How Does Working Memory Capacity Affect Prospective Mathematics Teachers' Creative Reasoning in Problem-solving?

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The mixed methods research reported in this article examined the relationship between differences in working memory capacity (WMC) and problem-solving and creative reasoning of 30 prospective mathematics teachers. WMC data were obtained using an OSPAN test instrument, and creative reasoning data were obtained using a problem-solving test. Quantitative data were analysed using linear regression. The qualitative data analysis process was conducted through data condensation, which involved selecting and presenting simpler data, labelling transcriptions, and coding. The validity of the findings was validated through data triangulation, which assessed data consistency. The research showed that WMC influences mathematical problem-solving, which obtained a significant positive correlation between the two variables. The prospective mathematic teachers with high WMC were more creative and flexible in creating problem-solving strategies compared to prospective mathematic teachers with low WMC. They also remembered more information and had better management in solving problems, using advanced strategies and finding appropriate problem solutions. In contrast, prospective mathematic teachers with low WMC were not as good at remembering and managing information, identifying missing vital information from problems, and using imperfect problem-solving strategies. In addition, they experience decreased cognitive performance when solving more complex problems, resulting in less appropriate problem-solving solutions.

Keywords: • working memory capacity • creative reasoning • problem-solving

Introduction

Considering the important role of mathematics in developing critical thinking and reasoning, mathematics needs to be understood and mastered by the entire community. One of the problems in mathematics education, however, is that many students memorise and think algorithmically (Lithner, 2008). Students need to develop strategies that support the transition from basic to secondary understanding to comprehend abstract mathematics, not just know general algorithms (Verschaffel et al., 2020).

A person will think and plan solutions using mathematical concepts when faced with a problem. Planning solutions leads to a creative process in reasoning. Steen (1999) revealed that people use mathematics in two different ways to solve problems. First, simple solutions usually use procedures or formulas that are commonly applied. Second, solving complex problems by applying relevant mathematical strategies such as looking for patterns, translating into mathematical models, using analogical reasoning, and using generalisation and simplification. According to Bergqvist (2007) and Lithner (2008), students prefer to solve problems through rote strategies when repeatedly faced with tasks that do not require the application of higher cognitive abilities. Another issue is that students cannot solve unknown problems or use their knowledge appropriately to solve unfamiliar problems.

Problem-solving is widely regarded as a difficult, complex task that often does not yield the desired outcomes (Schoenfeld, 1985). It is, however, an essential way of doing, learning, and teaching mathematics (Chapman, 2005). Problem-solving is the process of interpreting a situation mathematically, which usually involves several cycles of expressing, testing, and revising mathematical interpretations. Problem-solving also provides opportunities for students to practice advanced thinking skills. It is important to provide practice for everyday situations in applying problem-solving and mathematical modelling, where students can use what they learned in school.

Creative reasoning related to mathematical problem solving has become an increasingly popular research topic, but a gap remains between research findings and current teaching practices. Often, creative reasoning is not directly integrated into current mathematics education curricula, highlighting the discrepancy between research findings and everyday teaching practices in universities and schools. Upon entering teacher education institutions, prospective mathematics teachers assume multiple roles regarding mathematics, teaching, and learning, as well as their teaching abilities (Ball et al., 2005). Prospective mathematics teachers need to be able to identify this gap to prepare for implementing tasks that encourage reasoning and problem solving as effective mathematics teaching practices (Lerik et al., 2020).

Factors that cause difficulties in learning mathematics are shallow understanding and lack of effective reasoning skills (Lithner, 2003). To counter this problem, there is a need to implement strategies that promote reasoning and problem-solving as effective mathematics teaching practices (Fu & Kartal, 2023). Just engaging in problem-based instruction is not enough (King, 2019). Problem-solving and exploring many ways to solve and explain a problem helps develop self-efficacy. More generally, intense classroom routines when teaching mathematics through problem-solving seem to be essential for reducing the level of extraneous cognitive load experienced by students and for building autonomy (Russo & Hopkins, 2019). One well-established approach to supporting mathematics learning experiences is to allow students to work on mathematical problem-solving tasks in pairs or small groups (Russo & Hopkins, 2019).

The traditional approach to teaching and learning likely experienced by many prospective mathematics teachers is in stark contrast to the type of classroom environment and approach needed to teach through problem-solving (White et al., 2021). Experiencing various mathematical practice questions can add information for prospective mathematics teachers to understand mathematical problems and develop strategies for promoting creative reasoning and problem solving in the classroom.

The Literature

Creative Reasoning

Reasoning is defined as thinking to produce statements and produce conclusions. People understand things by reasoning. This means that they know the information that supports their thinking. Then, from the processed information, they can produce a statement or draw conclusions whose truth is supported by reasonable arguments. A statement or conclusion from the results of thought not accompanied by a reasonable argument is not yet said to be reasoning. The term reasoning in this study is defined as a way of thinking to produce statements in reaching conclusions (Boesen et al., 2010). According to Lithner (2008, 2017) reasoning is not always based on formal deductive logic; reasoning is more about the existence of reasonable arguments that guide one's thinking. Reasoning is not only limited to the results of proof but also the thinking carried out by students when facing mathematical tasks.

Two types of reasoning are often used by students in completing mathematics assignments, namely creative reasoning and imitative reasoning (Lithner, 2008). Creative reasoning has four criteria: novelty, flexibility, reasonableness, and mathematical foundation. Imitative reasoning is divided into several types, namely, memorised reasoning and algorithmic reasoning. Bergqvist (2007) analysed 16 introductory calculus courses at four universities in Sweden, finding that around 70% of the exams could be solved with reasoning that did not consider the intrinsic properties of mathematics, and 15 of the 16 exams allowed students to pass without using creative reasoning. In this case, it can be interpreted that 15 of the 16 exams allowed the students to graduate, potentially, with a type of superficial reasoning that has little or no relevance to a specific situation (Boesen et al., 2010).

Creative reasoning is the creation of a new dissertation task solution with feasible reasons (Lithner, 2008), such as research results. Jonsson et al. (2022) have compared creative reasoning approaches with imitative reasoning, especially algorithmic reasoning. The results of that study indicated that the creative reasoning approach is more effective than the algorithmic reasoning approach in terms of memory retrieval and knowledge construction.

