



Open-Open Problem Solving Strategy

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Abstract

Open-open problem are task that are open in both process and solution. This descriptive qualitative research aimed to identify strategies and responses to open-open problem solving. The subjects of this research were 54 students of Mathematics Education from the Universitas Khairum Ternate: 12 students from the 2017/2018 batch, 10 students from the 2016/2017 batch, and 32 students from the 2015/2016 batch. The instruments of this research were one open-open essay question and semi-structured interviews. The technique used in the research was the data resource triangulation technique. According to the students' work results, there are 5 strategies of problem solving: 1) Drawing strategy; 2) Arithmetic strategies such as a) direct guessing with trial and error, b) direct counting with algebraic operations like addition, subtraction, multiplication, and division, c) number patterns, and d) repeated addition; 3) Analogy strategies for variable determination such as a) the variable strategy in arithmetic, b) linear equation strategy system, and c) linear inequality; 4) Formula-Making Strategy; and 5) Narrative Strategy

Key Words: Open-open Problem, Problem Solving Strategy.

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Introduction

Mathematics includes solving problems, doing word problems, creating patterns, interpreting figures, developing geometric construction, proving theorems, etc. In teaching and learning mathematics, it is important to develop the ability to solve mathematics problems, particularly for problems in daily life. Students can apply useful knowledge and problem-solving skills in daily life, since the process of solving a mathematical problem is similar to general problem solving (Carpenter, 1988; Kannan, Sivapragasam, & Senthilkumar, 2016; Otten, 2010). Problem solving emphasizes developing thinking skills like creative thinking skills, and critical thinking skills (Kim & Pegg, 2019). This means that mathematics should be applicable to a variety of unfamiliar situations (Kannan, Sivapragasam, & Senthilkumar, 2016). Therefore, problem solving is the most important research topic in the field of mathematics teaching (Sawada, 1999). In order to develop mathematics problem-solving skills, a mathematics teacher needs to provide various kinds of mathematics problems. Preservice teachers (PTs) need to experience a

variety of problem-solving experiences and gain insights into the nature of problem solving before they can adequately understand the perspectives of [4101](#) their future students as problem solvers (Capraro, An, Ma, Rangel-Chavez, & Harbaugh, 2012). Mathematics problem can be classified in Figure 1 (Yee, 2000).

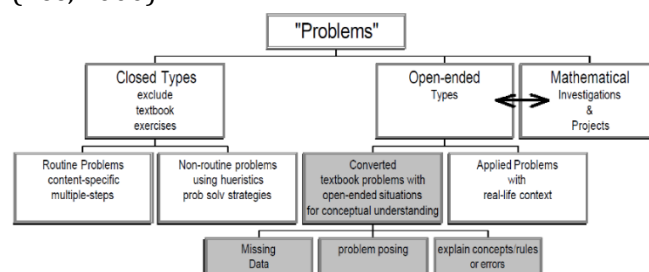


Figure 1. Mathematics Problem Classified Schema

Based on Figure 1, one type of mathematics problem is the Open-ended Problem.

To maximize mathematics learning, open questions need to be used because open problems have rich potential to improve the quality of learning (Barham, 2019; Csikos & Sztitanyi, 2019; Guzman, 2018; Keh, Ismail, & Yusof, 2016; Mahmudi, 2008).

