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Enhancing Mathematical Creativity, Self-Efficacy, and Problem-Solving Beliefs through Heuristic Instruction in Preservice Teachers

Joseph F. Bron
Bicol University, Philippines, *joseph.bron@bicol-u.edu.ph*

Maricar S. Prudente
De La Salle University, Philippines, *maricar.prudente@dlsu.edu.ph*

This classroom-based action research investigates the impact of teaching problem-solving heuristics on preservice teachers' mathematical creativity, self-efficacy, and problem-solving beliefs. The study was conducted with seven preservice teachers at a state university in the Philippines, using a Plan-Do-Study-Act (PDSA) cycle. Participants were assessed on their mathematical creativity in solving non-routine problems in terms of fluency, flexibility, and originality before and after the intervention. Results indicated a significant improvement in fluency, suggesting enhanced proficiency in tackling non-routine problems. However, gains in flexibility and originality were not statistically significant, highlighting the need for further practice and reinforcement. On the other hand, participants exhibited increased self-efficacy in mathematical creativity across all indicators. Despite these positive outcomes, their beliefs about mathematical problem-solving remained stable. The study underscores the importance of incorporating heuristic strategies into mathematics education to foster creativity and problem-solving skills, although extended and sustained efforts are required to develop flexibility and originality fully. These findings contribute to understanding practical pedagogical approaches for enhancing mathematical creativity, self-efficacy, and problem-solving beliefs through heuristic instruction among preservice teachers.

Keywords: beliefs, heuristics, mathematical creativity, self-efficacy, instruction, teachers, mathematics

INTRODUCTION

Mathematical problem-solving is regarded as a cornerstone of mathematics education (Szabo et al., 2020). Developing problem-solving skills is crucial for learners as it enhances their ability to navigate complex real-life situations. The emphasis on teaching through problem-solving is well-documented, underscoring its importance for educators. Problem-solving facilitates learning by enabling students to utilize diverse approaches, draw upon prior knowledge, and justify their solutions convincingly (Burke & Stewart, 2022). This dynamic learning environment encourages students to present solutions, engage in social interactions, negotiate meanings, and achieve a shared understanding of mathematical concepts (Sinaga et al., 2023).

To enhance problem-solving skills, the integration of heuristic approaches is essential (Hai et al., 2018). Heuristics, as defined by Polya (1973), are rule-of-thumb strategies that aid in tackling challenging problems by guiding the solver through multiple potential solutions. Unlike algorithms, heuristics do not guarantee a solution but provide a framework for exploring various possibilities. This method allows learners to address challenging or unfamiliar problems more efficiently (Semaan et al., 2020). However, the explicit teaching of heuristics is often overlooked in traditional classrooms

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(Ma, 2017). Rosyada and Retnawati (2021) emphasized that teaching heuristics explicitly can expedite the process of discovering, identifying, and applying these strategies in problem-solving.

Despite the benefits, applying heuristics in problem-solving is not without criticism. Studies have shown that reliance on heuristics can sometimes lead to errors (Costica, 2015; Liang, 2022; Safarini et al., 2021). For a balanced perspective, it is crucial to acknowledge these limitations while advocating for heuristic approaches. This duality underscores the need for comprehensive training that equips learners with both heuristic strategies and an understanding of their potential pitfalls.

The Importance of Problem-Solving in Mathematics

Problem-solving is a fundamental aspect of mathematics that transcends mere computational skills (Retnawati, 2022; Suarsana et al., 2019). It involves critical thinking, logical reasoning, and the ability to apply mathematical concepts to novel situations (Kusaeri & Aditomo, 2019). The significance of problem-solving in mathematics cannot be overstated, as it cultivates a mindset adaptable to various challenges. Hence, it should be central to mathematical instruction because it engages students in meaningful learning experiences (Khadka et al., 2022; Saputro et al., 2018). By encountering and overcoming problems, students develop perseverance, resilience, and the capacity for independent thinking.

Moreover, problem-solving is instrumental in bridging the gap between theoretical mathematics and practical applications (Amalina & Vidákovich, 2022). It allows students to see the relevance of mathematical concepts in real-world contexts, thus enhancing their motivation and interest in the subject. For instance, applying mathematical problem-solving in areas such as engineering, economics, and the sciences demonstrates the interdisciplinary nature of mathematics and its applicability in diverse fields. This interdisciplinary approach enriches students' understanding and prepares them for future academic and career pursuits (Suhodimtseva et al., 2020).

Problem-solving as a skill is crucial for students as it equips them with the ability to tackle complex and unfamiliar situations effectively (Simanjuntak et al., 2021). Research indicates that teachers with positive attitudes towards problem-solving tend to implement it more frequently in their classrooms, which in turn enhances students' mathematical knowledge and their ability to transfer this knowledge to new situations (Mršnik et al., 2023). Problem-solving fosters cognitive flexibility, enabling learners to approach problems from multiple perspectives and devise innovative solutions (Adeoye & Jimoh, 2023). Incorporating problem-solving into the curriculum promotes active learning, where students are not passive recipients of knowledge but active participants in the learning process, leading to higher achievements in mathematics (Doz et al., 2024).

The Role of Creativity in Mathematics

Creativity in mathematics is essential for innovation and the advancement of the field. It involves generating original ideas, seeing connections between seemingly unrelated concepts, and approaching problems from new angles (Basic et al., 2022). According to Elgrably and Leikin (2021), creativity is not just an ancillary skill but a core component of mathematical proficiency. Multiple research supports this, indicating a positive relationship between mathematical creativity and problem-solving performance (de Vink et al., 2022; Elgrably & Leikin, 2021; Sadak et al., 2022). Engaging in creative mathematical activities helps students develop higher-order thinking skills and fosters a deeper understanding of mathematical concepts.

