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Creative Thinking in Prospective Mathematics Teachers: Flexibility in Solving Systems of Linear Equation

Hevy Risqi Maharani*, Mochamad Abdul Basir & Niken Lusia Ningrum

Department of Mathematics Education, Universitas Islam Sultan Agung, Indonesia

*Corresponding email: hevyrisqi@unissula.ac.id

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Abstract: Creative Thinking in Prospective Mathematics Teachers: Flexibility in Solving Systems of Linear Equations. Objectives: The main aim of this research is to determine the flexibility of prospective mathematics teachers in solving systems of linear equations. Apart from that, this research also aims to find factors that are taken into consideration by prospective mathematics teachers in determining the method for solving systems of linear equations. **Methods:** Data collection techniques are carried out through tests. The test is used to determine the flexibility or number of methods used by prospective mathematics teachers in solving systems of linear equations. Qualitative descriptive methodology and interviews with prospective mathematics teachers were used in this research to interpret the results and analyze the factors considered by prospective mathematics teachers in choosing the method used to solve systems of linear equations. **Findings:**The results of this research reveal that prospective mathematics teachers have 6 methods that can be used to solve systems of linear equations. **Conclusion:** The factors taken into consideration by teachers in determining the chosen method are based on three numerical factors, namely the number of variables to be searched for, the number of operations to be used and the number of steps to be carried out in solving a system of linear equations.

Keywords: creative thinking, flexibility, mathematics.

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INTRODUCTION

Education is the backbone of a nation in the era of fourth industrial revolution (Alam et al., 2020; Bereketeab, 2020). Educational institutions are the right place to develop students' ability to think creatively and bring out their creative talents. Creative learning is needed in the optimization of creative thinking skills in this era, such as idea generation, assumption making, problem solving skills and building self-efficacy. Creative thinking cannot be separated from the teaching and learning process where there is a creative thinking process with interaction between teachers and students (Oktavianingsih & Pramudiani, 2022; Qadri et al., 2019; Yang & Huang, 2015). This is also what is done in math learning.

Mathematics learning is learning material that is related to everyday life. Students need to learn and understand this subject (Dwijanto et al., 2019; Nufus et al., 2018). Students' mathematical thinking patterns can develop through creative thinking ability so that they can use them in their daily activities. With the habituation of creative thinking, it will certainly be very useful for students in solving problems in everyday life (Junaedi et al., 2021). Students can construct mathematical models from everyday

problems they encounter. Transformation of problems in daily life into mathematical models can be learned by students in algebraic material.

Algebra is a branch of mathematics. Algebra has become an important aspect in student success at the high school and postsecondary levels. As the "gatekeeper" to postsecondary education, the skills and concepts necessary to successfully complete high school mathematics instruction (Bryant et al., 2020). The general properties of mathematical operations are proven for every other non-numerical mathematical object number in algebraic material. Quantity values are denoted by a letter to generalize results, show the rules and laws that apply to the operations performed, and learn how to change a form of expression and how to solve equations (Ibragimov & Kattaxo'jaeva, 2022). Algebra is a mathematical science that studies mathematical modelling, patterns and rules related to manipulating abstract symbols (Septiyana et al., 2023). These characteristics allow students to use their creative thinking abilities. Students can provide various answers, various ways and novelty in solving the problems given, so they can develop their creative thinking abilities. As stated by Torrance, the main components in creative thinking are flexibility, fluency and originality. The ability to "change the method" and not be bound by an established method once it is no longer working efficiently is called flexibility. The number of original ideas generated is called fluency. Originality means that rare answers, which occur only occasionally in a given population, are considered original (Astutik et al., 2020; Bhat & Siddiqui, 2017; Sitorus, 2020).

Students certainly have different creative thinking abilities that have an impact on their creativity in solving problems (Athifah & Syafriani, 2019). Mathematics learning contains several abstract concepts, causing both students and teachers to experience difficulties. This is also one of the factors causing students to be less active in communicating in class, which ultimately has an impact on their ability to think creatively. Teachers play an important actor in developing the creative thinking of students (Kampylis et al., 2009). This is in accordance with Mahayana (2020) stated that teacher's mastery of creative thinking abilities is an important factor that can have an impact on students' ability in creative thinking.

