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Analysis of Problem-Solving Behavior of Senior High School Students

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Abstract

Problem-solving behavior focuses on how students process to solve problems, while problem-solving ability is a student's ability to solve problems. Problem-solving behavior can identify students' problems in solving mathematical problems, so that students' mathematical problem-solving abilities are achieved as expected. Therefore, it is important for students to develop their problem-solving behaviors. By paying attention to problem-solving behavior, teachers can discover students' obstacles in solving problems. The study aims to describe the problem-solving behavior of students with low, medium and high ability levels. The subjects of the study were first-year senior high school students. The students were given mathematical problem-solving questions and then interviewed. Based on the interview transcripts, the students were grouped based on the problem-solving behavior rubric. However, a new category of problem-solving behavior, i.e., semi-routine, was proposed because the existing behavior categories did not fully represent the observed problem-solving behaviors. The results of this study showed that problem-solving behaviors are categorized into apathetic, semi-routine, routine, semi-sophisticated, and sophisticated. Aspects of problem-solving behaviors are knowledge ownership, control, beliefs, and affective. By improving students' problem-solving behavior, it is expected that students' mathematical problem-solving abilities will also improve.

Keywords: Apathetic, Semi-Routine, Routine, Semi-Sophisticated, Sophisticated

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INTRODUCTION

Behavior is a person's actions in response to an activity. It is not always associated with physical activity (Atkins et al., 2017; Chaput et al., 2020; Chen et al., 2016). In theory, behavior can be viewed as cognitive, affective, environmental, and social influences (Atkins et al., 2017; Kok et al., 2016; Oliveri & Reiss, 1981). In addition, behavior is a dimension of independent learning (Hawes & Ansari, 2020; Özcan, 2016). Students who have active behavior can choose, shape and create an ideal environment for their learning (Özcan, 2016; Zimmerman, 1989). One opportunity to observe student behavior is when students are solving mathematical problems (De Assis et al., 2020).

Students' mathematical problem-solving is one of the purposes of learning mathematics. Mathematical problem-solving is a student's ability to solve mathematical problems (Friedman et al., 2018; Fuchs et al., 2020; Ghadiri Nejad et al., 2018; Rohmah & Sutiarso, 2018; Susilo & Retnawati, 2018). In general, problem-solving is the process of applying current knowledge to novel circumstances (Özcan, 2016; Schoenfeld, 2016).

Problem-solving focuses not only on the end of the result, but also on the behavior of solving the problem. Problem-solving behavior is influenced by cognitive and affective constructions (Awofala & Ajao, 2021; Özcan & Eren Gümüş, 2019). Özcan & Eren Gümüş (2019) stated that cognitive and affective learning significantly influence each other (Rodríguez et al., 1996). Meanwhile, problem-

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solving behavior, according to Muir et al. (2008), involves the factors of "*knowledge acquisition and utilization, control, beliefs, affects, and socio-cultural contexts*".

Problem-solving is an important component of producing individuals who are capable of solving problems. To solve problems, students can combine mathematical concepts, use previous problems, and find new strategies (Muir et al., 2008; Özcan, 2016). Therefore, using appropriate problem-solving strategies is very important to improve problem-solving skills (DeCaro & Rittle-Johnson, 2012; Elia et al., 2009; Özcan, 2016). Usually, the problem-solving strategies suggested by researchers come from Polya (1973). In addition, the study of problem-solving behavior has implications for the teaching and learning process (Özcan, 2016).

For this reason, students are expected to be consistent in their mathematical problem-solving. Muir et al. (2008) suggested that "rather than focusing on whether and how a particular strategy teaches, educators should focus on examining what successful problem-solving "does" and then seek to develop individual problem-solving behaviors to achieve the goals". In reality, however, the standards for successful problem-solving are seen only from the final assessment, without explaining the process that students went through. Thus, in the learning process, teachers only focus on how to solve problems with appropriate strategies (Santoso & Syarifuddin, 2020; Suryani et al., 2020; Xin et al., 2020).