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Open problems are divided into 3 types: 1) Open-ended problems; 2) Semi-open-ended problems; and 3) Open-open problems. Open-ended problems have been regarded as powerful tools for teaching mathematics. These problems formulate the answer so that there is more than one solution or more than one way of solving (Cifarelli & Cai, 2005; Csikos & Szitanyi, 2019; Feijs & De Lange, 2004; Simada & Becker, 1997; Tambunan, 2019; Yew, Lian, & Meng, 2017). Several criteria for open-ended questions: 1) problems are rich in valuable mathematical concepts; 2) the level of the questions or math should be suitable for the students; and 3) the problems should invite the development of further mathematical concepts (Suherman, 2003). In semi-open-ended problems, students are encouraged to pose their own problems to open situations. Semi-structured problem-posing as “mathematical investigations.” This contrasts with a free or open-ended approach in which students pose any problem. In a semi-structured approach, an open situation is presented and students are encouraged to investigate it using prior knowledge (Barham, 2019; Capraro, An, Ma, Rangel-Chavez, & Harbaugh, 2012; Popham, Adam & Hodge, 2019). The term open-open refers to a task that is open in both the process used and solution found. In an open-open problem, the answer can be in the form of numbers, graphs, or formulas and several strategies can be used to find the answer. The scoring of open-open task offers a good opportunity to assess and develop students’ understanding. Thus, high-level students’ will differ in their descriptions of an open-open problem. The format of this task offers students many ways of problem solving, thereby enabling bigger ideas to emerge from the problem’s components.

Open-open problems are designed by teachers and curriculum developers to illustrate how a problem can be modified to produce an answer with different strategies. Open-open tasks therefore offer the opportunity to use different solution strategies and many mathematical concepts. Thus, they can be used as final assessment tasks for all levels: they can be used in balanced contexts, tests starting with easy problems, different representation models, and formal and informal combinations. In addition, open-open tasks are designed to evaluate students’ understanding of the material and whether they can apply the material to more complex problems. Thus, an open-open task designer wants the test to be realistic and simple. Open-open tasks make it

possible to measure whether students understand the main subject and can offer the chance to demonstrate real problem solving. In an open-open task, students use their own words to arrive at different correct solutions using various strategies. These tasks have several characteristics: 1) the context is familiar to students; 2) clear and simple wording; 3) easy problems; 4) appealing to students. The students are challenged by solving the problems and they have the opportunity to perform various strategies to do so. The richer and more open the problem, the more ways that students can express their levels of understanding and skills.

Methodology

This research was descriptive and qualitative. The subjects of this research were students majoring in Mathematics Teaching at the Universitas Khairun Ternate from three different batches: 2017/2018, 2016/2017, and 2015/2016. The research did not include all students. Purposive sampling was used to select subjects from these three batches for analysis. In total, 54 students were chosen as subjects for this research. The subjects included 12 students from the 2017/2018 batch, 10 students from the 2016/2017, and 32 students from the 2015/2016 ⁴¹⁰² batch. The techniques for data collection were an essay test and semi-structured interviews. The following open-open question was given to the subjects. The essay test is

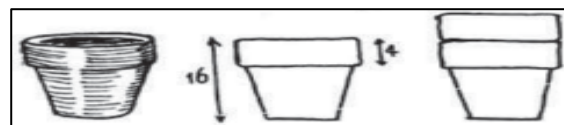


Figure 2. Open-open Question

Result and Discussion

The subjects’ open-open problem-solving strategies can be categorized into several types: 1) Drawing strategy; 2) Arithmetic strategies such as a) direct guessing with trial and error, b) direct counting with algebraic operations like addition, subtraction, multiplication, and division, c) number patterns, and d) repeated addition; 3) Analogy strategies for variable determination such as a) the variable strategy in arithmetic, b) linear equation strategy system, and c) linear inequality; 4) Formula-Making Strategy; and 5) Narrative Strategy. Below are explanations of each problem-solving strategy given to the open-open question.

Drawing Strategy

In the drawing strategy, students understand and finish the open-open question using the picture of

pots in a stack. Figure 3 below shows an example of a student using this strategy.