Open-ended problems are crucial in nurturing creativity (Simanjuntak et al., 2021). Unlike closed tasks with a single correct answer, open-ended problems require students to explore multiple solutions and justify their reasoning. This exploration is a fertile ground for creative thinking as students must navigate uncertainty and consider various approaches. Hidajat and Sa'dijah (2019) highlight that open-ended problems are more conducive to fostering mathematical creativity, as they challenge students to think divergently and innovatively.

In the context of teacher education, fostering creativity is paramount. For instance, the teacher-education program in the Philippines emphasizes the development of creative talents in problem-solving in the Commission on Higher Education (CHED) memorandum order 75 series of 2017. Preservice teachers are expected to demonstrate creativity in their mathematical tasks, which they will later impart to their students. However, as Andrade and Pasia (2020) found, there is a need for more targeted strategies to enhance creativity among preservice teachers in the Philippines. This highlights the importance of integrating creative problem-solving exercises in teacher training programs to cultivate a culture of creativity in mathematics education.

Heuristics in Problem-Solving

Heuristics are essential tools for resolving complex problems by providing a systematic approach to exploring potential solutions (Hjeij & Vilks, 2023). It does not ensure a correct answer but offers a flexible problem-solving method that saves time and effort. Heuristics can be particularly useful when an algorithmic approach is impractical due to the problem's complexity or time constraints.

For example, introducing high school students to probability theory through heuristics showed an increase in students' participation and motivation. The method helped students understand and avoid biases in probabilistic judgment, highlighting the practical benefits of teaching heuristics explicitly (Doz & Doz, 2022).

Despite their advantages, heuristics are rarely taught explicitly in classrooms (Ma, 2017), making their application mostly experiential or observational (Nefedchenko, 2018). This gap in instruction can result in missed opportunities for students to develop effective problem-solving strategies. Explicitly teaching heuristics can significantly enhance students' ability to approach problems methodically and creatively (Nokhatbayeva, 2020). For instance, Polya's four-step problem-solving process—understanding the problem, devising a plan, carrying out the plan, and looking back—provides a structured yet flexible framework that can be adapted to various problem-solving contexts.

Furthermore, using heuristics aligns with the broader educational goal of developing independent, lifelong learners (Nefedchenko, 2018). By equipping students with heuristic strategies, teachers empower them to tackle new and unfamiliar problems confidently. This approach also fosters a deeper understanding of mathematical concepts as students learn to see connections between different areas of mathematics and apply their knowledge in innovative ways. Integrating heuristics in teaching enhances problem-solving skills and supports the development of critical thinking and analytical abilities essential for academic and professional success (Doz & Doz, 2022).

In summary, integrating heuristics in teaching mathematical problem-solving can significantly enhance students' problem-solving abilities and creativity. This study aims to investigate the impact of teaching problem-solving heuristics on the mathematical creativity of preservice teachers. The objectives of this research are to:

1. Describe the methodology of teaching problem-solving heuristics.
2. Evaluate the participants' mathematical creativity, self-efficacy, and beliefs about problem-solving before and after the intervention.
3. Assess the significance of explicitly teaching problem-solving heuristics on the participants' mathematical creativity, self-efficacy, and problem-solving beliefs.

METHOD

Research Design

The study made use of a classroom-based action research design. Descriptive data was gathered and analyzed to establish the effectiveness of the proposed action. Moreover, the Plan-Do-Study-Act (PDSA) cycle was followed to test the change that was implemented. The PDSA cycle is a systematic series of steps for gaining valuable learning and knowledge to continually improve a process or product (Christoff, 2018). This iterative four-step management method used for the control and continuous improvement of processes and products is widely recognized in both educational and business settings (Abuzied et al., 2023). This study utilized the PDSA cycle to assess the impact of explicitly teaching problem-solving heuristics on preservice teachers. However, the study was only conducted over a single cycle, limiting the ability to observe long-term effects and improvements over multiple iterations.

Participants

The participants in this action research were 7 Bachelor of Secondary Education-Mathematics (BSED-Math) students at a state university in the Philippines for the academic year 2022-2023. After the communication was delivered to all BSED-Math students, they volunteered to join the study. Before that, the researcher sought approval to conduct the study from the institution, which they agreed with, provided the study would be conducted online since the students were on their academic break. All the participants were graduating students.

Research Instrument

Three (3) instruments were used in this study. Firstly, the problem-solving test with four non-routine problems. This instrument was adapted from Fortes & Andrade (2019). In this research, however, only four out of the six questions in consideration of time allotment for taking the test. This allows students to focus more on providing multiple solutions and answers to the tasks within the 40-minute test. The instrument has been had been evaluated by experts and thus deemed valid (Fortes & Andrade, 2019). The following non-routine problems were used in this study.

1. A dartboard has sections labeled 2, 5, 9, 13, and 17. Justine scored exactly 356. What is the minimum number of darts he might have thrown if each section was hit by at least one dart? How did you get your answer?
2. A piece of paper is 60 cm by 40 cm. It is to be divided into the biggest possible squares without any material wasted. How many squares can be formed? Explain your answer.
3. Quen had some stickers. He gave 1/3 of the stickers plus two stickers to his brother. Then he gave his sister 1/3 of the remaining stickers plus four stickers. Finally, he gave 1/2 of what remained, plus three stickers, to his best friend. He found that he had five stickers left. How many stickers did Ran have at first? Explain your answer.
4. A mathematics quiz consists of 50 multiple-choice questions. A correct answer is awarded five marks, and two marks are deducted for a wrong answer, while no marks (0) are awarded or deducted for each question left unanswered. If a boy scores 172 marks on the quiz, what is the greatest possible number of questions he answered? Explain how you worked it out.