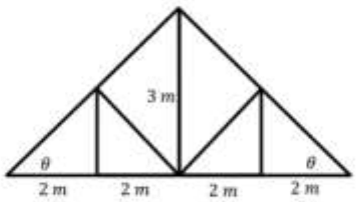
Previous studies (Adhimah et al., 2020; Harisman et al., 2021; Harisman & Khairani, 2021; Harun et al., 2019; Muir et al., 2008) investigated students' mathematical problem-solving behaviour. The results of the studies showed that the mathematical problem-solving behaviors of sixth grade elementary school students were categorized as naïve, routine, and sophisticated (Muir et al., 2008). However, in the study by Harisman et al. (2021), there was an additional category of problem-solving behavior, especially for junior high school students, which is semi-sophisticated. Thus, this study aims to discover how mathematical problem-solving behavior of students at the high school level and to discover new category of problem-solving behavior. The mathematics topic used in the study was trigonometric ratios, as this topic is first taught in the first year of senior high school. Each student was given a mathematical problem and then interviewed about the aspects of problem-solving behavior discussed in this study.

METHODS

This study used grounded theory approach. There were 36 students from 1st grade of Public Senior High School (SMAN) 12 Padang who were selected as subjects for the study. The activities in this study were started by giving student tests with indicators of mathematical problem-solving. Then, students' answers were corrected using the rubric for assessing mathematical problem-solving ability in Table 2. Next, students were grouped according to their ability level: high, medium, or low ability. From each ability level, one student was selected to be interviewed about solving the problems they had previously worked on. The indicator rubric of the students' problem-solving behavior was adapted from Harisman et al. (2021). Harisman et al. (2021) stated that the categories of problem-solving behavior are apathetic, routine, semi-sophisticated, and sophisticated.

The test given to students required their problem-solving on the topic of trigonometric comparisons (Figure 1). According to previous studies, students have difficulty solving trigonometry problems (Siahaan et al., 2018; Utami et al., 2019). In this study, the problems were designed so that students could use different strategies to solve problems.

Pak Budi akan membuat kuda-kuda rumah berbentuk segitiga saa kaki dengan desain sebagai berikut.



Jika harga balok kayu yang digunakan adalah $Rp80.000,00$ per $4\ m$. Berapakah biaya yang dikeluarkan Pak Budi untuk membuat kuda-kuda rumah?

Translated into English:

Mr. Budi is going to make a roof truss in the shape of an isosceles triangle with the following design.

(picture)

If the price of the wooden beams used is IDR 80.000,00 per 4 m. How much will Mr. Budi spend to make the roof truss?

Figure 1. Mathematics problem-solving question

Students' responses were then corrected using a rubric to asses mathematics problem-solving ability. The following Table 1 presents the rubric to assess mathematics problem-solving skills.

Table 1. Rubric to assess mathematics problem-solving ability

Score	Understanding the Problem	Selecting and Implementing a Solution Strategy	Solving the problem
0	No answer or incorrect understanding of the problem	No answer or incorrect way to select and implement a strategy	No answer or incorrect answer
1	50% understanding the problem correctly	50% correct in selecting and implementing strategies	Miscalculations or errors in some of the solution steps
2	100% understanding the problem correctly	100% correct in selecting and implementing strategies yang that can produce the correct solution	No incorrect or correct solution

Source: Muir et al. (2008)

Research by Harisman & Khairani (2021), the instrument tests mathematical problem-solving abilities to obtain data on aspects of knowledge ownership. Meanwhile, control, belief, and affective aspects were obtained using mathematical problem-solving ability test instruments and interview transcripts. Next, the data were coded and grouped based on Table 1 and Table 2. Analysis of data was performed by data reduction, data presentation, and conclusion.

RESULTS AND DISCUSSION

Based on the result of students' responses, the following category of students' mathematical problem-solving behavior is described.

Apathetic

Based on Figure 2, the following aspects of students' mathematical problem-solving behavior are described.

Knowledge Ownership

The students didn’t understand the problem well, so students could not find the right strategy to solve the problem. The concept used to calculate the length of wood used was not correct; they should use the Pythagorean theorem.

Control

The students made an error in calculating the length of the wooden trusses. The student used the formula for the area of a triangle that had no relation to the problem. As confirmed during the interview, a student was unable to use their prior knowledge. The following information was obtained from the interview:

Interviewer : Why did you find the length of wood [beam] for the house truss using this formula?
ZMR : Because the base and the height are known, ma'am.
Interviewer : Please look again. Are there any congruent triangles? What are the characteristics of congruent triangles? Can you solve it [based on the characterictics]?
ZMR : I don't remember any [of the characterictics].

Beliefs

The student had a conceptual error. On average, students with apathetic behavior have errors in concepts.