Creative reasoning exists when different approaches are used in completing tasks (Bergqvist, 2007). If a goal in teaching mathematics is to develop students' reasoning abilities, they must be given ample opportunities to complete assignments that require creative reasoning (Mac an Bhaird et al., 2017). This implies that mathematics teachers must provide tasks requiring complex thinking to promote creative reasoning. It is, therefore, pertinent to explore how prospective mathematics teachers employ creative reasoning when problem solving.

Problem-solving

Research on creative reasoning in the 1980s made problem-solving a keyword in mathematics education. Since then, research has proposed problem-solving aspects as central issues, such as the competencies and activities required to construct problem solutions (Schoenfeld, 1992). This is considered a quality of problem-solving reasoning with unique characteristics and higher order thinking than imitative reasoning. Descriptions of the characteristics of creative reasoning are accompanied by arguments that are reasonable, plausible, and have a mathematical foundation (Lithner, 2008). Problem-solving is doing non-routine tasks where the solver does not know the previously learned schema designed to solve it (Hasan et al., 2024). Whereas, creative reasoning has a prominent role in solving non-routine problems (Lithner, 2008).

Problem-solving is a form of mathematics that is valuable in increasing students' creativity, self-confidence, and curiosity in solving problems. Problem-solving is also defined as carrying out non-routine tasks whose completion procedures are unknown to the problem solver. In general, problem-solving helps develop students' cognitive skills (Marchisio et al., 2022). Specific cognitive skills are required in problem-solving (Öztürk et al., 2020); however, the problem is not an inherent characteristic of the mathematics task. Instead, it is the specific relationship between the individual and the task that makes the task problematic for that person (Schoenfeld, 1992). This means that a mathematics task may be problematic depending on the person's condition when facing it. Thus, problem-solving is oriented to thinking and reasoning abilities.

The cognitive domain is related to problem solving in the form of a series of skills in creating problem solving strategies. Provocations during the challenging and alternative phases of problem solving stimulate the emergence of new ideas that contribute to the improvement of individuals' mathematical creativity (Shodiq et al., 2023). The first phase of problem solving is *understanding the problem*. Namely, problem solvers understand the problem and identify problem elements they can control by reading carefully. The second phase is *devising a plan*. This phrase means the problem solver understands the problem and identifies and maps the problem elements that can be used. The next phase is *carrying out the plan*, which refers to using ideas that have been planned. The final phase is *looking back and reflecting,* namely checking the solution determined according to the core problem and the context of the problem or in relation to the original question asked (Chang, 2010; Polya, 1945/2004).

Working Memory Capacity

Apart from knowing mathematics, students must have skills in solving mathematical problems, such as procedures or operations used in the phases of problem-solving. Wang and Chiew (2010) defined problem-solving is a cognitive process of the brain that involves finding a solution to the problem and producing a solution Knowledge about mathematical concepts, facts, or principles stored in students' short-term memory or long-term memory are recalled when solving mathematical problems. To find effective and efficient problem-solving strategies, students need to call up mathematical knowledge relevant to the problem they are facing and process it when solving the problem to arrive at a correct solution. The cognitive process in reasoning accesses knowledge through mental activity to remember and change information accompanied by logical arguments to solve problems, in this case, mathematical problems. To achieve success in problem-solving, effective information processing is required. Information processing is related to working memory.

Working memory is the term for cognitive resources used in mental activity processes and recalling the results of these mental activity processes in a short period. (Stillman, 1996). The information received is stored in working memory as a mental activity; when faced with a problem, the mental activity works by calling up relevant information. Information that enters the system's conceptual connections will form a framework as complex cognitive activities can occur in problem-solving. Validating information's suitability in solving problems at local, regional, and global levels is desirable, but there may be no relevant or unclear information. When someone carries out mental activity, namely thinking in solving problems, information is needed that can be used to understand the problem faced to develop and implement appropriate strategies to find a solution to the problem. Working memory relies on a system with limited capacity that actively stores, manipulates and retrieves task-relevant information when needed for ongoing cognition. In line with Cowan et al. (2004) Working memory is limited in duration and capacity; the working memory limit for processing information is between plus seven and minus two. Limited working memory capacity limits the ability to process information. Working memory has limited capacity when carrying out cognitive roles. The information used in the cognitive role is tailored to the relevant problem. The cognitive work demands that result in problem-solving are defined as the demands on attentional resources and working memory that result from the task being completed (Stillman, 1996). This means that limited working memory capacity (WMC) may limit a person's ability to process information.

Information is needed to carry out mental activities when solving problems. The cognitive demands generated in problem-solving are defined as the recall of information or resources in working memory for problem-solving. When solving a problem, a person is faced with information that must be understood, selected for suitability to the topic of the problem being faced and processed so that it can be used to find the right solution to the problem. When the problem-solving process is effective, the problem-solving can be said to be successful, and success in solving the problem cannot be separated from the working memory capacity task.

In many cognitive processes, working memory capacity plays an important role, one of which includes problem-solving (Wiley & Jarosz, 2012). This means that working memory capacity is important in various cognitive processes, including problem-solving. Measuring working memory capacity can be done by giving a span task. This activity tests an individual's ability to focus on two tasks simultaneously. These two tasks compete for resources in working memory. An individual with a larger working memory capacity will show fewer performance deficits. In comparison, someone with a smaller working memory capacity will tend to show a performance deficit on one task at a time and do two tasks simultaneously. (Hasan et al., 2024).

As tasks compete for working memory resources, people with less working memory capacity are likely to show deficits in performance on one task, if not two tasks performed simultaneously. In comparison, people with larger working memory capacities will show fewer deficits in performance. Thus, it can be interpreted that a person's reasoning can be influenced by working memory capacity in solving problems. Working memory capacity stores information that can be reused when needed for the selection and implementation of new strategies, as required for creative reasoning. Working memory capacity affects how many information items can be worked on simultaneously and influences the type of strategy used when working on a task. Lerik et al. (2020) also found that each person has a different working memory capacity.

Differences in working memory capacity impact cognitive performance when reusing information needed to solve problems. Studies on working memory and mathematical problem-solving in various fields of mathematical study have been carried out intensively (Juniati & Budayasa, 2022), thinking and reasoning (Holyoak & Morrison, 2005). Many studies, however, only looked at the relationship between the two. Not many studied prospective teachers' working memory capacity and creative reasoning processes in solving problems. Therefore, the research questions to be answered are:

How is working memory capacity related to problem-solving ability?
How does creative reasoning of prospective mathematics teachers function at different levels of working memory capacity?