One aspect that plays an important role to improve the ability to think creatively in algebra is the aspect of flexibility in solving problems. Flexibility is considered unique because it is connected to working memory capacity due to the tasks given to produce various answers (Weiss & Wilhelm, 2022). This is further strengthened by the research results of Nuraida & Sugilar (2023) which stated that flexibility can influence higher-order thinking skills, one of which is creative thinking. The ability of flexibility allows students to persist in facing problems that are difficult to solve by utilizing previous knowledge. Retrieving information that has been stored in long-term memory can stimulate the mind to open up and produce other alternative solutions. Furthermore, this flexibility ability encourages students to be able to produce several alternative solutions.

Prospective mathematics teachers need to have this flexibility in solving mathematical problems. Flexibility of prospective mathematics teachers in mathematics is important because it can show the extent of the methods that prospective mathematics teachers have mastered which will later be used as a provision in teaching how to solve mathematics problems for their students. Furthermore, researchers can find out the extent of flexibility of prospective mathematics teachers in solving algebra problems and what factors are taken into consideration by prospective mathematics teachers in choosing and determining methods for solving the algebra problems. In this research, the algebra problem

that will be analyzed is related to how to solve a system of linear equations.

METHOD

Participants

Participants in this research were prospective mathematics teachers in the mathematics education study program at Universitas Islam Sultan Agung who had received linear algebra material. The population in this study was 97 prospective math teachers divided into 3 classes. The sample in this study was 36 prospective mathematics teacher who were determined based on recommendations from lecturers teaching algebra courses with the consideration that students could represent their creative thinking in solving systems of linear equations.

Research Design and Procedures

This research design is descriptive qualitative research which describes the flexibility of prospective math teachers in solving systems of linear equations. The first step in this research was to provide creative thinking test questions regarding systems of linear equations. Furthermore, from the results of the work of prospective math teachers in working on creative thinking test questions on systems of linear equations, observations were made of the results of the tests that had been carried out, then in-depth interviews were conducted with 6 people. Structured in-depth interviews are based on open-ended interview guidelines, so that the questions asked can develop according to the interview process between researchers and prospective math teachers to obtain clearer and more detailed information regarding their flexibility in solving systems of linear equations.

Instrument

The instruments in this research consist of the main instrument and supporting instruments. Researchers as the main instrument will collect, process and interpret data (Creswell, 2014). Supporting instruments are tests and interview guidelines. The test used consists of one question related to solving a system of linear equations that meets the indicators of flexibility in creative thinking. Flexibility refers to the number of ways that can be used to solve problems. This question has been validated by a vector algebra lecturer where it meets the flexibility indicators. Structured and open interview guidelines have also been prepared based on flexibility indicators.

Data Analysis

Analysis of all data in this study was carried out in 3 main steps, namely data reduction, data presentation, and conclusion drawing or data verification (Asipi et al., 2022; Creswell & Poth, 2016). Data reduction includes simplifying data obtained from tests and interviews to get important points in research. Presentation data is shown using tables to make it easier to show the information obtained. The final stage is to summarize the overall data. The validity of data in qualitative research is demonstrated by fulfilling credibility, transferability, dependability and certainty.

RESULT AND DISCUSSION

After analysis of the data test, the researcher find out there are six methods made by prospective mathematics teachers' to describe flexibility in solving the system of linear equations problem. An explanation of the six methods used by prospective math teachers is as follows.

Substitution Method

The substitution method is a method to solve one equation to find the value of one of the variables and then substitute the result into another equation. Through the substitution method, a pair of linear equations can be converted into one linear equation using only one variable which can

then be solved more easily and get definite results for each variable. This is in accordance with research results. The advantage of using the substitution method is that this method provides exact values for the variables (x and y) that correspond to the intersection points. Deogratias (2022) in his article said that the substitution method is one of the methods commonly used in secondary schools.

Elimination Method

Elimination method which is also commonly used in secondary schools (Deogratias, 2022). The way to solve a system of linier equations is by eliminating one of the variables to determine the value of the other variable. However, because the basic operations in the elimination method are based on row-to-row, column-to-column transformations, or equation-to-equation transformations, this method requires many operations when we encounter a more significant system of equations or matrices. Ultimately, this method will be a complicated process.

Combination of Elimination and Substitution

This method combines the elimination method and the substitution method at the same time in solving a system of linear equations, namely. The first step taken in this method is to eliminate a variable. Next, the elimination results obtained are substituted for other variables in an equation. By using these two methods, you can get results from solving systems of linear equations more quickly for small matrices.

Invers Method

The inverse method is carried out by entering and multiplying both sides $AX = C$ by A^{-1}, so that we get $A^{-1}AX = A^{-1}C$, which produces a solution to the system of linear equations, namely $X = A^{-1}C$. However, the matrix inverse method has several disadvantages as also stated by Maharaj (2018). The inverse method can only be used if the number of linear equations in the system and the number of variables are the same. Additionally, the inverse of the coefficient matrix must exist.