Affective

The students were incorrect in solving the problem. When confirmed, a student was hesitant to explain. This was because the student did not understand the concept. The following information was obtained from the interview:

Interviewer : Please explain how you found the unknown length of the wood [beams].
MF : I used the formula for the area of a triangle, ma’am.
Interviewer : Were you sure of your answer?
MF : I was not, ma’am.

One of the answers from students in the "apathetic" category is shown in Figure 2.

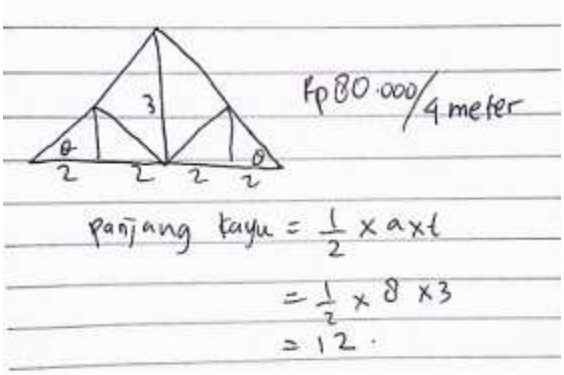


Figure 2. Answer from a representative of students with initial ZMR

Semi-Routine

Based on Figure 3, the following aspects of the students' mathematical problem-solving behavior are described.

Knowledge Ownership

Students were still confused about the problem, but they could be guided to understanding the problem and choose the strategy to solve it. They did not write down their answer, but when asked, they were able to explain the problem verbally. The students use the Pythagorean theorem to find the unknown length of a triangle.

Control

In fact, the students used prior knowledge by using the Pythagorean Theorem. However, when calculating the length of wood beam, the students used the formula for the area of a triangle instead. As confirmed during an interview, a student could not continue to solve the problem. The following information was obtained from the interview:

Interviewer : *Why did you find the length of wood beams for the house trusses using this formula?*

MF : *Because I didn't know what the next [step was] after I found the length of wood using the Pythagorean Theorem, ma'am.*

Interviewer : *Please look again. Are there congruent triangles? What are the characteristics of congruent triangles? Can you solve it [based on the charactericties]?*

MF : *[Triangles are said to be congruent] when the sides of the triangle are the same length, ma'am. But in this picture, I cannot find the congruent triangles.*

Beliefs

There were conceptual errors by the students. However, the students remembered the knowledge they had previously gained to solve the problem. If they were instructed to use a different strategy, they could recall the knowledge.

Affective

Similar to the student in the "Apathetic" category, a student in the "Semi-Rountine" category was also incorrect in solving the problem. When confirmed, the student was confident to explain. The following information was obtained from the interview:

Interviewer	:	*Please explain how you determined the unknown length of the wood.*
MF	:	*I used the formula for the area of a triangle, ma'am.*
Interviewer	:	*Are you sure of your answer?*
MF	:	*Yes, I am sure, ma'am.*

One of answers from students in the "Semi-Routine"category is shown in Figure 3.

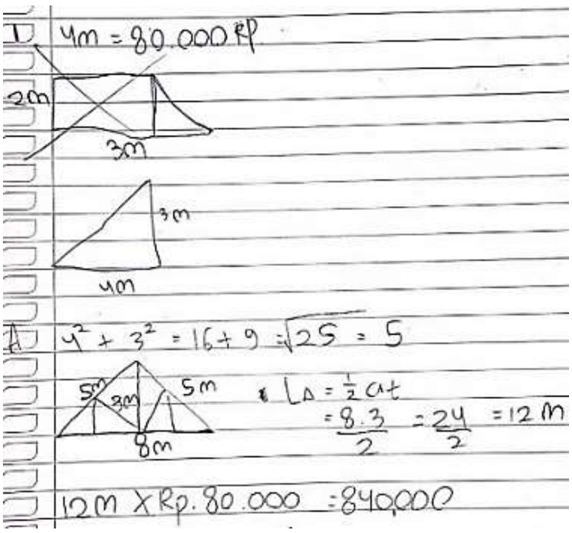


Figure 3. Answer from a representative of students with initial MF

Routine

Based on Figure 4, the following aspects of students' mathematical problem-solving behaviors are described.

Knowledge Ownership

Student understood the problem well, but the strategy they used was still incorrect. Students assumed that the height of all the trusses was the same, namely 2 cm, so there was an error when adding up the number of wood beams used.