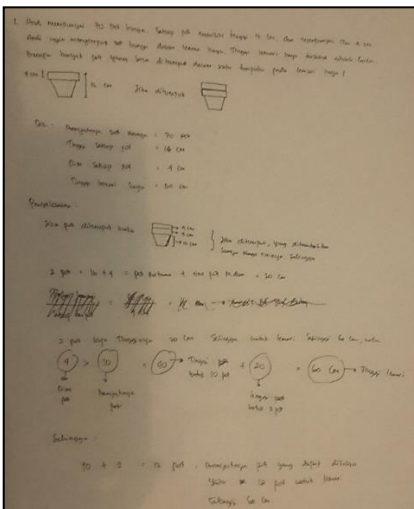


Figure 3. Drawing Strategy in solving the Open-open Question

Figure 3 shows that the student drew the pot to follow the directions and understand the question. The student interpreted 2 pots being stacked so that the height of the pot is $16 + 4 = 20$ cm. Next, the student related the pots' heights with that of the wooden wardrobe. The next step was to determine the number of pots stacked and calculate the height of the rims of the stacked pots. The student thought that if 2 pots were 20 cm tall and the height of the wardrobe was 60 cm, the remaining height of the wardrobe would be $60 - 20$ cm = 40 cm. Therefore,

the student divided the remaining height of the wardrobe with the rim height of the pot to be $10 \text{ pot} \times 4 \text{ cm} = 40$ cm. After that, the student added the height of 2 pots: $40 + 20 = 60$ cm (wardrobe's height). Finally, the student concluded that the number of pots that could be stacked in the wardrobe was $10 \text{ pots} + 2 \text{ pots} = 12$ pots. In order to check the answer, the student compared the rim's height from 10 pots stacked together and the wardrobe's height. This student described the open-open problem with a picture of two pots then found the relation between the rim's height and the wardrobe's height in order to solve the number of pots than can be stacked into the wooden wardrobe.

Arithmetic Strategy

To solve the open-open problem, some students used arithmetic strategies. These strategies can be categorized into several types: a) guessing directly with trial and error; b) calculating directly with algebraic operations like addition, subtraction, multiplication, and division; c) number patterns; and d) repeated addition. Below are some examples of students' work using arithmetic strategies.

Trial and Error

In this case, the student directly guessed the number of pots that could be stacked without calculating or giving any meaningful reason for the answer. Some examples of students' work are below.

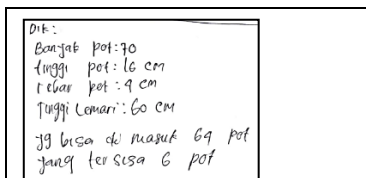


Figure 4. Incorrect Guessing Strategy

Figure 4 shows a student guessing the height of 64 stacked pots that could be inserted into the wardrobe with 6 remaining pots. The students guessed that 64 pots could be inserted into the wardrobe from $16 \times 4 = 64$. The student interpreted this result as meaning that the wardrobe could contain only 64 pots, with 6 pots remaining.

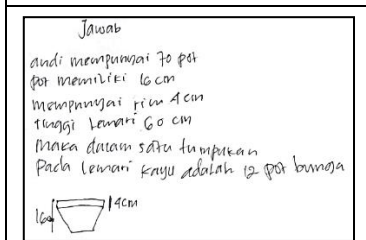


Figure 5. Correct Guessing Strategy

Figure 5 shows a student guessing that 12 pots could be stacked in the wardrobe. The student reasoned the answer from the picture the student drew: one pot is 16 cm tall and the rim is 4 cm tall. The reason for this was that the student guessed these 12 pots using calculations not mentioned in the answer sheet: one pot is 16 cm tall with a 4-cm rim, so 2 pots are 20 cm tall. As the height of 2 pots is 20 cm, the amount of stacked pots needed in order to fulfil the wardrobe is $2 + ((60-20)/4) = 2 + 10 = 12$ pots.

Calculating Directly with Algebraic Operations

In this strategy, the student detects the information in the question then calculates using algebraic operations such as addition, subtraction, multiplication, and division. An example of a

student's work can be seen in the image below.