Gauss Jordan Elimination Method

The algorithm for this method in solving systems of linear equations is carried out by performing row operations on the appropriate coefficient matrix. A series of row operations are carried out to modify the matrix, including scalar multiplication of a row, swapping rows, and scalar multiplication and addition. Therefore, the Gauss Jordan elimination method is an effective method with the lowest level of complexity. So, for large matrices this method has many advantages. The Gauss Jordan elimination method can also be applied to non-square matrices (i.e. equations with an unequal number of variables and equations). In addition, if there are multiple solutions (the number of solutions is unlimited), then this method can provide all existing solutions. Gharib et al. (2015) further stated that Gauss Jordan elimination is faster than other methods of solving systems of linear equations and has been used in various fields of science where complex systems of linear equations are calculated.

Cramer Method

Cramer's rule is carried out by converting a system of linear equations into matrix form. Determinants determine an important role in solving the system of linear equations. Let Has $n \times n$ matrix, the determinant of the matrix is denoted by or , is assumed to be the unique solution to the system of linear equations , where is a constant vector (). Then, replacing one column with , is the determinant of this new matrix. Repeating this to all columns, so we use the formula:

$$Y_n = \frac{\det(H_n)}{\det(H)} \text{ for n= 1, 2, 3, …, n.}$$

The denominator is the determinant of the original matrix. And the numerator is the determinant of the matrix in which one of the columns is replaced by a constant vector (). This method can be used for a matrix. This is accordance with (Luo et al., 2021) which states that can only be used for small matrices. The advantage of this method is that the determinant can be calculated quickly using formulas for various types of matrices. Unlike the elimination method, Cramer's rule does not require entering one variable to find another variable. This method is relatively easy to handle small matrices. However, if the determinant is zero, Cramer's rule cannot be applied because the denominator is zero. The frequency of flexibility the prospective mathematics teachers in use six methods are shown in Table 1.

Table 1. Method of flexibilities made by prospective mathematics teachers

No.	Method of flexibilities	Frequency
1	Substitution Method	4
2	Elimination Method	20
3	Combination of Elimination and Substitution	36
4	Invers Method	12
5	Gauss-Jordan Elimination Method	36
6	Cramer Method	20

Table 1 describe that, all of prospective mathematics teachers have at least 2 flexibility methods to solve systems of linear equations, including using a combination of elimination and substitution and Gauss-Jordan Elimination. Apart from these two methods, 55% of prospective mathematics teachers were able to use the elimination method and the Cramer method. Furthermore, there are two more methods used by several prospective mathematics teachers, including the substitution and invers method.

The combined method of elimination and substitution and Gauss-Jordan elimination are the two methods most widely used by prospective mathematics teachers because these two methods are considered effective for solving systems of linear equations more efficiently than other methods. It is seen in Dialogue 1.

Dialogue 1

Researcher : *Why have you use the combined method of elimination and substitution in solving systems of linear equations?*

Prospective math teachers : *Because the combination of these two methods makes it possible to solve systems of linear equations more efficiently. The elimination method helps eliminate one of the variables gradually, while the substitution method makes it possible to replace the eliminated variable into another equation to find the correct solution. Both work together to provide a systematic and effective approach to completing systems of linear equations.*

Researcher : *Next, why do you use the Gauss-Jordan elimination method for the second method?*

Prospective math teachers : *Gauss-Jordan Elimination method has been frequently used because it provides a systematic approach to finding systems of linear equations solutions by converting the coefficient matrix into a reduced echelon form or identity matrix. This makes it possible to find the systems of linear equations solution directly without the need to perform additional steps such as in the*

combined elimination and substitution method. This method also provides advantages in finding unique solutions and identifying cases of infinite systems of linear equations or no solution. Thus, Gauss-Jordan Elimination is a popular choice due to its efficiency in solving systems of linear equations with high clarity and accuracy.