Control

Students were able to retell what they had written. Then they realized that there was an error in the calculation, so the answer was not correct and they made errors also in the next step. The interview confirmed one student's answer. The following information was obtained from interviewing a student:

Interviewer : *Why did you assume that the height of the inner easel is 2 cm?*

MRE : *Because it is estimated that the height of the horses inside is the same, ma'am.*

Interviewer : *Please look again. Are there any congruent triangles? What are the characteristics of congruent triangles? Can you solve it [based on the characteristics]?*

MRE : *Triangles are congruent when their sides have the same length. From the picture, there are no congruent triangles, ma'am.*

Beliefs

The students understood the concepts of the Pythagorean Theorem. However, there was an error in the calculation operation that resulted in an incorrect answer.

Affective

One student explained his answer confidently. Then he realized there was an error in the calculation, so he was doubted his own answer. An interview confirmed his answer. The following information was obtained from the interview:

Interviewer : *Please explain how you found the unknown length of the wood beams.*

MRE : *I used the Pythagorean Theorem, ma'am.*

Interviewer : *Were you sure of your answer?*

MRE : *I was sure, ma'am, but I think I made an error in my calculation.*

One of the answers from students in the "routine" category is presented in Figure 4.

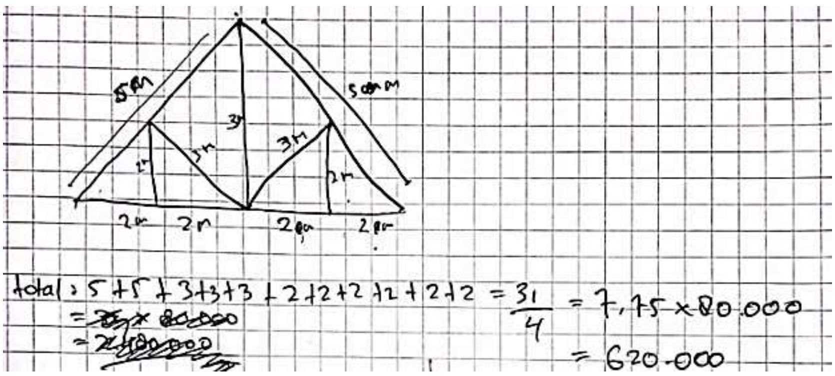


Figure 4. Answer from representative of students with initial MRE

Semi-Sophisticated

Based on Figure 5, the following aspects of students' mathematical problem-solving behavior are described.

Knowledge Ownership

The students understood the problem well, so the students managed to find the right strategy to solve the problem. However, there are an error in the addition operation, so the results were incorrect.

Control

Students were able to explain again what they had written. However, on the answer sheet, students noticed that there was still one step that they had not completed. When this was confirmed, one student forget to calculate the costs incurred. However, during the interview, the student answered correctly. The following information was obtained from interviewing the student:

Interviewer : *Is the answer you gave correct?*

MA : *Yes, it is, ma'am, but I forgot to multiply the cost of the wood per meter by the number of woods needed.*

Interviewer : *Yes, you're right. Why didn't you write it down, dear?*

MA : *I forgot that too, ma'am. When I looked back, I realized there was something I hadn't written down.*

Beliefs

The students answered correctly. Even though there were steps that were not written down, they were able to solve the problem correctly.

Affective

There was still one step that students had not completed. When it was confirmed to a student, the student was confident to explain. The following information was obtained:

Interviewer : *Please explain how you determined the unknown length of the wood.*

MA : *I used the Pythagorean Theorem, ma'am.*

Interviewer : *Were you sure of your answer?*

MA : *I was, ma'am, but something was missing from my answer.*

One of the answers from students in the "semi-sophisticated" category is presented in Figure 5.

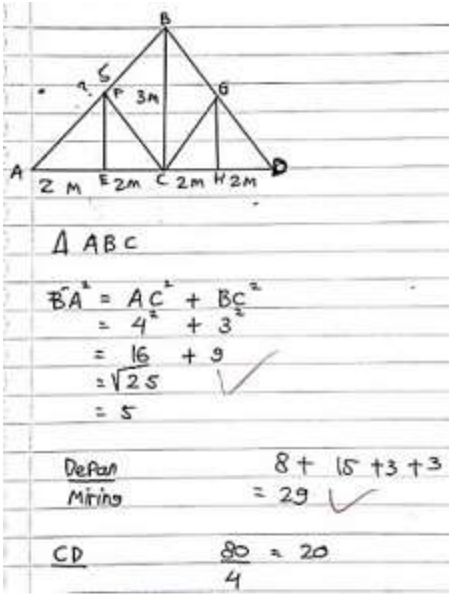


Figure 5. Answer from a representative of students with initial MA

Sophisticated

Knowledge Ownership

According to Figure 6, students understood the problem well, so they managed to find a strategy to solve it, and the answer was correct until the end. Variations in students' answers present in Figure 7. Based on Figure 7, students also understood the problem well and chose the correct and different strategy. Thus, students had different strategies to solve the problems.