Method

This research used a mixed-method sequential explanatory design. Mixed-method offer a holistic approach to answering research questions, providing a deeper and more valid understanding of the phenomena being studied (Ivankova et al., 2006). The mixed method research strategy was chosen to gain a more comprehensive understanding of working memory capacity and problem-solving by viewing it from various perspectives. Quantitative methods were used to determine the effect of working memory capacity on creative reasoning in problem-solving, and qualitative methods were used to examine the creative reasoning process in problem-solving. The combination of quantitative and qualitative data provides the opportunity to triangulate the findings from various perspectives to increase the validity of the research findings.

Data Collection Instruments and Data Analysis

Data were collected using two instruments, one of which was the Operation Span (OSPAN) test instrument, which was designed to collect working memory capacity data. The OSPAN test contains a series of mathematical tasks presented in PowerPoint format, with a short time provision of between 4 to 10 seconds automatically. The OSPAN test used in this study was adopted from the OSPAN test developed by Juniati and Budayasa (2020).

During implementation of the test, tasks are given in the form of mathematical operations. Participants are asked to work on several mathematical operations on the answer sheet provided, and during the time given, they are also asked to remember numbers. The ability of participants to perform operations and remember numbers simultaneously is the main point in determining a person's working memory capacity. Working memory capacity scores range from 0 to 100. This study used the quartile separation technique described by Conway et al. (1942), and Juniati and Budayasa (2020), regarding the OSPAN test. The results of this OSPAN test are the basis for grouping samples into two categories: high working memory capacity and low working memory capacity. Participants with OSPAN test scores above 50% are included in the high working memory capacity category. The low working memory capacity category includes participants with OSPAN task scores below or equal to 50%.

The second instrument was a problem-solving test used to obtain data on problem-solving abilities and creative reasoning processes. The problem-solving test instrument was in the form of non-routine open-ended questions. The problem-solving test instrument was developed from flat geometry material that was adjusted to the indicators of creative reasoning: novelty, plausibility, and mathematical basis. Before the instrument was used, the instrument was validated by linguists and mathematical material experts to determine the readability and suitability of the material to the research objectives.

The problem-solving test assesses creative reasoning by giving participants non-routine questions. The assessment rubric evaluates the level of creativity shown in each response. Non-routine problem-solving questions are assessed based on novelty. The aspect of generating new ideas or strategies in solving problems is given a maximum score of 30; this score is given based on the flexibility of the new ideas created; the more ideas or strategies created, the score will reach the maximum value, then the plausibility aspect, this aspect is given a maximum score of 30. The more logical the argument given to support the accuracy of the idea or strategy created, the maximum score will be obtained. The last aspect is the mathematical foundation; in this aspect, the maximum score is 20. This aspect is related to the accuracy of the use of mathematical concepts in solving problems. The ranking for this test ranges from 0 to 80, with the final score calculated by dividing the total score obtained by the maximum possible score and multiplying by 100.

The WMC score served as the dependent variable. In contrast, the creative reasoning score in problem-solving was treated as the independent variable, and both were analysed using multiple linear regression analysis. This process was carried out to determine the relationship between working memory capacity and creative reasoning of prospective mathematics teacher students in solving problems. Furthermore, quantitative data were analysed and reported using quantitative descriptive statistical methods.

Next, problem-solving data and interview transcripts were analysed using a qualitative approach. Qualitative research methods are becoming popular, especially in social sciences and educational sciences (Kılıçoglu, 2018). According to Bryman (2004) in regard to qualitative research, it is characteristic that data are collected in verbal and visual form. When analysing the collected data, statistical procedures are also not used; instead, qualitative analysis is dominant, the essence of which is to find patterns and themes in the material analysed. Qualitative analysis of the material is formed by the coding process, namely interpreting the analysed text and connecting meanings to its respective parts (Bryman, 2004; Kolachi & Wajidi, 2011). The analysis steps in this study included coding, selecting relevant data, grouping data, and making summaries based on the grouped data.

The data obtained were narrative data, which were used to define the research process and findings. Before qualitative data analysis, the data obtained were validated using the time triangulation and member check methods. Time triangulation is carried out by giving the problem-solving questions back to the participants at different times to see the consistency of the answers given by the participants. The qualitative data were analysed through condensation, presentation, and conclusion. First, participant work data and interview data were grouped to consider its suitability. Then, the data were sorted and reduced, where information relevant to the creative reasoning indicators were used. Finally, conclusions were drawn based on the validity of the data obtained from the creative reasoning indicators. First, the research results were compiled, and the research results validated by reviewing the data obtained. The conclusion was intended to answer the research question, namely, how working memory capacity affects the creative reasoning ability of prospective mathematics teachers in solving problems.

A prospective mathematics teacher with a high working memory capacity can have sound creative reasoning if it meets the novelty aspect: prospective mathematics teachers create new ideas or draw on previously known ideas by taking an innovative approach to solving problems. In the plausibility aspect, prospective mathematics teachers can provide predictive and verification arguments to support the truth of the ideas created. Finally, prospective mathematics teachers can use mathematical concepts correctly to apply the ideas created in solving problems. Conversely, creative reasoning in prospective mathematics teachers with low working memory capacity, if it does not bring up aspects of novelty, does not provide logical arguments for the answers they make.

Participants

This study included 30 participants who were prospective mathematics teachers at one of the higher education institutions in Madura, Indonesia. The initial population was 68 participants, and screening was carried out based on the results of the mathematics ability test. Thus, 30 prospective mathematics teacher participants were obtained with equivalent mathematics abilities, namely above a score of 75. In addition, the researcher also calculated 44% of the initial population, which means that they have met the selection requirements as a sample. Then, 30 of the participants selected were invited to take the OSPAN test as a step to categorise the participants' working memory capacity. The results of the categorisation of working memory capacity obtained 14 participants in the high working memory capacity (HWMC) category and 16 participants in the low working memory capacity (LWMC) category (Table 1).

Table 1
Participant Selection Process

Participants (*N* = 68)		
Participants with equivalent mathematics abilities	Working Memory Capacity	
	High	Low
n = 30	*n* = 14	*n* = 16

Participants volunteered without researcher intervention; this was done to maintain the authenticity of the research data. In exploring creative reasoning, the researcher interviewed one prospective mathematics teacher participant with a high working memory capacity and one prospective mathematics teacher participant with a low working memory capacity. The two participants were selected based on differences in the their WMC and communication skills so that the researcher could obtain detailed creative reasoning information.