Researcher : *Why did you use a combination of substitution and elimination in the first method? Is the method you have used easier?*

Prospective math teachers : *Because I am used to using a combined method of elimination and substitution. The Gauss-Jordan Elimination method is taught at college level, while the elimination and substitution method has been taught at school level, so it is likely that someone will be more proficient and comfortable using elimination and substitution method than using Gauss-Jordan Elimination method.*

Based on dialogue 1, information was obtained that, although the combined method of elimination and substitution and the Gauss-Jordan elimination method were both effective and efficient to use, prospective mathematics teachers felt more familiar with the combined method of elimination and substitution. This is because this method has been taught starting from school level. As the results of research by Brewer & Unsworth (2012) stated that there is an effect of calling up memory that is more easily accessed to solve problems faced if the memory has been stored in long-term memory. Furthermore, Lyle et al. (2019) explained that the use of retrieval strategies to improve memory is known as retrieval practice. Teachers can exert considerable control over students' retrieval practice, by determining when and how much students practice. The more students do practice, the easier it is to retrieve memories from long-term memory.

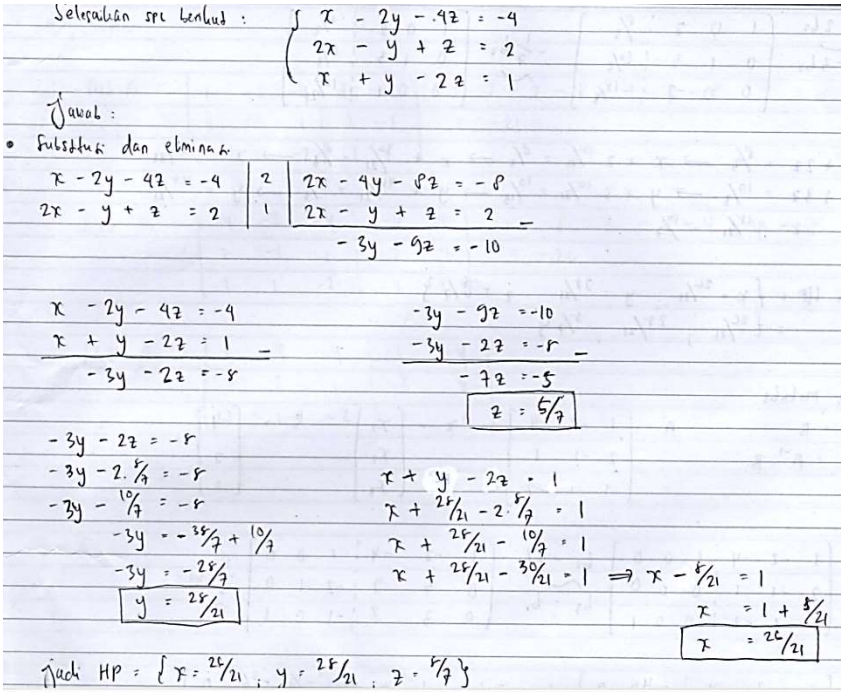

Figure 1. The combined method of elimination and substitution in solving systems of linear equations

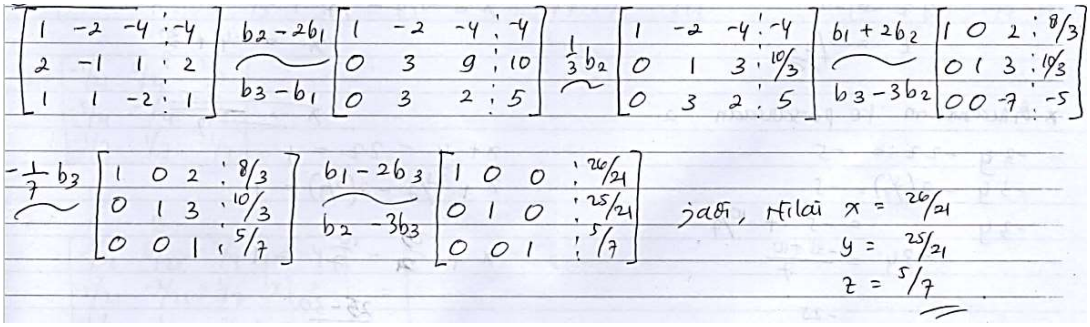

Figure 1. The combined method of elimination and substitution in solving systems of linear equations

Figure 1 and figure 2 present the solution of a system of linear equations using a combined method of elimination and substitution and the Gauss-Jordan elimination method. Both methods use 5 solving steps to obtain the final result, so both can be said to be more effective and efficient in solving systems of linear equations compared to other methods which require more and longer steps. However, if the variables being searched for in a system of linear equations are more than 3 variables the Gauss-Jordan elimination method will be more effective because the processing steps are simpler than using a combined method of elimination and substitution. This is in accordance with the research results of Mandal et al. (2021) which stated that the best and easiest method to use for solving systems of linear equations is the Gauss-Jordan elimination method. The characteristic of the Gauss-Jordan elimination method is reduction to an upper triangular matrix which can be processed in matrix columns (Tiruneh et al., 2019). By changing the original matrix of the system of linear equations into a triangular matrix, it will be easier for us to determine the solution results.