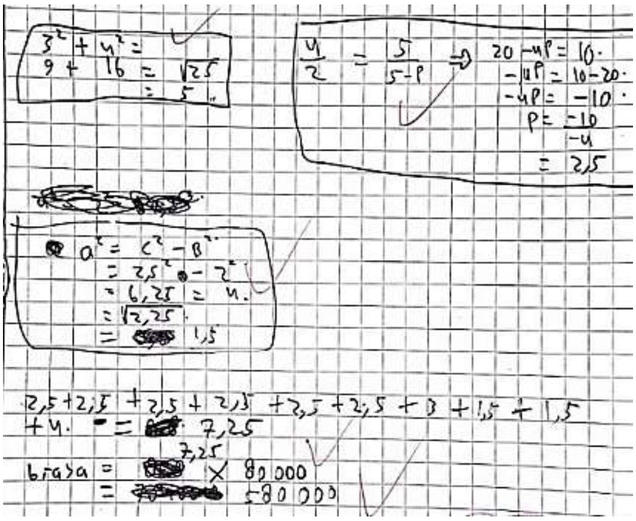


Figure 6. Answer from a representative of students with initial MI

Control

According to Figure 6, students were able to explain their answers. The concepts of ratio and the Pythagorean Theorem were well understood. The following information was obtained from an interview with one student:

Interviewer	:	*Is the answer you gave correct?*
MA	:	*Yes, it is, ma'am.*
Interviewer	:	*Could you please explain how you solved it?*
MA	:	*First, I determined the length from vertex A to point C using the Pythagorean Theorem. Then I calculated the height of the small triangle using the triangle ratio. After that, I added up the lengths of the pieces of wood. In the question, the price for 4 meters of wood is known, so it means that [the price for] 1 meter [of wood] is IDR 20,000.00. I multiplied IDR 20,000.00 by 29.*
Interviewer	:	*Yes, you're right*

Beliefs

There are many variations in the answers of the students in the " sophisticated" category. One of the students answered by skipping several steps, but the answer was correct. Some students used different strategies to solve the problem. This present in Figure 6 and Figure 7. Based on Figure 7, there were steps that the students took to solve it and the answer given was correct. The student first used the Pythagorean Theorem, then ratios. However, based on Figure 6, the students used different strategies. Even though they both use thed concepts of ratios and the Pythagorean Theorem, the order in which they used the concepts was different.

Affective

Based on Figure 6, one student solved the problem correctly. When interviewed, the student also answered correctly without showing any doubt. The following information was obtained from an interview with the student:

Interviewer	:	*Please explain how you determined the unknown length of the wood.*
MA	:	*First, I determined the length from vertex A to point C using the Pythagorean Theorem. Then I calculated the height of the small triangle using the triangle ratio. After that, I, added up the length of the wood. In the question, the known price is for 4 meters of wood, so [the price for] 1 meter [of wood] is IDR 20,000.00. I multiplied IDR 20,000.00 by 29.*
Interviewer	:	*Are you sure of your answer?*
MA	:	*Yes, I am, ma'am, because I double-checked my answer.*

One of the answers from students in the "sophisticated" category is shown in Figure 6.

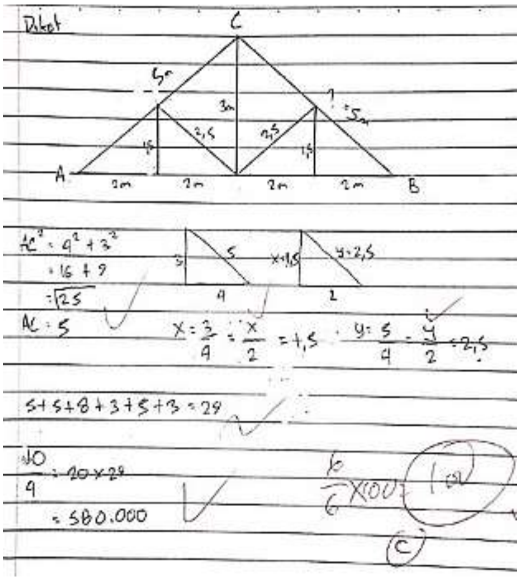


Figure 7. Answer from a Representative of Students with Initial MYM

Based on the students' answers, five categories of students' mathematical problem-solving behavior were obtained, i.e., apathetic, semi-routine, routine, semi-sophisticated, and sophisticated, because the behavior categories from previous studies (Harisman et al., 2021; Muir et al., 2008) did not fully represent the observed problem-solving behavior. Table 2 shows the categories of problem-solving behavior observed in this study.