Results

Qualitative Research Results

Working memory capacity data were obtained using the OSPAN test instrument. A total of 30 participants took the working memory capacity test. Data on problem-solving abilities were obtained by giving problem-solving tests in the form of flat geometric geometry mathematics questions. OSPAN test scores and problem-solving tests were then analysed using a linear regression test. The results of the quantitative data are presented in Table 2.

Table 2
Statistics of WMC and Mathematical Problem-solving

Variable	*n*	Minimum	Maximum	Mean	Standard Deviation *(SD)*
Problem-solving	30	15.00	100.00	60.83	28.77
WMC	30	36.00	90.00	67.30	21.13
Valid *N*	30				

Descriptive Statistics of Problem-solving and Working Memory Capacity

Based on Table 2, it was found that the average problem-solving ability of prospective mathematics teacher students was in the medium category. The average standard deviation of mathematics problem-solving abilities of prospective mathematics teacher students was 28.77. The average problem-solving ability and standard deviation obtained is a categorisation of the problem-solving abilities of 30 prospective mathematics teacher students, including 14 students in the high category, in the medium category there were seven students, and the remaining nine students in the low category.

The average working memory capacity of prospective mathematics teacher students was 67.38, with a standard deviation 21.13. These results showed that the prospective mathematics teacher students could correctly remember around 67% of letters presented sequentially when solving problems in the form of mathematical operations. Referring to the OSPAN test quartile separation technique (Kane et al., 2007), scores were obtained from 30 prospective mathematics teacher students; 22 prospective mathematics teacher students had high working memory capacity (HWMC), and eight prospective mathematics teacher students had low working memory capacity (LWMC).

The Effect of Working Memory Capacity on Mathematical Problem-solving Abilities

A simple regression analysis was conducted to see the effect of working memory capacity (independent variable) on mathematical problem-solving abilities (dependent variable). The simple regression test used SPSS analysis data. The results of the working memory capacity (WMC) regression test for prospective mathematics teachers and their mathematical problem-solving abilities are presented in Table 2.

Based on the information in Table 3, the data illustrate that WMC and mathematical problem-solving ability have a strong, significant and positive relationship, which has a significance value of $p = 0.014 < 0.05$ and a Multiple *R*-value of 0.492. Thus, it can be interpreted that there is a positive relationship between WMC and problem-solving abilities. This means that if the WMC of prospective mathematics teacher students increases, their mathematical problem-solving abilities will also increase and vice versa. The determinant coefficient, or R^2, measures the suitability of the regression equation. The R^2 of 0.242 shows that working memory capacity (WMC) as an independent variable influences mathematical problem-solving abilities as a dependent variable. In this case, problem-solving ability was obtained at 24.2%, while other factors influenced the rest.

Table 3
Summary Output of Regression Analysis Mathematical Problem-solving and WMC

Model	Multiple *R*	R^2	Adjusted R^2	Std. Error	Observations
1	0.492	0.242	0.207	26.65	30

As a statistical analysis technique. This analysis determines whether the overall regression model significantly explains the variation in the data. The researchers used analysis of variance (ANOVA). The multiple linear regression statistical test results have 27 degrees of freedom (df) associated with the residual. The residual degree of freedom value is obtained from the number of observations minus the number of predictors and one ($n - k - 1$), where n is the total observations and k is the number of predictors. The total degrees of freedom are equivalent to the total observations minus one ($n - 1$). The sum of the regression (*SS*) squares was 4985.957, the residual *SS* was 15629.66, and the total *SS* was 20615.625. The mean square (*MS*) is the result of dividing the *SS* by the corresponding degrees of freedom. This analysis obtained an *F* value of 7.0181 and a significance value of 0.0146, thus, the level of significance of the results of the ANOVA analysis was strong statistical empirical evidence to reject the null hypothesis, which stated that there is no relationship between the dependent and independent variables. Thus, it can be concluded that there was a significant relationship between the independent and dependent variables based on the results of the ANOVA analysis. The statistical test results also showed a significance value smaller than the alpha level (.05). So, it can be concluded that working memory capacity has a significant effect on problem-solving ability. The regression model explained some of the variance identified through the *F* test so that a significant effect appears, although the previous Adjusted *R*-squared only reflected about 20% of the variance explained by the predictor.

Table 4
Mathematical Problem-solving and Working Memory Capacity, Analysis of Variance from Regression Analysis

Model	*df*	*SS*	*MS*	*F*	Significance *F*
Regression	1	4985.957468	4985.957468	7.018131644	0.014653307
Residual	27	15629.66753	710.4394333		
Total	29	20615.625			

Based on the information in Table 5, a standard error of 20.14 was obtained. This value represents the estimated standard error of WMC. This value is lower when compared to the standard deviation of mathematical problem-solving ability, namely 28.77 (Table 1). Based on these data, it is concluded that the standard error is smaller than the standard deviation. So, it can be interpreted that the smaller the standard error value compared to the standard deviation value of mathematical problem-solving ability, the more accurate the results of the regression model conclusions are in predicting mathematical problem-solving ability, the more accurate the resulting conclusion from the regression model is in predicting mathematical problem-solving ability. Apart from that, the regression coefficient value for working memory capacity was also obtained at 0.728 with the regression equation for mathematical problem-solving ability y = 9,354 + 0.726x with a confidence level of 95%.

The linear graph in Figure 1 presents the relationship between the x- and y-values. In this context, the x-value is interpreted as the percentile of the independent variable in the form of working memory capacity, while the y-value as the dependent variable is the problem-solving ability according to the numerical representation of the percentile. Percentiles divide the data into one hundred equal segments, each representing a certain percentage of the total population. For example, in the first row of data, the distribution of the y variable and statistical characteristics are evaluated across the range of percentile data. This linear graph shows a positive correlation between the dependent and independent variables. With the value of the regression equation y = 9.35 + 0.726x, the linear graph shows that the higher the working memory capacity (WMC) value, the greater the mathematical problem-solving ability. Although a significant influence has been found, there are still other factors that influence the problem-solving ability of prospective mathematics teachers; this is indicated by the R square result equal to 24.2% (Table 3).