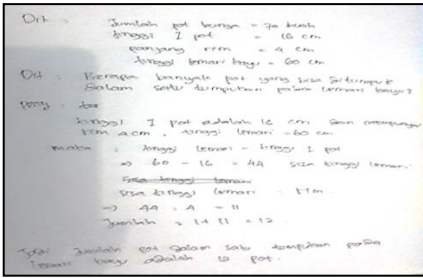


Figure 6. Calculation Strategy using Algebraic Operations

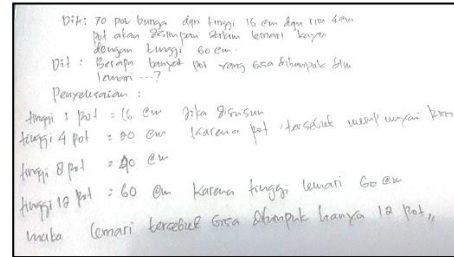


Figure 7. Correct Number Pattern Strategy

Figure 6 shows that the student tried to solve the problem using the arithmetic strategy by applying algebraic operations. The student created a formula that relates the wardrobe's height with the pot's height, which was the wardrobe's height - a pot's height. The result was $60 - 16 = 44$ cm. The student interpreted the result as the remaining space in the wardrobe. Then, the student determined the height of the stacked pots and counted the rim's height from the stack. The student calculated the remaining space, which is 44 cm, divided by the rim's height: $44/4 = 11$ pots. Lastly, the student concluded the amount of the pots stacked in the wardrobe is 11 pots + 1 pot = 12 pots.

Number Patterns

Figure 7 shows an example of using a geometric number pattern. Student tried to solve the problem by reasoning the result with words and forming number patterns. First, the student stated that a pot's height is 16 cm and the stack of 4 pots' height is 20 cm by reasoning that the pot has a rim; then the student continued by determining that 8 pots' height is 40 cm and 12 pots' height is 60 cm. The student's logic was that 4 pots have the same height: according to the student, 4 pots' height is 20 cm, so the next 4 pots' height is $20 \text{ cm} + 20 \text{ cm} = 40 \text{ cm}$; another 4 pots gives the result $40 \text{ cm} + 20 \text{ cm} = 60 \text{ cm}$. The result for 12 pots (4 pots x 3 stacks) was compared with the wardrobe's height. Finally, the student concluded that 12 pots could be stacked in the wardrobe. A similar logical way of thinking was used by other students, as shown Figure 8.

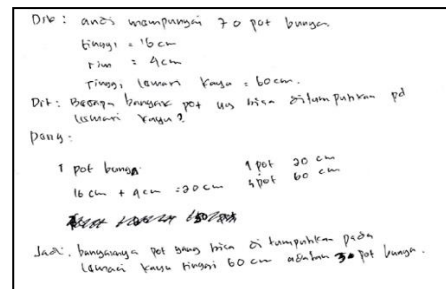


Figure 8. Incorrect Number Pattern Strategy

Repeated Addition

Figure 9 below shows that the student used the repeated addition principle on the pot rim's height, as well as the number sequence concept. In this context, the first term was the pots' height, which was 16 cm. Each pot was named pot 2, pot 3... pot 12. Then, the student combined the repeated addition concept to the rim's height and the pot's height on the first term using the known wardrobe's height. Finally, the student concluded that the number of pots stacked in the wardrobe was 12 pots. Below is another example of a student who used the repeated addition strategy.

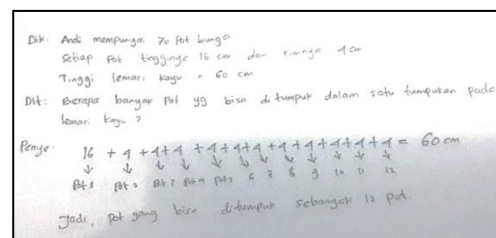


Figure 9. Repeated Addition and Number Pattern Strategy

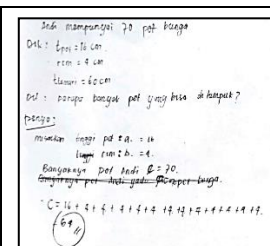


Figure 10. Repeated Addition Strategy

Figure 10 shows that the student used the repeated addition principle on the pot rim's height. In this context, the first term was a pot's height, which was 16 cm. Then, the student did repeated addition on the pot rim's height, $4+4+4+...+4$, up to 12 times. Next, the student calculated the overall height, which was 64 cm ($16 \text{ cm} + (12 \times 4) = 64 \text{ cm}$). The student did not relate this with the wardrobe's height but directly decided the number of pots that could be stacked where each stack consisted of 13 pots and the overall height of the stack was 64 cm.