This instrument was used to gauge the mathematical creativity level of the participants under the indicators of fluency (number of correct answers), flexibility (number of strategies applied), and originality (rarity of the solution). The following point system was used in the scoring rubric to determine how much fluency, flexibility, and originality were present in the solutions: high - 5 points, moderate - 3 points, and low - 1 point. A solution was given a score of 2 (or 4) if it met the requirements for a score of 1 (or 3) but fell short of those of 3 (or 5). The researcher adapted the scoring description provided by the authors in their paper but adjusted it since fewer questions were used in this study.

The maximum score a student could achieve on the problem-solving test is 20, which was obtained from 4 items, wherein the maximum score for each item is 5. To classify the level of the students, the interval from 0 to 20 was divided into three equal parts. This classification was applied to the three indicators used to gauge creativity. Each part represents a category of creativity level:

- *Lowly Creative (0.00 - 6.67):* This level indicates that the student showed limited creativity in their problem-solving approach. They might have provided few correct answers, used a limited number of strategies, and their solutions were not particularly unique or original.
- *Moderately Creative (6.68 - 13.33):* This level indicates that the student demonstrated a moderate level of creativity. They provided a fair number of correct answers, used several different strategies, and had some unique solutions, though not highly original.
- *Highly Creative (13.34 - 20.00):* This level indicates that the student exhibited a high level of creativity. They provided many correct answers, used various strategies, and their solutions were highly original and rare.

The researcher also looked at the participants' mathematical creativity self-efficacy perception using the instrument developed by Acikgul and Altun in 2022. It also assesses creative tendencies based on fluency, flexibility, and originality. This instrument has 27 items, nine for fluency, flexibility, and originality. The instrument has been subjected to scrutiny to establish its validity. The reported reliability index of the instrument ranges from 0.907 to 0.980 using different formulas for reliability. Thus, the instrument has been deemed valid and reliable (Acikgul & Altun, 2022).

To interpret the results, the participants were categorized based on the sum of the scores from their submitted responses. Since all the indicators have nine statements, each answerable by a linear scale of 1 to 5, the maximum score per indicator is 45. The classification intervals were set to provide clear distinctions between different levels of self-efficacy perception. Here is how the intervals were determined:

- *Low (0-15):* This interval suggests a low mathematical creativity self-efficacy perception. The upper limit of 15 was set to reflect a threshold where the participants' responses indicate minimal to no confidence in their creative abilities in mathematics.
- *Moderate (16-30):* The starting point of 16 marks the transition from low to moderate, implying that participants are beginning to show some level of confidence. The end point of 30 was chosen to encapsulate those who demonstrate an average degree of confidence, suggesting that they are neither overly confident nor lacking in self-efficacy.
- *High (31-45):* This interval reflects a high perception of mathematical creativity self-efficacy. The starting point of 31 shows a strong confidence level in their creative abilities. The upper limit of 45 corresponds to the maximum possible score, indicating that the participants consistently selected the highest option (5) for all nine statements, reflecting a very high self-efficacy perception.

The third instrument relates to measuring beliefs about mathematical problem-solving. The instrument was developed by Stage & Kloosterman in 1992. It has 36 questions, with six questions for each belief. The researchers identified the first five beliefs, while the last one was adapted from the Fenema-Sherman Usefulleness scale. The reliability of the first five beliefs ranges from 0.54 to 0.84, while the last was at 0.87 (Stage & Kloosterman, 1992). For presentation purposes, the following words/phrases would be used to represent the different beliefs.

Difficult Problems	:	I can solve time-consuming mathematics problems.
Steps	:	There are word problems that cannot be solved with simple, step-by-step procedures.

Understanding	:	Understanding concepts is important in mathematics.
Word Problems	:	Word problems are important in mathematics.
Effort	:	Efforts can increase mathematical ability.
Useful	:	Mathematics is useful in daily life.

The ratings provided by the students in every statement based on the different beliefs were added. The obtained sum was used to categorize their level of how they associate themselves with the belief. The classification intervals were determined based on the distribution of potential scores and the desire to create meaningful categories that reflect varying degrees of belief association. Each belief is assessed by six questions, with responses likely scored on a Likert scale (e.g., 0-5). Therefore, the total score for each belief can range from 0 to 30.

- *Low (0-10):* This range represents a minimal association with the belief. Students scoring in this interval likely disagree or are neutral on most questions related to the belief.
- *Moderate (11-20):* This range indicates a moderate association with the belief. Students scoring here may show a mix of agreement and disagreement or be neutral across the questions.
- *High (21-30):* This range signifies a strong association with the belief. Students in this category likely agree with most or all of the statements related to the belief.

The intervals guarantee that the classifications accurately represent a progression from weaker to stronger belief associations, enabling an intricate understanding of students' mathematical problem-solving beliefs.

Procedure

Plan

The planning phase involved setting a clear objective to enhance the mathematical creativity of preservice teachers through the explicit teaching of problem-solving heuristics. This phase began with a thorough review of relevant literature to identify effective teaching strategies and understand the importance of mathematical creativity in problem-solving. A detailed lesson plan was developed, following a top-down approach to break down general heuristic strategies into specific, actionable steps. Essential materials, such as PowerPoint presentations and problem sets, were prepared, and approval was obtained from the institution to conduct the study online. Reflective practice was crucial during this phase to anticipate potential challenges and ensure the lesson plan was comprehensive and aligned with educational objectives.