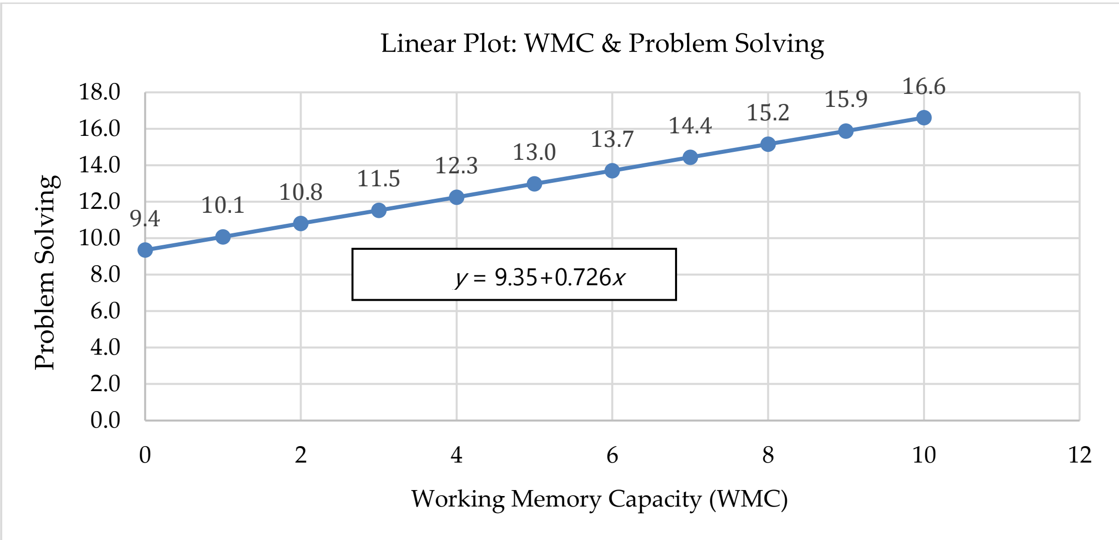

Figure 1. Linear plot of WMC and problem-solving.

Qualitative Research Results

Based on quantitative analysis, the researchers found significant results between WMC and problem-solving abilities. Next, the researcher selected two participants based on their OSPAN test score classification and their problem-solving results for interviews. The average WMC score of 30 participants was 19.95. Participants with a score ≥ 21 were included in the high working memory capacity (HWMC) category, namely 14 participants or the equivalent of 47% and scores <21 were included in the low working memory capacity (LWMC) category, namely 16 participants or the equivalent of 53%. This was to examine the creative reasoning of prospective teacher students with high working memory capacity

(HWMC) and low and low working memory capacity (LWMC). Both participants selected for interviews also had equivalent mathematical abilities. The basis for selecting two participants for the interview process was based on differences in working memory capacity and communication skills so that the researchers could obtain more detailed information.

Qualitative data were collected using problem-solving tests like geometry questions about flat shapes. The topic was chosen because geometric material can be visualised in real-life problems. So, examining creative reasoning in non-routine and open-ended problems is appropriate. Next, interviews were conducted, referring to the work results of each participant in completing problem-solving tasks. Participants were selected based on flexibility and fluency in communicating so that researchers obtained precise data. The form of the problem-solving test is presented in Figure 2. The participants are called Aina and Faro (pseudonyms).

Mr Andi has a house equipped with a large garden. In the middle of the garden there is a rectangular fish pond. On the side of the pool there is a 1 meter wide road that surrounds it. The road will be installed with attractive gradations of ceramic shapes as depicted below;

The ceramic forms provided are: a right triangle, with a right side length of 20 cm, Square with sides 20 cm, rectangle measuring 40 cm x 20 cm, Parallelogram with parallel sides = 40 cm, height = 20 cm, and s (hypotenuse) = $20\sqrt{2}$ cm, a right-angled trapezoid with parallel sides of 40 cm and 20 cm respectively, and a height of 20 cm, the bishop's hat has a base length of 40 cm, parallel sides of 20 cm and a height of 40 cm. Mr Andi's fish pond measures 2x3 meters. So that it looks beautiful and neat, Mr. Andi wants the ceramics installed without any cuts. Make the ceramic installation models as varied as possible on the road, provided that all ceramic shapes must be installed. Provide an explanation for your answer!

Figure 2. Mathematical problem solving task.

Analysis of problem-solving results refers to problem-solving steps, according to Polya (1945/2004). The problem-solving process consists of four stages. The first stage is understanding the problem. Namely, problem solvers understand the problem and identify the elements of the problem that they can control by reading carefully. The second stage is devising a plan. This phrase means the problem solver understands the problem and identifies and maps the problem elements that can be used. The next stage is implementing the plan, which refers to the use of the ideas that have been planned. The final stage is looking back and reflecting, namely checking the solution determined according to the core of the problem.

Participants with High Working Memory Capacity

Understanding the Problem

Participants with high HWMC understood the questions well. When understanding a problem, participants with high working memory capacity stated all the information in the question or problem, which was proven by the researcher's confirmation of the solution. The HWMC participant stated that the information obtained from the questions included, among other things, the width of the road surrounding the pool is 1 metre, while the size of the pool is the same as 2 x 3, then there are six different shapes of ceramics that will be installed. In addition, the HWMC participant provided additional information by stating that the length of the side all ceramic shapes were slanted so that the participant could easily combine or pair ceramic shapes that had slanted sides measuring $20\sqrt{2}$ metres.

Researcher:	What information do you know?
Aina:	The width of the road surrounding the pool is 1 metre, and the size of the pool is 2 x 3 metres, there are six different shapes of ceramics, then there is a requirement that all ceramic shapes must be installed, and no ceramics can be cut
Researcher:	So, is there any additional information?
Aina:	It turns out that the length of all the slanted sides of the ceramic shape is the same.
Researcher:	How many?
Aina:	$20\sqrt{2}$.

Apart from the information in the question, participants with high working memory capacity provided additional information about the length of the slanted side of all ceramic shapes. The additional information provided by participants with high working memory capacity made it easier to solve the problem. So, the solution form made by the HWMC participant, Aina, is more creative and faster to complete because the settlement pattern was already known. Information about the length of the slanted side, which is a reference for solutions carried out by participants with high working memory capacity, is a form of creative reasoning that emerges from the reasoning of HWMC participants.

Devising a Plan

The planning strategy created by the participant came from his ideas, not using standard procedures but looking for easy ways to solve problems. The method used is to look for shapes that have sloping sides. The shapes that have slanted sides include right triangles, parallelograms, trapezoids and bishop's hats. Aina calculated the slanted sides of the four shapes so it would be easier to combine shapes that have slanted sides. Apart from that, Aina also made ratios or comparisons. This was done to produce precise and beautiful ceramic installation sketches. Then, the participant looked for any shapes that could be combined to make it easier to install the ceramics. As a form of creativity in solving problems, Aini made variations in the gradation of installing ceramics starting from the side of the road surrounding the pool. Aina divided the road surrounding the fishpond into four parts. Aina believed the other three parts would be the same after making one variation model for installing ceramics. The strategies created by Aina are steps that the participant used to make the problem-solving easier.