The following table shows the results of students' who used arithmetic strategies.

Table 1. Arithmetic Strategy for Open-Open Problem

	Response Category	Student
Correct Answer	a. Trial and Error	3
	b. Calculating with algebra	1
	c. Number patterns	1
	d. Repeated addition	2
Incorrect Answer	e. Trial and Error	1
	f. Calculating with algebra	25
	g. Number patterns	1
	h. Repeated addition	0
No Answer		7

question, then continued by using algebraic operation similar to the comparison concept, as in Figure 11 below.

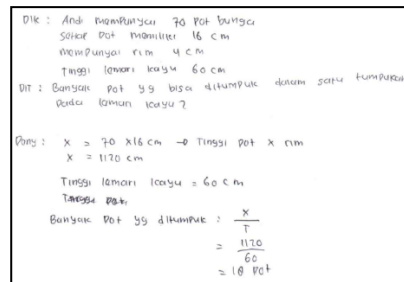


Figure 11. Variable Strategy in Arithmetic

Analogy Strategies for Variable Determination

Analogy strategy, in this context, means that the students make a variable analogy in the open-open question and continue it by forming a mathematical model from the problem given. Some students only did the analogy then continued with algebraic operations. In contrast, other students made linear equation systems or linear inequality systems from the open-open problem. Therefore, analogy strategies are divided into 3 categories: a) variable strategy in arithmetic; b) linear equation system strategy; c) linear inequality strategy.

Variable Strategy in Arithmetic

This means that the students determined the influential and known variable in the open-open

Figure 11 shows that the student used analogy x for the overall pots' height and the student determined the value of x as $70 \times 16 \text{ cm} = 1120 \text{ cm}$. In order to identify the number of pots in the stack, the student used the formula x/T where T is the wardrobe's height: $1120/60=18$. Consequently, the student calculated by determining the pots' height then dividing this with the wardrobe's height. The student rounded down to 18 pots. In the student's mind, the pots were stacked without considering the pot rim's height. So, if there were 70 pots, then the pot's height would be 1120 cm dividing this by the wardrobe's height gave 18 pots. Other students used the analogy strategy with the comparison concept, as follows.

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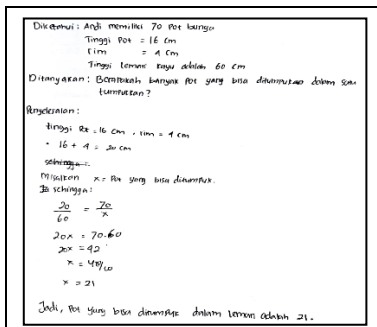


Figure 12 shows that the student used analogy x as the number of pots that could be stacked. Then, the student did the comparison: $\frac{20}{60} = \frac{70}{x}$. The comparison shows that $\frac{\text{a pot's height}}{\text{wardrobe's height}}$ is equal to $\frac{\text{overall number of pots}}{\text{the number of pots stacked}}$. Therefore, the student did the grouping for the pot's height divided with the wardrobe's height: the overall amount of the pots was divided by the amount of pots that can be stacked. In this context, the student assumed that both comparisons are equal. The result was $x = 21$ pots.

Figure 12. Variable Strategy in Arithmetic

Linear Equation System Strategy

This means that after using the analogy to determine the variable in the open-open problem, the student

continued by forming a linear equation system. Some examples of students' work follow.

Figure 13. Two-Variable Linear Equation System Strategy Type 1

Figure 13 shows that the student made analogy x the number of pots and y as the amount of the pot's rim. In this case, the student considered a 3-variable linear equation system. The student formed a mathematical model $\begin{cases} 16x + 4y = 70 \\ x + y = 60 \end{cases}$ that gave $y = 7$ without determining x .