Do

During the implementation phase, four lessons were conducted over two weeks, each focusing on different heuristic strategies: representation, simplification, pathway, and generic heuristics. These lessons were delivered through Google and Zoom meetings, adhering to a structured format of activity, analysis, abstraction, and application. After each lesson, students were presented with non-routine problems to solve using the taught heuristic strategies. Discussions were facilitated via Google Forms to encourage students to share their solutions and reflect on their learning experiences. This reflective practice allowed real-time adjustments to the teaching approach, ensuring adequate support for students' learning processes.

Study

In the study phase, the collected data was analyzed to evaluate the effectiveness of the teaching intervention. Pretest and posttest results were compared to assess changes in the participants' mathematical creativity, self-efficacy, and problem-solving beliefs. Reflection was vital in this phase, involving a critical examination of the data to understand the impact of the lessons and identify areas for improvement. This analysis provided insights into the strengths and limitations of the intervention, considering factors such as time constraints and the diversity of problem-solving strategies used by students. This helped to refine the understanding of how the teaching methods influenced students' mathematical creativity.

Act

Drawing from the insights gathered in the previous stages, a detailed plan will be devised to enhance actions in the upcoming cycle. This plan will concentrate on strengthening areas identified as weak, ensuring that these specific issues are effectively addressed. Moreover, there is a clear objective for standardizing the outcomes. To achieve this, the strategy will be extended to a broader audience and implemented over a longer period. This broader application aims to ensure that the improvements are effective and consistent across different groups and over time. By doing so, the strategy can achieve more reliable and uniform results, benefiting a larger segment of the target audience.

Data Analysis

The data was summarized in MS Excel sheets and analyzed using *Jamovi*. Descriptive statistics were used to present pertinent data about the participants. Due to the small sample size, the inferential statistics were carried out using non-parametric tests.

FINDINGS AND DISCUSSION

This section presents the result of the data analysis to establish evidence that the objectives of this study were met.

Teaching problem-solving heuristics

To improve the mathematical creativity of the participants in solving non-routine problems, the researcher looked at the literature on the approaches that may aid in teaching the skills. The review guided the researcher in teaching problem-solving heuristics using the top-down approach. The lesson plan was designed to follow this approach to teaching. The top-down approach involves breaking down general heuristics into specific heuristics. The idea of such an approach is to introduce to students the ideas behind the heuristics and why they are used first before breaking them down to more specific heuristics and applying them to problem-solving (Tiong, 2005). Teaching using this approach was motivated by the problem-solving model Tiong et al. developed in 2005 (Figure 1). The model categorized the different heuristics into general ideas. It was argued that solving mathematical problems can be viewed as finding suitable representations, simplifications, and pathways (Tiong et al., 2005). These ideas were used to design and develop lesson plans to present the heuristics and teach the students how to apply them. Four lessons were developed in this study, covering representation, simplification, pathway, and generic heuristics.

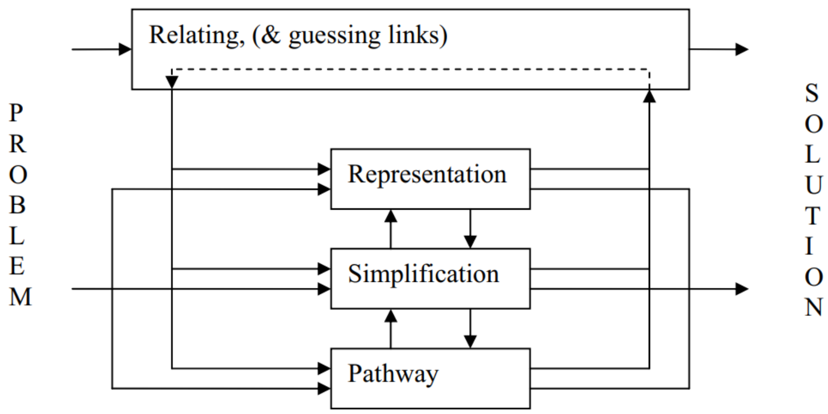

Figure 1
Model for problem-solving in mathematics by Tiong et al. (2005)

The lessons followed the 4A's (i.e., activity, analysis, abstraction, and application) adult learning format. An evaluation after every lesson was also added to determine whether the participants managed to learn and apply the heuristics of interest. The researcher also seeks the aid of two teachers with master's degrees to elicit suggestions on how it can be further improved. The action prompted the revision of the lesson plan prior to its implementation. The quality of problems was adjusted to a level that would facilitate understanding of the heuristic application.

After making adjustments, the researcher created PowerPoint presentations for each lesson. Since the approval given was limited to conducting classes online, the lessons were carried out in Google and Zoom meetings. In the activity part, the researcher posted a problem. Then, the students were asked to work on a strategy to solve the problem. In this part, students worked individually. The processing of students' responses took place in the analysis part. The researcher asks some students to share their ideas on how to solve the problems. The teacher raised queries on how they go about their solution until the students explicitly mentioned a heuristic strategy in their solution (e.g., using diagrams, using equations, creating systematic lists). At this point, the researcher does not comment on whether the student's solution promises the correct answer. Banking on the student's response, the researcher would discuss the basics (i.e., general characteristics) of the heuristic idea. The discussion would cover the principles behind a heuristic idea and the different considerations in applying it to problem-solving. After the general characteristics of a heuristic idea were presented, the researcher would break it down into specific examples usually used in problem-solving. It is how the top-down approach was described by Tiong in 2005. To cite an example, for lesson 1, the topic was all about representation heuristics. The researcher asked a student to share his solution (e.g., The student described that his solution involved drawing diagrams about the given problem). The diagram is an example of representation. The researcher would use it to start the discussion about representations. The different types of representations were discussed (i.e., enactive, iconic, symbolic), and examples were given. The examples would constitute specific representation heuristics like creating a Venn diagram and organizing the data in a table. Then, the researcher would ask the students to raise questions about their solutions, and feedback was provided. The students would return with their solutions and make adjustments. After that, the researcher would ask someone to present his solution, and this time, feedback on whether the answer was correct would be given. After the problem had been solved, the researcher presented the different heuristic strategies under an idea and provided one problem for each. The research would explain how a specific strategy is applied to problems and, most importantly, how to assess its suitability to given problems. Table 1 presents the different heuristic ideas and the strategies classified under them.

