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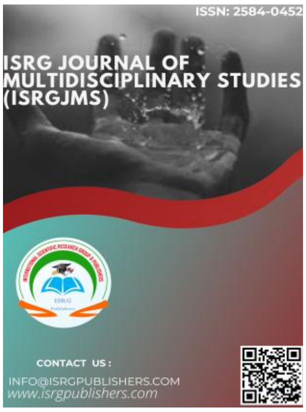

The Effect of Creative Problem Solving on Students' Mathematical Creative Thinking: Controlling for Prior Mathematical Ability

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Abstract

Mathematical creative thinking is an essential competence that enables students to generate diverse ideas, develop alternative solution strategies, and produce original and detailed mathematical solutions. However, conventional mathematics instruction may provide limited opportunities for students to explore multiple approaches to mathematical problems. This study aimed to examine the effect of the Creative Problem Solving (CPS) learning model on students' mathematical creative thinking while controlling for prior mathematical ability. A quantitative approach with a quasi-experimental posttest-only control group design was employed. The participants were 20 eleventh-grade students at UPTD SMK Negeri 1 Aralle, Indonesia, consisting of 13 students in the experimental group and 7 students in the control group. Data were collected using a prior mathematical ability test, a mathematical creative thinking test, and a student response questionnaire. The data were analyzed using descriptive statistics and Analysis of Covariance (ANCOVA) with IBM SPSS Statistics 27. The results showed that the mean mathematical creative thinking score of students in the CPS group was 78.97, compared with 49.52 in the conventional learning group. After controlling for prior mathematical ability, ANCOVA revealed a significant effect of the learning model on students' mathematical creative thinking, $F = 11.695$, $p = .003$. The effect size, indicated by a Partial Eta Squared of .408, demonstrated a large practical effect. The adjusted mean scores also favored the CPS group (80.478) over the conventional group (46.398). Furthermore, students who participated in CPS demonstrated higher achievement across all four indicators of mathematical creative thinking: fluency, flexibility, originality, and elaboration. These findings indicate that Creative Problem Solving can serve as an effective instructional approach for fostering students' mathematical creative thinking, particularly by providing structured opportunities to generate, evaluate, and develop multiple mathematical solution ideas.

Keywords: *Creative Problem Solving; mathematical creative thinking; prior mathematical ability; mathematical problem solving; vocational high school students)*

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INTRODUCTION

Mathematics education in the twenty-first century is expected to develop students' abilities beyond procedural knowledge and computational accuracy. Students need to be able to reason, solve unfamiliar problems, generate ideas, and adapt mathematical knowledge to new situations. Among these competencies, mathematical creative thinking has received increasing attention because it enables learners to approach mathematical problems from different perspectives and develop solutions that are varied, flexible, original, and elaborated. Mathematical creative thinking is therefore an important component of higher-order thinking and an essential goal of contemporary mathematics education.

Mathematical creative thinking involves the ability to generate multiple mathematical ideas, employ different strategies, produce original approaches, and develop solutions in detail. These characteristics are commonly reflected in four dimensions: fluency, referring to the ability to generate multiple ideas or solutions; flexibility, referring to the ability to use different approaches or perspectives; originality, referring to the ability to produce uncommon or novel solutions; and elaboration, referring to the ability to develop and explain ideas in greater detail. In mathematics learning, these dimensions are particularly important because mathematical problems may often be solved through more than one strategy, representation, or line of reasoning.

Despite its importance, students' mathematical creative thinking remains a challenge in many educational settings. Classroom mathematics instruction is frequently dominated by teacher explanations, worked examples, and procedural exercises. Such practices can help students acquire computational skills, but they may provide insufficient opportunities for students to explore alternative strategies or construct their own solutions. When students are primarily accustomed to following predetermined procedures, they may experience difficulties when confronted with open-ended or non-routine mathematical problems that require them to generate and evaluate possible approaches.