In contrast to the answer in Figure 13 above, other students answered as follows.

Figure 14. Two-Variable Linear Equation System Strategy Type 2

Figure 14 shows that the student made analogy x the flower pot's height and y the wardrobe's height. The mathematical model formed was $\begin{cases} 16x + 60y = 70 \\ x + y = 70 \end{cases}$ with the result that $y = 1$ and $x = 1$. The analogy was inconsistent and wrong, so the linear equation system was also incorrect.

Linear Inequality Strategy

the linear inequality concept, as shown below.

One student solved the open-open question by using

Figure 15. Three-Variable Linear Inequality Strategy

Figure 15 shows that the student made analogy x the number of flower pots, y the height of the pots' rims, and z the wardrobe's height. The mathematical model was $16x + 4y + 60z \leq 70$, which gave the result that *If $x = 0$ then $y = 17.5$ and if $y = 0$ then $x = 4.3$* ; the value of z was not yet determined. This mathematical model was incorrect.

For the Analogy strategy with the variable composition, Table 2 shows that no students did it correctly.

stacked, the pot's height, the pot rim's height, and the wardrobe's height. Below is an example of a student's work using a formula.

Table 2. Arithmetic Strategy for Open-Open Problem

	Response Category	Student
Correct Answer	a. Variable in Arithmetic	0
	b. Linear Equation System	0
	c. Linear Inequality	0
Incorrect Answer	a. Variable in Arithmetic	7
	b. Linear Equation System	4
	c. Linear Inequality	1
No Answer		1

Figure 16 shows that the student tried to analyze the relation between the total number of pots, the pot's height, the pot's rim, and the wardrobe's height using the formula shown below.

$$\frac{\text{Total Pots} \times \text{Pot's Height} + \text{Pot's Rim}}{\text{Wardrobe's Height}}$$

Formula-Making Strategy

In this strategy, the students used a formula to solve the open-open problem. The formula reflects the relationship between the total number of pots



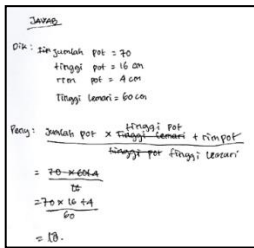


Figure 16. Formula Making Strategy

The result from the formula was 18 pots. The student stated that he or she would determine the overall pots' height, so the first formula formed by the student was the number of all pots multiplied by the height of a pot. For the height of a pot, the student added a pot's height to the rim's height: $70 \times (16+4)$. Then, the student divided by the wardrobe's height, resulting in the number of pots in the stack. Overall, 4 students solved the open-open question by using a formula. The rest were unable to design the formula correctly, so the results were all wrong.

Narration Strategy

The narration strategy means that the students solved the open-open question by interpreting or reasoning it. This strategy begins informally and then later becomes formal. Some students reasoned correctly and others could not. Four students solved the open-open question by using narration to reason and understand the question. One of these four students had the correct understanding and reasoning to solve the open-open question; the rest did not correctly solve the question. Below is an example of a student using reasoning to solve the open-open question.

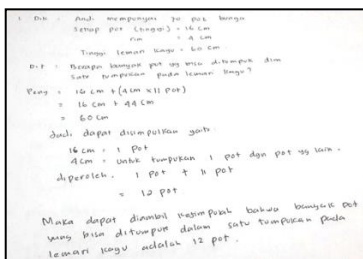


Figure 17. Formal Strategy with Correct Narration

Figure 17 shows that the student tried to solve the problem formally by directly using the algebra operation combined with an explanation. First, the student directly associated the problem with the mathematical model $16 \text{ cm} + (4 \times 11 \text{ pots})$. The student formed the algebra equation using addition and multiplication operations. The student formed the algebra equation by finding the relation between 16 cm (the pot's height), 4 cm (the pot rim's height), and 60 cm (the wardrobe's height). Then, the

student gave an analogy for 16 cm (the pot's height) and 4 cm (for 1 stack of a pot with another pot) and continued it by adding 1 pot + 11 pots = 12 pots. Finally, the student concluded that the number of pots that could be stacked in the wardrobe is 12 pots. The student reasoned correctly for the open-open question. However, some students could not do the reasoning correctly, as shown below.