Researcher:	What did you do to solve this problem?
Aina:	I'm looking for sloping sides that can be combined. After I searched, the length is the same as 20 roots 2, so all these hypotenuses can be combined.
Researcher:	Then, what else?
Aina:	In Zoom out, what is the ratio called, sir?
Researcher:	Why create a ratio?
Aina:	Let's talk about precision, sir. So, I looked for shapes that could be made on each side.
Researcher:	Are there any other steps?
Aina:	I started from the edge first because I usually know that pools have to be on the edge, but they are different.

On the edges of Aina's solution, the ceramic shapes were parallelogram, triangle, trapezoid and square. The placement of the ceramics from the four shapes was made differently at the edges so that the variations in the ceramics installed look more beautiful and symmetrical.

Researcher:	Is that enough here?
Aina:	So, made it focus on this side (participant pointing to the edge) first so that the other side will be the same as this one (participant pointing at the picture).

In each section, Aina created variations in installation using four ceramic installation patterns. Figures 3–6 show the four variation models.

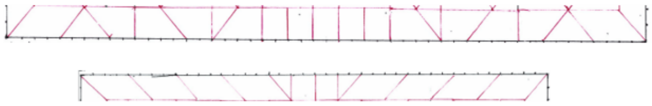

Figure 3. Variations in Installing Ceramics on The Side of The Road

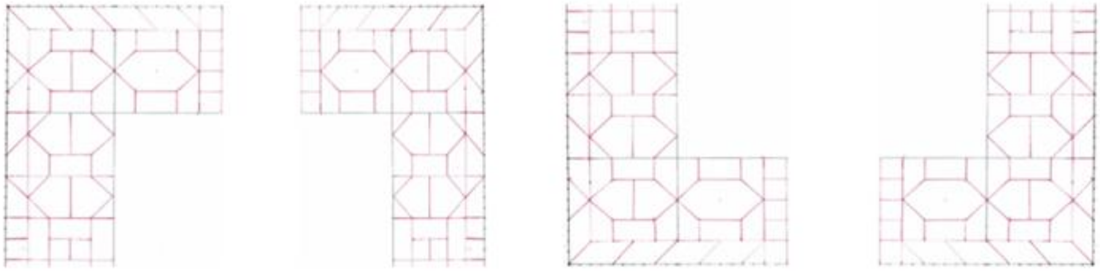

Figure 4. Variations in Ceramic Installation in Each Part

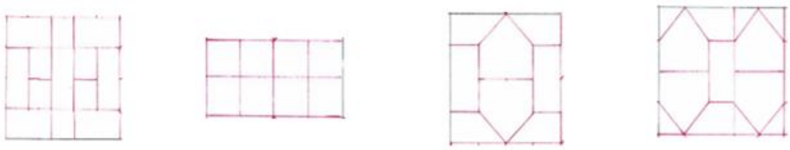

Figure 5. Types of Ceramic Installation Variations

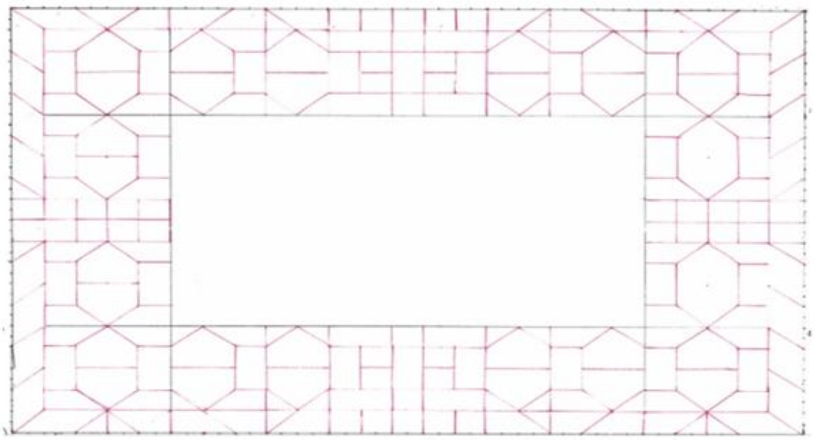

Figure 6. Gradation of Ceramic Installation Models

Carrying Out a Plan

Aina carried out the settlement by referring to the plan made previously. The participant calculated the hypotenuse of the parallelogram trapezoidal right-angled triangle and the bishop's hat was $20\sqrt{2}$ metres. Next, Aina made a ratio to make it easier to solve the problem and make variations in the gradation of the ceramic installation more precise or symmetrical. Aina made variations in installing ceramics, starting from the edge and installing a parallelogram ceramic shape. Then, from mapping the four sections of the road surrounding the fishpond, Aina only made one variation of ceramic installation.

This was done because of the participant's assumption that by making only one part, the other three areas of the ceramic variation model would be the same.

The solution steps taken by Aina are the result of the reasoning used by the participant to make it easier to solve the problem. In the problem-solving steps implemented by Aina, he also tried to combine several ceramic shape models. Especially when making variations on the roadside that surrounds the fishpond. The variations in ceramic installation made by Aina met the requirements specified in the question, namely that all ceramic shapes must be installed and no ceramics must be cut during installation. The participant used these conditions to create variations in ceramic installation models. In other words, Aina solved the problem well and creatively.

Looking Back and Reflecting

Participants with high working memory capacity recheck the answers they have worked on to ensure that the answers written are correct. Aina's form of re-checking was comparing the area between the ceramics installed and the area of the road surrounding the swimming pool. After calculating, it turns out that the area is the same, so the participant with high working memory capacity was confident that the answer found was correct.

Participant with Low Working Memory Capacity

Understanding The Problem

Participants with low working memory capacity understand the questions well. This was obvious when Faro stated all the information written in the question. The information obtained by Faro included the width of the road surrounding the pond being 1 metre and the size of the fishpond 2 x 3 metres. Then he stated that there were six different ceramic shapes: square, rectangle, parallelogram triangle, trapezoid and bishop's hat. Then, he went on to say that Mr Andi must meet two conditions when installing the ceramics: all ceramics must be installed, and no ceramics must be cut during installation. The following are the results of interviews between the researcher and Faro.

