning can apply solutions, but sometimes still hesitate or need validation. Meanwhile, students with low self-regulated learning often had difficulty applying ideas completely and tended to follow other people's solutions. Overall, the implementation of each stage of CPS showed a positive contribution to the development of students' creative thinking and mathematical communication skills, especially when combined with collaborative learning and teacher support responsive to students' different characteristics.

The results of this study indicate that, in terms of learning models, the CPS learning model produces better mathematical creative thinking skills than the direct learning model. This is because this model encourages students to explore concepts, think flexibly, and solve problems openly. Through the stages of this model, students can learn to develop their thinking so that they can develop aspects of creative thinking such as fluency, flexibility, and uniqueness (Treffinger et al., 2006; Munandar, 2009). Additionally, CPS emphasizes teamwork, discussion, and idea presentation, which directly contribute to improving students' mathematical communication skills, both oral and written (Apiati & Fatimah, 2017). Unlike direct instruction, which tends to be teacher-centered, CPS actively involves students and encourages them to reflect on and explain their thinking processes (Zimmerman, 1990). Therefore, CPS is able to stimulate the development of both of these skills.

Regarding the self-regulated learning factor, the results show that students with high self-regulated learning have better mathematical creative thinking and mathematical communication skills than students with moderate self-regulated learning, and both have better mathematical creative thinking and mathematical communication skills than students with low self-regulated learning. This occurs because students with high self-regulated learning have the ability to plan, monitor, and evaluate their learning process independently, as well as demonstrate high motivation and confidence in completing mathematical tasks. They are more active in exploring ideas, developing problem-solving strategies, and are able to convey their ideas coherently and logically, both verbally and in writing. This behavior directly contributes to improved creativity and communication scores. However, some studies, such as those by Runisah et al. (2020) and Sulastrri & Sofyan (2022), found that the influence of SRL is not always consistent, depending on learning strategies and students' understanding of the material. This indicates that while SRL is important, its success is also influenced by a supportive learning environment.

For the interaction factor, no further tests were conducted because H_{AB} was rejected, meaning there was no interaction. At each level of self-regulated learning, this means that differences in students' mathematical creative thinking and mathematical communication abilities do not depend on the type of learning model used. The Creative Problem-Solving model is effective when applied to students with various levels of self-regulated learning in general, but this does not mean that all students benefit equally in practice. Students with low self-regulated learning may still face challenges in participating in Creative Problem-Solving-based learning, as this model requires active engagement, open-minded thinking, and independence in problem solving (Treffinger, Isaksen, & Stead-Dorval, 2016). Therefore, teachers still need to provide gradual, tailored guidance so that students with low self-regulated learning can still participate in learning

optimally (Teng, 2020; Lai, 2021). This is in line with findings that responsive teacher support can help students with low self-regulated learning adapt to active and open learning (Cho & Shen, 2013). Thus, even though there is no statistically significant interaction, teachers still need to consider the differences in student characteristics and adjust their approaches to ensure all students can maximize the benefits of learning.

Furthermore, the absence of interaction when viewed from each learning model indicates that differences in students' mathematical creative thinking and mathematical communication abilities do not depend on the self-regulated learning possessed by students. This absence of interaction is because the series of learning activities carried out in learning with the CPS model can better facilitate the development of students with high self-regulated learning in developing their creative thinking and mathematical abilities. The presence of discussion activities and the use of student worksheets can also facilitate students with high self-regulated learning to express their creative ideas with friends and maximize their thinking abilities. In addition, the implementation of learning with the direct learning model is less than optimal. This is because students often do not focus on listening to the teacher's explanations and are not monitored closely. Additionally, students do not explore answers and learning resources because they focus only on the teacher's explanations. This hinders the proper development of students' mathematical creative thinking and communication skills.

Based on the findings of this study, the CPS learning model can be used as an alternative learning model to be applied in the classroom because it has been proven to have an impact on students' creative thinking and mathematical communication skills. However, its implementation must take into account the characteristics of students, particularly those with low SRL, who still require additional teacher guidance in the form of scaffolding, such as step-by-step instructions, targeted feedback, and encouragement to participate actively, so that they can engage in learning optimally.

This study has limitations, as the scope of the research was conducted in only one school. Therefore, further research is recommended to involve more schools and students, as well as develop specific strategies to support students with low SRL in CPS-based learning, in order to obtain more comprehensive and relevant results.

▪ CONCLUSION

The first conclusion that can be drawn from this study is that there is a difference in mathematical creative thinking skills and mathematical communication skills produced by the Creative Problem Solving (CPS) learning model and the direct learning model. Mathematics learning using the CPS model produces better mathematical creative thinking skills and mathematical communication skills than the direct model. The second conclusion is that students with high, medium, and low self-regulated learning exhibit differences in mathematical creative thinking and mathematical communication skills. Students with high self-regulated learning have better mathematical creative thinking and mathematical communication skills than students with medium and low self-regulated learning, and students with medium self-regulated learning have better mathematical creative thinking and mathematical communication skills than students with low self-regulated learning. These findings suggest that developing self-regulated learning is important, as students who are more independent in managing their learning tend to be more active, confident, and effective in solving problems and expressing mathematical

ideas logically and structurally. The third conclusion shows that there is no interaction effect between the learning model and the level of self-regulated learning. This means that the effectiveness of the CPS learning model in improving mathematical creative thinking and mathematical communication skills is consistent across all levels of self-regulated learning. Similarly, differences in these skills among students with high, medium, and low levels of self-regulated learning occur regardless of the type of learning model used.

This study implies that teachers can apply the CPS model as an option to improve students' mathematical creative thinking and mathematical communication skills while still paying attention to students' self-regulated learning. Additionally, this study can serve as an additional reference regarding the relationship between learning models and self-regulated learning on mathematical creative thinking and communication skills. However, this study is limited to a single school. Therefore, further research is recommended to expand the scope or incorporate other skills to be measured and employ different review methods.

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