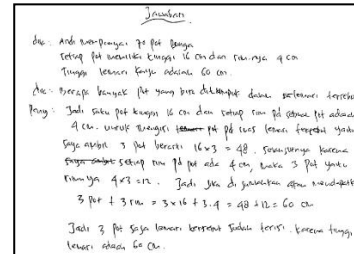


Figure 18. Incorrect Narration Strategy

Figure 18 shows that the student reasoned that the pot's height is 16 cm and each pot rim's height is 4 cm. Then, the student assumed by taking 3 pots. Based on this assumption, the student determined the pots' height as $3 \times 16 \text{ cm} = 48 \text{ cm}$ and the rim's height as $3 \times 4 \text{ cm} = 12 \text{ cm}$. Both of these measures were added to give the result $48 \text{ cm} + 12 \text{ cm} = 60 \text{ cm}$, which equals the wardrobe's height. The student's logic was that the wardrobe could be filled with the stack of 3 pots with a height of 60 cm. Therefore, each stack has 3 pots

As said above, open-open problem solving consists of 5 strategies: 1) Drawing Strategy; 2) Arithmetic Strategy; 3) Analogy Strategy for Variable Determination; 4) Formula-Making Strategy; and 5) Narration Strategy. In the Drawing Strategy, the students drew the pot and its stack to understand the problem, then related it to algebra. In the Arithmetic Strategy, the students did direct calculations based on reasoning or just guessing randomly. This strategy covers: a) direct guessing with trial and error; b) direct counting with algebraic operations like addition, subtraction, multiplication, and division; c) number patterns; and d) repeated addition. In the Analogy Strategy for variable determination, the students determined the problem of the variable by making an analogy with a lowercase symbol. After determining the research variable, the students formed linear equations or inequalities or they directly did the arithmetic. Therefore, this strategy covers: a) the variable strategies in arithmetic, b) the linear equation system strategy, and c) the linear inequality strategy. In the Formula-Making Strategy, the students identified things known in the open-open problem then formed mathematical models. Many



students made mistakes in forming the mathematical models. In the Narration Strategy, the students described their reasoning related to the open-open problem then related this with a mathematical concept. Some students were correct in reasoning, but other students still made mistakes. The results of the research slightly differ from other research like (Barham, 2019; Feijs & De Lange, 2004; Guzman, 2018; Yew, Lian, & Meng, 2017). Especially open-open problem solving strategies, there are three strategies when students were faced with open-open questions (Feijs & De Lange, 2004): 1) informal solving using drawings; 2) arithmetic; and 3) pre-algebra, which covers a) the use of arrow language and b) the use of a tree representation. Compared to the previous research, the present research shows that students' open-open problem-solving strategies are more diverse. The students interpreted these open-open questions formally and associated them with the mathematical concepts they have learned. The students used formulas, linear equations or inequalities, number patterns, and arithmetic. Most students incorrectly formed math models to relate this everyday problem with mathematical concepts. This situation shows that problem-solving abilities are still low and the students experience difficulties in associating an everyday problem with mathematical concepts.

Conclusion

Based on the research results, there are five open-open problem solving strategies: 1) Drawing strategy; 2) Arithmetic strategies such as a) direct guessing with trial and error, b) direct counting with algebraic operations like addition, subtraction, multiplication, and division, c) number patterns, and d) repeated addition; 3) Analogy strategies for variable determination such as a) the variable strategy in arithmetic, b) linear equation strategy system, and c) linear inequality; 4) Formula-Making Strategy; and 5) Narrative Strategy.

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