This problem was also observed at UPTD SMK Negeri 1 Aralle, where preliminary observations indicated that students tended to depend on examples and solution procedures provided by the teacher. Students showed limited independence in identifying mathematical problems and encountered difficulties when solving problems that allowed multiple approaches. Their mathematics achievement over the previous several years also tended to remain below the established learning achievement criterion. These conditions suggest that students need learning experiences that provide greater opportunities for exploration, reasoning, and creative mathematical problem solving.

One instructional approach that has the potential to address this challenge is the Creative Problem Solving (CPS) learning model. CPS is designed to facilitate problem solving through a systematic process that combines divergent and convergent thinking. Rather than immediately directing students toward a predetermined procedure, CPS encourages learners to clarify the problem, generate multiple ideas, develop possible solutions, evaluate alternatives, and implement an appropriate solution. Such characteristics make CPS particularly relevant to the development of mathematical creative thinking.

The relationship between CPS and mathematical creative thinking can be explained through the cognitive demands embedded in its learning process. During the generation of ideas, students are encouraged to produce as many possible alternatives as they can, which provides a direct opportunity to develop fluency. The exploration of different approaches supports flexibility, while the search for distinctive or less conventional alternatives encourages originality. The subsequent development and refinement of selected ideas provide opportunities for elaboration. Thus, the structure of CPS provides a learning environment in which the four dimensions of mathematical creative thinking can be developed through authentic problem-solving activities.

The theoretical foundation of CPS is closely associated with creative problem-solving perspectives developed by Treffinger, Isaksen, and Dorval (2003). Their framework emphasizes a structured process for understanding problems, generating ideas, developing solutions, and planning their implementation. The model does not treat creativity and problem solving as separate abilities; rather, creative thinking is integrated into the process of constructing and evaluating solutions. In mathematics classrooms, this orientation can shift students' activities from reproducing known procedures toward actively constructing and comparing mathematical possibilities.

Previous studies have reported positive relationships between creative problem-solving-oriented instruction and students' mathematical creative thinking. Research has indicated that students who participate in CPS-based learning can demonstrate better creative thinking performance than students who experience conventional instruction. Other studies have also suggested that CPS is applicable to different educational levels and can support higher-order mathematical competencies. These findings provide empirical support for the use of CPS as an alternative instructional model for developing students' mathematical creativity.

However, an important issue remains concerning the role of students' prior mathematical ability. Students do not enter a learning environment with identical mathematical backgrounds. Differences in prior knowledge and mathematical competence may influence how easily students understand problems, select strategies, and generate mathematical solutions. Consequently, a difference in creative thinking performance between instructional groups cannot always be attributed entirely to the instructional model if prior mathematical ability is not taken into consideration.

Controlling for prior mathematical ability is therefore important when examining the effectiveness of an instructional model. By treating prior mathematical ability as a covariate, the analysis can provide a more precise estimate of the relationship between the learning model and students' subsequent creative thinking performance. In this respect, an Analysis of Covariance (ANCOVA) provides an appropriate analytical framework for examining whether students exposed to CPS demonstrate different levels of mathematical creative thinking after statistically controlling for differences in prior mathematical ability.

Another gap concerns the educational context in which CPS has been examined. Much of the existing research on mathematical creative thinking has focused on elementary, junior high, or general senior high school students. Comparatively less attention has been given to vocational high school (SMK) students, whose learning contexts emphasize both academic knowledge and competencies relevant to practical and professional settings. Developing creative mathematical thinking in vocational education is particularly important because students may encounter situations

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requiring them to interpret problems, generate alternatives, and make decisions rather than simply apply routine procedures.

The present study addresses these gaps by examining the effect of the Creative Problem Solving learning model on the mathematical creative thinking of vocational high school students while controlling for prior mathematical ability. The study also examines students' performance across four dimensions of mathematical creative thinking: fluency, flexibility, originality, and elaboration. This approach provides not only evidence concerning whether CPS is statistically effective but also a more detailed picture of the aspects of creative mathematical thinking that may benefit from CPS-based instruction.

Accordingly, this study aims to determine whether the Creative Problem Solving learning model has a significant effect on students' mathematical creative thinking after controlling for prior mathematical ability. Specifically, the study addresses the following research question: Does the Creative Problem Solving learning model significantly affect students' mathematical creative thinking after prior mathematical ability is statistically controlled?