Table 1
Heuristic ideas and the different strategies

Heuristic Ideas	Strategies
Representation	• Act it out • Use a diagram/model • Use equations
Simplification	• Restate the problem in another way • Make suppositions • Look for patterns • Solve part of the problem
Pathway	• Work backwards • Use before-after concept
Generic	• Think of a related problem • Use guess-and-check • Make a systematic list

In the abstraction, the researcher would summarize the lesson by asking the students to describe the heuristic idea and identify the strategies classified under it. The question would also include asking the students about the advantages of using the heuristics and the challenges one can encounter in applying it in their solution. In the application part, the student's understanding of the heuristics and ability to apply it were tested in answering mathematical problems. The students were also asked to share their solutions with the class. In this part, constructive feedback was also given, whereas, in the evaluation, the only focus was to check whether the students learned the different heuristics.

Mathematical Creativity in Problem-Solving Test Results

Table 2 presents the distribution of the participant's mathematical creativity scores in the problem-solving test during the pretest and posttest. The solutions submitted were rated in terms of fluency, flexibility, and originality. Then, the students were categorized and grouped according to their level of mathematical creativity.

Table 2
Distribution of the participants` level of mathematical creativity in the problem-solving

Level	Fluency				Flexibility				Originality			
	Pre	%	Post	%	Pre	%	Post	%	Pre	%	Post	%
Lowly Creative	3	43	0	0	4	57	3	43	6	86	4	57
Moderately Creative	3	43	5	71	2	29	3	43	1	14	2	29
Highly Creative	1	14	2	29	1	14	1	14	0	0	1	14

It could be gleaned from the table above that, in the pretest, most of the students were lowly creative. It is especially true with the originality indicator, where all but one was under the *"Lowly Creative"* category. The remaining student was observed to be in the "Moderately Creative "category. The students had low scores in this category since they had difficulty answering the non-routine problems correctly. Examining their posttest revealed a slight improvement from the initial results. At this point, three students managed to transition to the upper level. However, the challenge of finding a unique solution relative to the responses provided by other students was still pervasive. The same observations could be made with the other indicators. For the flexibility indicator, only two students managed to improve from being *"Lowly Creative"* to *"Moderately Creative"*, but one student regressed from "*Moderately Creative"* to *"Lowly Creative"*. Upon analyzing the submissions in the posttest, it was observed that more students had applied varied heuristics after the proposed action compared to what was observed in the pretest, where some would directly go with using equations to solve problems. While using equations makes solving problems efficient, some problems cannot be solved using them. There were also submitted works that used other strategies like guessing and checking, using diagrams, and working backward. However, their attempts were unsuccessful due to misrepresentations, incomplete understanding of the problem, and lack of organization in the solution. It was likewise observed that when students found the correct answer, they stopped there and did not explore other solutions that could also provide correct answers. The researcher surmised that the time allotment was a significant concern among the participants, as they prioritized solving all the problems rather than providing multiple solutions to a specific problem.

The improvement in the fluency indicator seemed to be the best among the three. Three students reached a higher level in this category, while no one regressed. After learning the different heuristic strategies, more students successfully provided correct answers in the posttest. The number of students who provided correct answers increased since they were informed of the other means of creating solutions. Teaching problem-solving heuristics led them to scrutinize problems and choose the most efficient strategy to yield correct answers.

To summarize, the concentration of the participants from the pretest to the posttest transitioned from *"Lowly Creative"* to *"Moderately Creative"*. The findings reveal a nuanced picture of the student's mathematical creativity as measured through fluency, flexibility, and originality in problem-solving tasks. Initially, most students exhibited low levels of creativity, particularly in originality, which is consistent with the literature that indicates students often struggle with non-routine problems (Andrade & Pasia, 2020). After the intervention, there was a slight improvement, with a few students advancing to higher creativity levels. However, the overall progress underscores several significant implications for educators.

The observed improvements align with the assertion that mathematical problem-solving performance and mathematical creativity are positively correlated (Miranda & Mamede, 2022; Muzaini et al., 2023). The need for targeted instruction in mathematical creativity is evident, as teaching heuristic strategies helped students enhance their problem-solving skills. This finding reinforces the importance of incorporating creativity-focused pedagogy in mathematics education to foster a deeper understanding and more innovative approaches to problem-solving. Recent studies further support these findings. For instance, Wigert et al. (2022) discuss the necessity of teaching diverse problem-solving strategies to nurture students' creative thinking. These studies suggest that creativity in mathematics can be developed through deliberate instructional practices, echoing the improvements seen in this study.

Mathematical Creativity Self-Efficacy Results

This study also examined participants' perceptions of mathematical creativity self-efficacy. The results of this perception survey are summarized in Table 3.

Table 3
Distribution of the participants` level of perceived MC self-efficacy

Level	Fluency				Flexibility				Originality			
	Pre	%	Post	%	Pre	%	Post	%	Pre	%	Post	%
Low	1	14	0	0	0	0	0	0	2	29	0	0
Moderate	6	86	1	14	7	100	2	29	5	71	1	14
High	0	0	6	86	0	0	5	71	0	0	6	86

Regarding perceived fluency, most students were at a moderate level in the pretest, with 86%. In comparison, only one student (14%) was categorized with a low level of fluency. In the posttest, however, the majority shifted to a moderate level (86%) and the remaining 14% to a low level. The analysis of the individual results showed that five students` perceptions moved from *"Moderate"* to *"High"*; one moved from *"Low"* to *"High";* and the remaining one student did not move from his initial category (i.e., *"Moderate"*).