Researcher:	What information do you know?
Faro:	Here, the width of the road is 1 metre, then the area of the fishpond is 2 by 3 metres, and there are six ceramic shapes, namely square, rectangle, triangle, parallelogram, trapezoid, and bishop's hat
Researcher:	Is there any other information?
Faro:	That's all, sir
Researcher:	Is there any other information?
Faro:	What, sir? The ceramics installed on the road are 1 metre wide, and all must be installed.
Researcher:	Keep going. What is asked in this question?
Faro:	Make as varied a ceramic installation model as possible on the road

When understanding the problem, Faro did not provide complete information about the problem given. In the problem there is important information that must be known as knowledge in making a solution plan. In this problem, the condition is given that all shapes must be installed, and no ceramics must be supported. In addition, it is also known that the shape of the ceramic that has a slanted side is the same size, namely, $20\sqrt{2}$. By utilising this important information, Faro could have built a solution idea by pairing ceramics that have slanted sides side by side.

Devising a Plan

In contrast, Faro's planning strategy was carried out using easy strategies to solve problems. The method used is to determine the size of the side of the pool or the width of the road and the size of the ceramic shape. The size of the road on the side of the pool is 1 metre, whereas the unit is metres. Meanwhile, the unit for measuring ceramics was centimetres, so the participant equated the units from metres to centimetres and then found the total area of the road and the area of each ceramic shape in centimetres. The following are the results of interviews with Faro.

Researcher:	What did you do to solve this problem?
Faro:	First, determine the size of the side of the pool and the shape of the ceramic.
Researcher:	Is there another strategy?
Faro:	There isn't any.

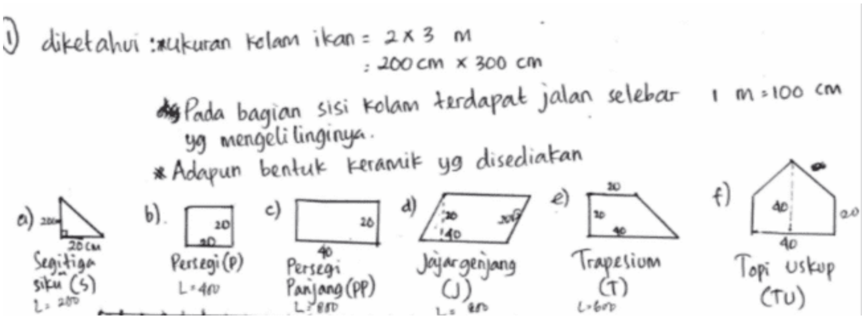

Figure 7. Process of calculating ceramic area by Faro.

The area of the triangular ceramic was 200 cm^2. The square ceramic was 400 cm^2, the parallelogram ceramic was 800 cm^2, the trapezoid ceramic was 600 cm^2, and the rectangular ceramic was 800 cm^2. The bishop's hat ceramic was 1200 cm^2. Thus, the total area of the installed ceramic should be the same as the area of the road. Faro, however, did not find this idea even though he had calculated each ceramic shape to be installed.

Carrying Out a Plan

For the initial step in solving the problem, Faro carried out the process according to the previously mentioned solution plan and found variations in ceramic installation models. However, he still needed to do calculations before installing the ceramics. The following are the results of Faro's answer (Figure 8).

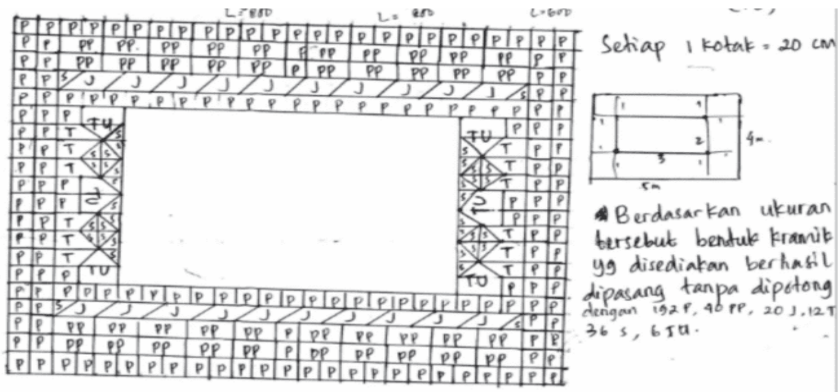

Figure 8. Model of ceramic installation made by

A ceramic installation model was obtained by calculations, as shown in Figure 6. The new strategy that Faro used to solve the problem was to sketch the road that was to be tiled. Next, Faro calculated the area of all the tile shapes that to be installed on the road. According to Faro, this strategy was the right way to solve the problem, because installing the tiles required knowing the area of each tile. The solution, however, did not require calculating the area of the tiles. Thus, Faro's reasoning did not support the strategy created. Then Faro gave a symbol to each tile shape. The symbols were letters—square tiles were denoted by the symbol (P), rectangles by (PP), triangles by (S), parallelograms by (J), bishop's hats by (TU), and trapezoids by (T). According to Faro, by giving a symbol to each tile shape, the installed tiles were not mixed up. This reasoning was not appropriate, because visually, all the tiles were obvious and not likely to be mixed up. Based on the results of the drawing made by Faro, there were 192 square tiles, 40 rectangular tiles, 20 parallelogram tiles, 12 trapezoid tiles, 36 triangular tiles, and six bishop's hat tiles. Faro created the drawing by multiplying the square and rectangular tiles because it was easier to position them during the drawing process. Based on these measurements, Faro believed his answer was correct, as it met the requirements: all the tiles were in place, and no cutting was required. Faro, however, did not express a clear rationale to support his strategy.

Looking Back and Reflecting

When rechecking the answers, it turned out that participants with low working memory capacity were not sure about the answers they made. This can be seen from the area where the number of ceramics were installed and the area of the road surrounding the edge of the pool, which is not the same. This occurred due to the Faro's inaccuracy in not re-checking the answers, which resulted in the answers not being as expected. The following is an excerpt from an interview with Faro.

Researcher:	Are you sure your answer is correct?
Faro:	Not sure, Sir...!
Researcher:	Is there another strategy?
Faro:	There isn't any
Researcher:	How vast is the road?
Faro:	1400 cm, Sir.
Researcher:	Is the area where the ceramic was installed the same as the area on the road?
Faro:	He, it's different. It should be the same.