The findings are expected to contribute empirical evidence concerning the implementation of CPS in mathematics education, particularly in vocational high school contexts. The study may also provide practical implications for mathematics teachers seeking instructional approaches that encourage students to generate multiple solutions, explore alternative strategies, develop original mathematical ideas, and communicate their solutions in greater detail.

RESULTS AND DISCUSSION

Descriptive Results of Mathematical Creative Thinking

The descriptive analysis showed a substantial difference in students' mathematical creative thinking between the Creative Problem Solving (CPS) group and the conventional learning group. The experimental group, which consisted of 13 students, obtained a mean score of 78.97, whereas the seven students in the control group obtained a mean score of 49.52. The mean difference between the two groups was 29.45 points. These results indicate that students who participated in CPS-based learning demonstrated considerably stronger mathematical creative thinking than those who experienced conventional mathematics instruction. The difference is particularly meaningful because mathematical creative thinking requires students not only to obtain correct answers but also to generate multiple ideas, use different approaches, formulate original solutions, and provide detailed explanations.

Group	n	Mean
CPS	13	78.97
Conventional	7	49.52

The higher mean score in the CPS group suggests that the learning environment created through CPS provided students with greater opportunities to engage in mathematical exploration. Rather than immediately applying a procedure demonstrated by the teacher, students were encouraged to identify the problem, generate possible ideas, examine alternative strategies, and develop an appropriate solution. Such activities are closely related to the characteristics of mathematical creative thinking. The finding is consistent with the conceptualization of Creative Problem Solving as a structured process that combines divergent and convergent thinking. Divergent thinking allows students to generate various possible ideas, while convergent thinking helps them evaluate and select the most appropriate alternatives (Treffinger et al., 2003). In mathematics, the combination of these two forms of thinking can create opportunities for students to move beyond a single predetermined procedure and consider several possible solution strategies.

Effect of Creative Problem Solving on Mathematical Creative Thinking

To examine whether the observed difference was statistically significant while taking students' prior mathematical ability into account, an Analysis of Covariance (ANCOVA) was conducted. Prior mathematical ability was included as a covariate because differences in students' initial mathematical knowledge may influence their subsequent performance in mathematical creative thinking.

Source	F	Sig.
Prior Mathematical Ability	2.109	.165
Learning Model	11.695	.003

The ANCOVA results demonstrated that the learning model had a statistically significant effect on students' mathematical creative thinking, with $F = 11.695$ and $p = .003$. Because the significance value was below .05, the null hypothesis that there was no difference in mathematical creative thinking between the two learning groups after controlling for prior mathematical ability was rejected. In contrast, prior mathematical ability did not show a statistically significant effect on the posttest measure of mathematical creative thinking, with $F = 2.109$ and $p = .165$. This finding strengthens the interpretation that the difference in mathematical creative thinking was primarily associated with the instructional treatment rather than simply reflecting differences in students' initial mathematical ability. The adjusted means further illustrate this pattern. After controlling for prior mathematical ability, the estimated marginal mean for the CPS group was 80.478, whereas the corresponding mean for the conventional group was 46.398. Thus, even after statistical adjustment, students receiving CPS instruction maintained a substantial advantage. The result indicates that CPS may provide an instructional mechanism that directly supports the development of mathematical creative thinking. The CPS model does not merely present students with mathematical problems; it organizes learning around a sequence in which students clarify problems, generate ideas, evaluate alternatives, and develop solutions. This structure creates repeated opportunities for students to practice the cognitive processes underlying creative mathematical activity. From a constructivist perspective, the finding can be understood as the consequence of placing students in an active role in constructing mathematical knowledge. Students are not simply recipients of procedures but are expected to interpret situations, connect existing knowledge with new problems, and construct possible solutions. This orientation is consistent with the view that meaningful mathematical learning requires students to engage in reasoning, problem solving, and reflection rather than merely reproduce previously demonstrated procedures.