For the flexibility indicator, all seven students reported a moderate level of flexibility in the initial testing. Two remained at a moderate level after the proposed action's implementation, while the remaining improved their levels. Lastly, five students were categorized for perceived originality at a moderate level and two with low originality. An improvement in the posttest was observed, with six students having a high level of perceived originality and one at a moderate level. Specifically, six students reported improved self-efficacy assessments, of which two moved from *"Low"* to *"High"* and the remainder from *"Moderate"* to *"High"*.

These findings align with existing research on the impact of targeted instructional strategies on students' mathematical creativity and self-efficacy. For instance, previous studies have highlighted the importance of fostering a supportive learning environment that encourages creativity and problem-solving (Lim & Han, 2020; Newton et al., 2022). The results are consistent with these findings, demonstrating significant improvements in students' perceived mathematical creativity self-efficacy after the implementation of structured problem-solving strategies. The substantial increase in high-level perceived self-efficacy across these dimensions suggests that the intervention effectively nurtured these aspects of creativity, further validating the instructional strategies employed.

The observed improvements in students' self-efficacy can be attributed to the systematic presentation and application of diverse problem-solving strategies. By exposing students to various methods and allowing them to practice these techniques in a structured manner, they were able to build confidence in their ability to tackle creative mathematical problems. This finding underscores the critical role of explicit instruction and practice in developing mathematical creativity, suggesting that educators should incorporate diverse problem-solving strategies into their curriculum. The significant shift from moderate to high levels of self-efficacy in fluency, flexibility, and originality indicates that students became more confident in their ability to generate multiple solutions, adapt their thinking, and produce unique answers. This outcome has important implications for classroom practice, highlighting the need for teachers to create opportunities for students to engage in creative problem-solving and to provide feedback that reinforces their creative efforts.

Beliefs about Mathematical Problem-Solving Results

Belies about mathematical problem-solving is an area that could be studied to describe better how students learn problem-solving. Certain beliefs motivate students to perform better in mathematics class, but some impede or hinder learning.

Table 4
Distribution of participants` level of beliefs about mathematical problem-solving

Level	Difficult Problems				Steps				Understanding			
	Pre	%	Post	%	Pre	%	Post	%	Pre	%	Post	%
Low	0	0.	0	0	0	0	0	0	0	0	0	0
Moderate	1	14	4	57	6	86	4	57	0	0	0	0
High	6	86	3	43	1	14	3	44	7	100	7	100
Level	Word Problems				Effort				Useful			
	Pre	%	Post	%	Pre	%	Post	%	Pre	%	Post	%
Low	0	0	0	0	0	0	0	0	0	0	0	0
Moderate	2	29	3	43	0	0	1	14	0	0	0	0
High	5	71	4	57	7	100	6	86	7	100	7	100

In Table 4, it can be observed that the student's belief that they can solve difficult mathematics problems regressed. Though their beliefs never reached *"Low"*, three students changed their beliefs from *"High"* to *"Moderate"*. A similar change in perception was observed from the second belief (i.e., There are word problems that cannot be solved with simple, step-by-step procedures), where one student moved down from *"High"* to *"Moderate"*. Since the second belief is phrased negatively, the regression is an improvement, implying one student changed his perspective that problems can be solved if one follows a systematic process. For the third belief, which relates to acknowledging the importance of having a solid grasp of mathematical concepts to be successful in problem-solving, no movement was observed.

A slight improvement was observed for belief 4 (i.e., Word problems are important in mathematics). The number of students with *"Moderate"* perception decreased by one, consequently increasing the number of students with *"High"* perception. It is, however, essential to report that there were changes that were not accessible in the figure; that is, one student who regressed from *"High"* to *"Moderate"* for it was compensated by one student moving up from *"Moderate"* to *"High"*. In terms of the belief that effort can increase mathematical ability (i.e., Belief 5), one student moved down from *"High"* to *"Moderate"*. Lastly, no development was observed in the last belief, stating that mathematics is useful in daily life.

Research on beliefs about mathematical problem-solving, such as the work of Hidayatullah and Csíkos (2023), emphasizes that students' beliefs can significantly influence their engagement and performance in mathematics. The findings align with this perspective, demonstrating that targeted lessons on heuristic strategies can shift students' beliefs, although not uniformly across all belief categories. For instance, the study revealed a regression in students' confidence in solving time-consuming problems, with three students' beliefs shifting from *"High"* to *"Moderate"*. This finding resonates with the complexity of developing problem-solving skills. Prendergast et al. (2018) highlighted that overcoming deeply ingrained negative beliefs requires sustained and multifaceted instructional efforts.

The observed changes in beliefs suggest that while instructional interventions can positively impact students' mathematical beliefs, these changes are nuanced and may vary among individuals. For example, the improvement in belief 4 (importance of word problems) and the regression in belief 5 (effort increases ability) indicate that students' perceptions are influenced by their experiences and the nature of the problems they encounter. The regression observed in belief 1 (solving time-consuming problems) might be due to students facing more challenging problems that tested their perseverance. This underscores the need for educators to provide continuous support and encouragement to help students build resilience in problem-solving.

Comparison of the Pretest and Posttest Results

One of the objectives of this study is to assess the significance of teaching problem-solving heuristics to preservice teachers' mathematical creativity in solving non-routine problems. To that end, Table 5 presents the result of the comparison of the pretest and posttest scores and perceptions using the paired-sample sign test.