The next methods for solving systems of linear equations that are quite dominantly used by prospective mathematics teachers are the elimination method and the Cramer method. The elimination method and Cramer's method are considered effective for few variables and most people tend to use this method because it is more flexible to apply. However, the elimination method can become complicated if the system of linear equations has many variables or the coefficients have complex values. Meanwhile, Cramer's method requires calculating determinants, which becomes inefficient and complicated when dealing with systems of linear equations with many variables or having large coefficient matrices. The Cramer method itself uses a determinant basis, which means someone must also understand the concept of determinants if they want to work using the Cramer method. This is in line with (Babakordi & Allahviranloo, 2022) who said that there are many challenges in solving systems of equations, such as a lack of solutions, inaccurate or even wrong solutions because they do not utilize all available information, complicated processes, and high computational burdens.

The results of the analysis of the use of the elimination method and the Cramer method found that the factor that prospective mathematics teachers consider in solving systems of linear equations is how effective and efficient they are when using these methods. This is relevant to research by Pongsakdi et al. (2019) which shows that numerical factors are one of the factors that influence students in solving problems. Numerical factors in solving problems include number properties, required operations, and the number of solving steps.

The research results also show that the substitution method and inverse method are

methods that are rarely used by prospective mathematics teachers in solving systems of linear equations. Prospective mathematics teachers assume that these two methods have a higher level of difficulty compared to the other four methods. The results of interviews with prospective mathematics teachers regarding the reasons why they do not use the inverse method and the substitution method can be seen in Dialogue 2.

Dialogue 2

Researcher : Why didn't you use the substitution method and inverse method in solving systems of linear equations?

Prospective math teachers : Substitution methods often require complex steps to find variable values one by one, which can be impractical especially in SPLs that have many variables. Meanwhile, the inverse method requires calculating the inverse of the coefficient matrix, which can be difficult or even impossible, especially in the case of systems of linear equations which have a coefficient matrix that cannot be inverted. Additionally, matrix inverse calculations also require a lot of mathematical operations, which makes them inefficient in situations where speed and efficiency are essential.

Based on Dialogue 2, information was obtained that numerical factors are still a factor causing prospective mathematics teachers not to use a method in solving problems. Large systems of linear equations cannot be easily solved because they require more time and energy to solve.The more variables to be searched for in a system of linear equations required a greater number of operations and stages of completion. Therefore, prospective mathematics teachers tend to choose effective and efficient methods to be able to solve systems of linear equations in a shorter time and with simpler stages.

Various methods for solving systems of linear equations depend on speed and accuracy as both are important factors in solving large systems of equations. Large systems of linear equations cannot be easily solved because they require more time and energy to solve (Borzykh, 2019; Meghwar et al., 2024). As the results of research conducted by Mandal (2021) show that the number of calculations involved in determining the solution is the main thing. Solving systems of linear equations can be considered a slow process for large systems of equations and requires special treatment to avoid calculation errors.

The results of research related to the flexibility aspect of prospective teachers' creative thinking in solving systems of linear equations have shown that numerical factors are the main factors that influence prospective teachers in determining the flexibility of the methods to be used in solving systems of linear equations. Numerical factors in solving a system of linear equations include the number of variables of the system of linear equations to be searched, the number of operations that will be used to find the solution and the number of solution steps that will be carried out.

■ CONCLUSION

The results of this research show that prospective mathematics teachers have 6 methods that can be used as a flexible way to solve systems of linear equations. There are three numerical factors that influence the flexibility of prospective mathematics teachers in solving systems of linear equations. First, the number of variables to be searched in the system of linear equations. Second, the number of operations that will be used in the process of solving systems of linear equations. Lastly, the number of steps that must be taken in the process of solving a system of linear equations.

The impact of this research is that lecturers can find out what factors students consider in choosing the method used to solve systems of linear equations. These results will be the best reason for lecturers in determining appropriate

learning trajectory on systems of linear equations and implementing the learning design to solve systems of linear equations for the next research. This research has a drawback, namely that it is limited to problems with systems of linear equations that must be solved with the same number of variables and the same number of linear equations. Other research can be developed for systems of linear equations that have a different number of variables and a different number of linear equations. Research can also be carried out for more complex systems of linear equations.

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