Effect Size of the Learning Model

Although statistical significance indicates that the difference between groups is unlikely to be attributable to sampling variation

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alone, the magnitude of the effect is also important. The Partial Eta Squared value for the learning model was .408, indicating a large effect.

Variable	Partial Eta Squared	Interpretation
Prior Mathematical Ability	.110	Medium
Learning Model	.408	Large

The Partial Eta Squared of .408 indicates that approximately 40.8% of the variance associated with the adjusted outcome was attributable to the learning model within the statistical model used in this study. The magnitude of this effect suggests that the difference between CPS and conventional instruction was not only statistically significant but also educationally meaningful. The relatively large effect may be explained by the nature of the CPS learning process. Conventional mathematics instruction often emphasizes the explanation of procedures followed by guided practice. Although this approach can be useful for developing procedural fluency, it may provide fewer opportunities for students to produce alternative ideas or justify unconventional solution strategies. CPS, in contrast, explicitly creates space for students to explore and evaluate multiple possibilities. This finding supports previous research indicating that CPS-oriented instruction can contribute to students' mathematical creative thinking. The present study extends this evidence by examining the effect in a vocational high school context and by statistically controlling for prior mathematical ability. Thus, the findings suggest that CPS has potential not only in general secondary mathematics classrooms but also in vocational education, where students need to develop adaptive and creative problem-solving competencies.

Mathematical Creative Thinking across Indicators

Further analysis was conducted based on four indicators of mathematical creative thinking: fluency, flexibility, originality, and elaboration. The CPS group obtained higher percentages than the conventional group on all four indicators.

Indicator	CPS (%)	Conventional (%)	Difference (%)
Fluency	82.35	55.14	27.21
Flexibility	81.47	50.29	31.18
Originality	73.53	40.14	33.39
Elaboration	70.29	40.00	30.29

The largest difference occurred in originality, with a difference of 33.39 percentage points. This result is particularly relevant to the characteristics of CPS because students are encouraged to produce ideas that are not limited to the examples or procedures previously provided by the teacher. When students are confronted with open-ended mathematical problems, they have opportunities to construct solutions that differ from those of their peers. The second largest difference occurred in flexibility, with a difference of 31.18 percentage points. Flexibility reflects students' ability to use different approaches or categories of strategies when solving a mathematical problem. The CPS process naturally encourages this ability because students are asked to generate and consider alternative solutions before selecting an appropriate strategy. The elaboration indicator showed a difference of 30.29 percentage points. Students in the CPS group demonstrated greater ability to develop and explain their mathematical ideas in greater detail. This may be related to the evaluation and solution-development stages of CPS, where students are required to examine their ideas and transform promising ideas into more complete solutions. Meanwhile, fluency showed a difference of 27.21 percentage points. Although this was the smallest difference among the four indicators, the CPS group still achieved a considerably higher percentage. The finding suggests that CPS supports students' ability to generate multiple mathematical ideas rather than immediately settling on a single solution. Overall, the pattern across the four indicators provides a more detailed explanation of the significant ANCOVA result. The advantage of the CPS group was not concentrated in a single dimension of mathematical creativity. Instead, students demonstrated stronger performance across fluency, flexibility, originality, and elaboration. This indicates that CPS may support mathematical creative thinking as a multidimensional competence.