Table 5
Paired-sample sign test on mathematical creativity scores in the problem-solving test

Indicators	z-value	p-value
Fluency	1.89	0.03*
Flexibility	1.63	0.05
Originality	1.63	0.05

Regarding the participant's level of mathematical creativity in solving non-routine problems, it was only under the fluency indicator that the posttest score was significantly better than the pretest score ($z=1.89$, $p<0.05$). This improvement indicates that students became more proficient at correctly answering non-routine problems after learning to apply different heuristic strategies. Initially, many students struggled to find correct solutions, often relying heavily on equations that may not always suit non-routine problems. Post-intervention, most students managed to apply the appropriate heuristic strategies effectively, leading to more correct answers. However, the persistent issue of not verifying their answers suggests that additional training is necessary to develop thorough problem-solving skills.

For flexibility, the improvement observed was not statistically significant at α=.05. Analysis of the responses revealed that most students tended to use the same strategy for different problems. As Tiong (2005) argues, problem-solving heuristics are not typically emphasized in classrooms, so students' ability to use various strategies largely depends on their prior experiences. Heuristics must be explicitly taught to enhance flexibility, and students should have ample opportunities to apply these strategies. Furthermore, students who correctly solved a problem often did not attempt alternative solutions, likely due to time constraints. Allowing more time for tests could encourage students to explore multiple solutions.

In terms of originality, the improvement was not significant ($z=1.63$, $p=0.05$). Originality scores were closely linked to flexibility; students who provided only one solution were rated *"Lowly Creative"* because their strategies were often similar to those of other students. Only one student demonstrated multiple strategies, resulting in a high originality score. Additionally, there was only one instance where a student solved a problem uniquely, indicating that his understanding differed significantly from the rest of the class, leading to a high originality score.

The findings support existing literature on the importance of heuristic teaching in enhancing problem-solving skills. For instance, research by Kaitera and Harmoinen (2022) emphasizes that heuristic strategies are crucial for developing students' mathematical thinking and creativity. Moreover, students who engage in heuristic problem-solving are more likely to develop flexible and original approaches to mathematical problems (Wakhata et al., 2023).

Table 6
Paired-sample sign test on MC self-efficacy perception scores

Indicators	z-value	p-value
Fluency	1.89	0.03*
Flexibility	1.89	0.03*
Originality	1.89	0.03*

Table 6 presents the results of testing the hypothesis that the participants` mathematical creativity self-efficacy improved after receiving lessons on the different heuristics applied in problem-solving. The results demonstrate a significant improvement in the participants' mathematical creativity self-efficacy following lessons on various heuristics applied in problem-solving. Specifically, the paired-sample sign test results indicate significant positive changes in fluency, flexibility, and originality, with p-values of 0.03 for each indicator. These findings suggest that the intervention effectively enhanced students' confidence in their mathematical creativity.

The increase in self-efficacy is crucial as it correlates with higher motivation for learning and better performance in mathematics classes (Aswin & Herman, 2022). Zetriuslita et al. (2021) emphasize the importance of self-efficacy in educational settings, noting that students who believe in their abilities are likelier to engage in and persist with challenging tasks. This notion is supported by Gunawan et al. (2022), who found that equipping students with the necessary knowledge and skills boost their self-efficacy. When students understand which strategies to apply and how to execute them, they are more likely to develop confidence in their ability to succeed.

Furthermore, the findings align with recent research in the field. For example, Dempster et al. (2017) found that teaching specific problem-solving strategies significantly enhanced students' self-efficacy and creative problem-solving skills. Similarly, research by (Wakhata et al., 2023) demonstrated that students who received targeted instruction in mathematical heuristics showed marked improvements in their confidence and ability to tackle complex problems.

Table 7
Paired-sample sign test on beliefs about mathematical problem-solving scores

Indicators	z-value	p-value
Difficult Problems	0.38	0.35
Steps	1.34	0.09
Understanding	1.13	0.13
Word Problems	0.82	0.21
Effort	0.82	0.21
Useful	1.34	0.09

The results from this study indicate that there were no significant improvements in participants' beliefs about mathematical problem-solving after the proposed intervention, as shown in Table 7. This outcome suggests that the intervention did not significantly affect these beliefs, which might initially seem disappointing. However, it is crucial to consider that the participants already held positive beliefs about mathematical problem-solving before the intervention.

This observation aligns with existing literature. Buliņa and Cibulis (2023) highlight that problem-solving is an essential skill for prospective mathematics teachers, who typically gain extensive experience and understanding of mathematical problem-solving during their four years of teacher education. Therefore, it is reasonable to infer that the participants had already developed a strong foundation in problem-solving, making significant changes in their beliefs less likely. Furthermore, Samfira (2017) argues that beliefs, particularly those related to educational practices, are deeply ingrained and resistant to change. Our findings support this notion, suggesting that the participants were already content with their views on mathematical problem-solving and self-perception as learners. This contentment could have contributed to the stability of their beliefs despite the intervention.

In summary, the results suggest that interventions to alter deeply held beliefs may need to be more intensive or sustained over a more extended period to be effective. This understanding aligns with existing literature, such as that by Boeve-de Pauw et al. (2022), who found that transformative professional development programs, which are extended over time, have a more substantial impact on teachers' beliefs and practices. Moreover, the lack of significant change in beliefs highlights the importance of starting interventions at an earlier stage in teacher education. Developing positive beliefs about mathematical problem-solving early on can establish a strong foundation that supports future growth and adaptation (Pardimin & Huda, 2018). It is supported further by Wicaksono and Witoelar (2019), which emphasize the role of early educational experiences in shaping long-term beliefs and attitudes.