Discussion

The study's simple regression analysis showed that WMC and mathematical problem-solving ability had a significant positive relationship. This is proven by the results of the multiple R of 0.492 and the significance value of $p = 0.014 < 0.05$, which means a positive relationship exists between working memory capacity and problem-solving ability. The working memory capacity of prospective mathematics teacher students increases when their mathematical problem-solving abilities increase; the opposite applies. WMC is a capability that focuses on the main task of carrying out a necessary operation and reduces less relevant information.

Calculating the regression equation equal to 0.242 shows that working memory capacity influences problem-solving ability by 2.2%, and other factors influence the rest. Measurement of working memory for children who have completed formal education is the best predictor of reading and numeracy skills (Gathercole & Pickering, 2000). WMC have a significant influence on a person's problem-solving ability, which is directly proportional to a person's working memory. This study is supported by research related to children's working memory and learning and achievement in mathematics (Alloway & Passolunghi, 2011; Friso-Van Den Bos et al., 2013; Miller & Bichsel, 2004).

Based on the results of the answers and interviews from the two prospective mathematics teachers, it was found that in the process of understanding the problem, both participants provided relevant information related to the problem. Among other things, the width of the road surrounding the fishpond is 1 metre, and the size of the pond is 3 x 4 metres. In addition, six forms of ceramics have different sizes, and the ceramics must be installed on the road surrounding the fishpond. Apart from that, both participants also mentioned the conditions for installing ceramics, namely that the ceramics installed must not be cut, and all ceramic shapes must be installed. The two participants, however, differed in their reasoning. The participant with high working memory capacity provided more detailed information and additional information, namely provided the length of the slanted side on ceramics that had slanted sides, which was $20\sqrt{2}$ metres. The prospective teacher with low working memory capacity knew this information after carrying out calculations. This differentiates the reasoning process of each participant. The participant with high working memory capacity stored more information, which became useful when understanding the problem at hand.

The results showed that the prospective teachers of mathematics with low working memory capacity could provide information in understanding the problem. Still, they obtained a solution that was less appropriate to the task domain on completion. This finding was caused by the participants' lack of focus when solving the problem. Participants with low working memory experienced significant cognitive decline when the level of problem complexity changed. Participants with high working memory capacity had more information as cognitive resources that they reused when solving the problem with increasing complexity. Those participants handled the task well compared to participants with low working memory capacity (Céspedes et al., 2016). This is in line with Wiley and Jarosz (2012), who stated that individuals with high WMC can focus on dealing with cognitive distractions that hinder their thinking in solving problems. This enables the elimination of information that is not relevant to the task at hand.

Furthermore, in implementing the solution plan, the participants with high working memory capacity could solve problems well; participants were more creative and found solutions easier without doing calculations first. Cognitively and creatively, the participants with high WMC were better at solving problems than those with low WMC. Participants with high working memory capacity where their attention is more focused on the solution process; they found many ways to solve problems. In contrast, the low WMC participants, were less flexible and less focused on implementing problem-solving strategies. In addition, participants with low WMC were less able to eliminate cognitive distractions that hinder the problem-solving process.

According to Wiley and Jarosz (2012), apart from storing and managing information that underlies the problem-solving process, WMC also reflects control or attention in the problem-solving process. In the problem-solving process, high WMC facilitates good attention control. The research results showed differences in problem-solving between individuals with high WMC and individuals with low WMC, where high WMC individuals are better at problem-solving than individuals with low working memory capacity. Research carried out by Palengka et al., 2019 regarding mathematical reasoning, determined that individuals with high and low WMC showed differences in the structure of mathematical reasoning. When implementing strategies, individuals with high WMC use flexible and practical strategies and produce maximum solutions. In contrast to low WMC individuals, who use a one-way strategy and typically find solution that are less precise.

Other research results show that children with high WMC generally have more advanced problem-solving strategies and higher mathematics achievement than children with low WMC (Alloway & Passolunghi, 2011; Beilock & Carr, 2005; Céspedes et al., 2016). This means that when the complexity of the problem increases, children with high WMC can use their information to control the interference that gets in their way. This happens because children with high WMC have more information. If the difficulty of a problem increases, they can use the strategies they learned during formal schooling to help them because students with high WMC have more cognitive resources (Céspedes et al., 2016; Wiley & Jarosz, 2012). Besides that, this research also found that prospective mathematics teachers with high WMC were better at solving problems than those with low WMC. This can be seen from the ability of their cognitive control to eliminate irrelevant information and solve more complex problems.

In addition, high WMC individuals can remember and process the information they have understood well, thus supporting the discovery of more efficient solution strategies. Individuals with high working memory capacity can retrieve information from situations or information related to mathematical concepts and use them appropriately to find solutions when given mathematical problems. High WMC is beneficial in successful problem-solving (Wiley & Jarosz, 2012).

Conclusion

The results of this research show that working memory capacity (WMC) influences the problem-solving abilities of prospective mathematics teachers; the dependent variable and the independent variable have a significant positive correlation (namely, R = 0.492, p-value = 0.014). This means that WMC impacts mathematical problem-solving abilities. Individuals with high working memory capacity (HWMC) have more advanced problem-solving strategies and better attention control than those with low working memory capacity (LWMC). Individuals with HWMC can remember and manage more information well to support further strategies on more complex problems and produce appropriate solutions. Meanwhile, individuals with LWMC are less good at remembering and managing information so the solutions they create are less appropriate.

This research contributes to knowledge about creative reasoning and problem-solving in mathematics. This research also contributes to designing learning strategies. Teachers can design mathematics learning based on creative reasoning with an innovative and flexible approach by presenting contextual problems and problem-based learning. This can train students to think creatively when solving problems and encourage them to think critically and analytically. By asking challenging questions and complex problems, students are trained to evaluate in-depth information and make better decisions. This approach has the potential to motivate students to find innovative solutions to problems. In addition, by stimulating imagination and creativity, there is the opportunity for students to learn to create various alternative solutions and then the best one. Creative reasoning can involve group work, where students must collaborate and communicate in problem-solving (Russo & Hopkins, 2019). This develops important social and interpersonal skills, including listening and appreciating multiple perspectives. Thus, creative reasoning research contributes to deeper and more holistic learning, preparing prospective mathematics teachers for future challenges, and creating positive and productive learning environments when teaching mathematics in schools.

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Ethical approval

This study was conducted with ethical approval was granted by the Ethics Committee of the Institute for Research and Community Service of STKIP PGRI Bangkalan for the data to be reported using the participants first names. The participants provided active written consent before data collection and gave informed consent for the use of their first names for publication purposes.

Competing interests

The authors declare there are no competing interests

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