Why Creative Problem Solving Supports Mathematical Creative Thinking

The effectiveness of CPS can be explained by the interaction between the stages of the learning model and the cognitive processes involved in mathematical creativity. In the problem clarification stage, students are encouraged to understand the mathematical situation, identify relevant information, and determine what needs to be solved. This activity provides a foundation for meaningful engagement with the problem. During idea generation, students are encouraged to produce as many possible ideas or strategies as they can. This stage is particularly relevant to fluency and flexibility because students are not immediately required to select one answer. Instead, they are given opportunities to explore alternatives. The evaluation and solution-development stages then engage convergent thinking. Students examine the feasibility of their ideas, compare alternative strategies, justify their choices, and develop the selected solution. These activities provide opportunities to strengthen originality and elaboration because students must not only propose ideas but also explain and develop them mathematically. The process therefore creates a balance between freedom to generate ideas and structure to evaluate them. This balance is important because creativity in mathematics does not mean producing random or unusual answers. Rather, mathematically creative responses should be meaningful, logically defensible, and appropriate to the problem. The findings also suggest that the teacher's role changes under CPS instruction. Instead of functioning primarily as a provider of procedures, the teacher becomes a facilitator who guides students through questioning, discussion, evaluation, and reflection. Such a learning environment can reduce students' dependence on worked examples and encourage greater intellectual autonomy. The results are also consistent with the broader theoretical view that mathematical creative thinking develops when students encounter tasks that require more than routine application of known procedures. Students need opportunities to interpret problems, make conjectures, test strategies, compare solutions, and communicate mathematical reasoning. CPS provides a structured framework for these activities.

Implications for Mathematics Learning in Vocational Schools

The findings have important implications for mathematics instruction in vocational high schools. Vocational students are expected to develop competencies that can be applied to practical

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and professional contexts. Consequently, mathematics instruction should not be restricted to procedural mastery but should also develop students' capacity to analyze unfamiliar situations and construct alternative solutions. CPS can be integrated into mathematics lessons through contextual and open-ended problems that allow more than one strategy or representation. Teachers can begin by presenting a problem situation, guide students to clarify the problem, encourage individual or group idea generation, facilitate comparison of alternative strategies, and conclude with reflection on the strengths and limitations of the solutions produced. The findings should nevertheless be interpreted in light of the study limitations. The sample consisted of only 20 students from one vocational school, and the groups were relatively unequal in size. The quasi-experimental design also involved intact classes, which limits the extent to which causal conclusions can be generalized to other populations. In addition, the intervention focused specifically on mathematical creative thinking and did not examine other outcomes such as mathematical reasoning, motivation, or long-term retention. Despite these limitations, the consistency between the overall statistical result and the indicator-level findings provides evidence that CPS is a promising approach for developing mathematical creative thinking among vocational high school students. Future studies should involve larger samples, multiple schools, longer interventions, and broader outcome measures to determine the robustness and generalizability of these findings.

CONCLUSION

This study examined the effect of the Creative Problem Solving (CPS) learning model on students' mathematical creative thinking while controlling for prior mathematical ability. The findings demonstrated that students who participated in CPS-based mathematics learning achieved substantially higher mathematical creative thinking scores than students who experienced conventional instruction. The mean score of the CPS group was 78.97, compared with 49.52 for the conventional group. The ANCOVA results confirmed a statistically significant effect of the learning model, with $F = 11.695$ and $p = .003$, after controlling for prior mathematical ability. The Partial Eta Squared value of .408 indicated a large effect. The adjusted mean also favored the CPS group, with an estimated marginal mean of 80.478 compared with 46.398 for the conventional group. These findings indicate that the advantage of CPS cannot be adequately explained by differences in students' prior mathematical ability. At the indicator level, students in the CPS group performed better in all four dimensions of mathematical creative thinking: fluency, flexibility, originality, and elaboration. The largest difference occurred in originality (33.39 percentage points), followed by flexibility (31.18), elaboration (30.29), and fluency (27.21). This pattern suggests that CPS provides students with meaningful opportunities to generate diverse mathematical ideas, consider alternative strategies, develop original solutions, and communicate those solutions in greater detail. Overall, Creative Problem Solving can be considered a promising instructional model for fostering mathematical creative thinking in vocational high school mathematics. Its emphasis on problem clarification, idea generation, evaluation, and solution development provides a structured environment for both divergent and convergent thinking. For mathematics teachers, integrating CPS with open-ended and contextual mathematical tasks may provide an effective way to move students from procedural learning toward more creative, flexible, and independent mathematical thinking. Further research should examine CPS with larger and more diverse samples, longer instructional interventions, and additional learning outcomes. Comparative studies involving other student-centered learning models may also provide further evidence regarding the conditions under which CPS is most effective for developing mathematical creative thinking.

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