CONCLUSION

This classroom-based action research investigated the impact of teaching problem-solving heuristics on preservice teachers' mathematical creativity, self-efficacy, and beliefs about problem-solving. The findings reveal that explicitly teaching heuristic strategies can enhance mathematical creativity, although the extent of improvement varies across different indicators of creativity: fluency, flexibility, and originality. The results indicated a significant improvement in fluency among participants. It suggests that preservice teachers became more proficient at solving non-routine mathematical problems after learning and applying heuristic strategies. The structured approach provided by heuristics enabled students to explore multiple pathways to arrive at correct solutions, thereby increasing their problem-solving fluency. However, the improvements in flexibility and originality were not statistically significant. Many participants continued to rely on familiar strategies rather than exploring diverse problem-solving methods. It indicates a need for more extensive practice and reinforcement of heuristic strategies to develop greater flexibility and originality in problem-solving. The limited time for problem-solving during the study might have constrained the participants' ability to explore and present multiple solutions.

The study also examined changes in participants' mathematical creativity self-efficacy. The significant improvement across all indicators—fluency, flexibility, and originality—suggests that the intervention positively influenced participants' confidence in problem-solving abilities. This enhanced self-efficacy is critical for fostering a positive learning environment and encouraging ongoing engagement with complex mathematical problems. On the other hand, beliefs about mathematical problem-solving remained generally unchanged, with most participants maintaining positive beliefs both before and after the intervention. This stability suggests that while heuristic instruction can improve problem-solving skills and self-efficacy, altering deeply ingrained beliefs may require more sustained and intensive efforts.

This study underscores the importance of incorporating heuristic strategies in mathematics education to enhance problem-solving skills and creativity. The findings suggest that while heuristic teaching can significantly improve problem-solving fluency and self-efficacy, further efforts are needed to develop flexibility and originality. It also contributes valuable insights into the pedagogical strategies that can support the development of mathematical creativity in preservice teachers, emphasizing the need for comprehensive and sustained instructional approaches.

RECOMMENDATION

Based on the findings of this study, several recommendations can be made to further enhance the mathematical creativity of preservice teachers through heuristic instruction. First, extending the duration of interventions may provide students with more opportunities to practice and internalize diverse heuristic strategies. A more extended period of instruction and practice could help students develop greater flexibility and originality in problem-solving by allowing them to explore multiple methods and solutions more thoroughly.

Secondly, incorporating more varied and complex non-routine problems into the curriculum can challenge students to think creatively and apply heuristic strategies in novel ways. Providing a more comprehensive range of problem types will encourage students to move beyond familiar strategies and develop a more robust toolkit for tackling different mathematical challenges. This approach can also help to address the observed limitations in flexibility and originality.

Integrating reflective practices into the instructional process can also enhance students' awareness of their problem-solving approaches and promote metacognitive skills. Encouraging students to reflect on their use of heuristics, evaluate the effectiveness of different strategies, and consider alternative solutions can foster more profound understanding and creativity. Structured reflection activities, such as journaling or group discussions, can facilitate this process and support continuous improvement.

To address the limited impact on beliefs about mathematical problem-solving, educators should consider implementing more sustained and comprehensive professional development programs. These programs can focus on shifting deeply ingrained beliefs by providing ongoing support, feedback, and reinforcement of heuristic strategies. Engaging preservice teachers in long-term projects and collaborative problem-solving activities can also help to solidify positive beliefs and attitudes towards mathematics.

Finally, future research should explore integrating technology and digital tools in teaching problem-solving heuristics. Interactive platforms and software can offer dynamic and engaging ways for students to practice heuristic strategies and receive immediate feedback. Leveraging technology can also facilitate personalized learning experiences, catering to students' needs and paces.

These recommendations aim to build on the findings of this study and contribute to the ongoing improvement of mathematics education.

LIMITATION

While this study provides valuable insights into the impact of teaching problem-solving heuristics on the mathematical creativity of preservice teachers, several limitations must be acknowledged. Firstly, the study was conducted over a single cycle. This limited timeframe restricts the ability to observe long-term effects and improvements that might occur with continued practice and instruction. A more extended intervention period could provide a more comprehensive understanding of how heuristic strategies influence mathematical creativity.

Secondly, the small sample size of only seven participants limits the generalizability of the findings. With such a small group, the results may not represent the broader population of preservice teachers. More extensive studies involving more participants would be needed to confirm the observed effects and ensure the findings apply to a broader audience.

In addition, the study was conducted in an online format due to the participants being on academic breaks. This mode of delivery may have influenced the outcomes, as the dynamics of online learning can differ significantly from in-person instruction. Factors such as limited interaction, technical issues, and reduced engagement in an online environment may have affected the participants' learning experiences and the overall effectiveness of the intervention.

Moreover, the study focused primarily on the immediate impact of heuristic instruction on mathematical creativity, self-efficacy, and beliefs about problem-solving. It did not examine other potential influences, such as prior knowledge, individual differences in learning styles, or external factors that might affect the results. Future research should consider these variables to provide a more holistic view of the factors contributing to the development of mathematical creativity.

Lastly, the assessment of mathematical creativity relied on specific indicators—fluency, flexibility, and originality—measured through problem-solving tests and self-efficacy surveys. While these indicators are valuable, they may not capture the full spectrum of mathematical creativity. Incorporating additional qualitative measures, such as interviews or observational data, could provide a richer and more nuanced understanding of how heuristic strategies impact creative problem-solving skills.

Addressing these limitations in future research will help to build a more comprehensive understanding of the effectiveness of heuristic instruction in enhancing mathematical creativity, self-efficacy, and problem-solving beliefs among preservice teachers.

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