Table 2. Mathematical problem-solving behavior in senior high school

No	Behavior Aspect	Indicator	Behavior Category				
			Apathetic	Semi-Routine	Routine	Semi-Sophisticated	Sophisticated
1	Knowledge Ownership	Application of Polya's proposed steps in mathematical problem-solving	Making errors in all steps of mathematical problem-solving	Failure to select and implement mathematical problem-solving strategies	No solution verification (Occurrence of errors in several mathematical problem-solving steps)	Verifying the solution verification, but still making errors in the mathematical steps of solving the problem	High score for each step of mathematical problem-solving
		Use of prior knowledge in mathematical problem-solving	Not being able to use previously solved problems	Being able to use previously solved problem	Being able to identify similar problems, but not based on their mathematical structure	Being able to identify similar problems, but not based on their mathematical structure, but being able to be guided to look at	Being able to identify similar problems based on their mathematical structure

No	Behavior Aspect	Indicator	Behavior Category: Apathetic	Semi-Routine	Routine	Semi-Sophisticated	Sophisticated
						problems in their mathematical structure	
		Use of many methods in mathematical problem-solving	Usually using the same method to solve all problems due to insufficient knowledge	Usually using the same method to solve all problems due to insufficient knowledge, but intending to use other methods	Focusing on one way to solve the problem, but not intending to use the right way to solve the problem	Focusing on one way to solve the problem, but having the intention to use the correct way to solve the problem	Identifying alternative ways of solving problems
		Written and verbal communication in mathematical problem-solving	Inadequate written and verbal communication	Inadequate written and verbal communication, but able to be guided to explain through verbal but not written communication	Unclear written communication, which can be clarified through verbal communication.	Unclear written communication that can be clarified through verbal communication	Inadequate written and verbal communication
2	Control	Metacognitive thinking when communicating mathematical problem-solving	No metacognitive thinking either in written or verbal communication	No metacognitive thinking in either written or verbal communication, but able to be guided verbally and unable to be guided to written	Failure to demonstrate metacognitive thinking in written communication but in verbal communication	No metacognitive thinking in the written but in the verbal communication and being able to be guided to perform the metacognitive process in the written answers	Metacognitive thinking demonstrated in written and verbal responses

No	Behavior Aspect	Indicator	Behavior Category				
			Apathetic	Semi-Routine	Routine	Semi-Sophisticated	Sophisticated
				metacognition			
3	Beliefs	Beliefs about how to apply mathematical problem-solving strategies	Using the same strategy	Using the same strategy, but needing guidance to systematically implement the strategy	Implementing strategies systematically	Implementing strategies systematically and being able to be prompted to suggest their own strategies	Suggesting their own strategy
		Beliefs about the variety of strategies used in mathematical problem-solving	Relying on one strategy	Relying on one strategy, but being able to be corrected if the strategy used did not work	Relying on more than two strategies and not using another strategy when the one used did not work	Relying on more than two strategies, not using another strategy when the strategy used did not work, but being able to be guided to switch strategies	Intending to use multiple and combined strategies
4	Affective	Often expressing a lack of confidence in solving problems, but intending to continue exploring how to solve them with confidence	Sometimes lacking confidence in solving mathematical problems	Being confident in mathematical problem-solving	Demonstrating confidence by answering quickly	Often showing a lack of confidence in their ability to solve problems	Demonstrating confidence in their ability to solve problems

The results of this study are consistent with the study by Muir et al. (2008), in which the subjects were sixth grade students. In addition, Harisman et al. (2021) studied problem-solving behavior, but among junior high school students with the different categorization of problem-solving behavior. Adhimah et al. (2020) also conducted a study on students' problem-solving behavior but in terms of mathematics anxiety by categorizing problem-solving behavior of students with high anxiety, i.e. Direct

Translation Approach-not proficient (DTA-np) and Direct Translation Approach-proficient (DTA-p), and students with low anxiety, i.e. Meaning-Based Approach-justification (MBA-j).

Furthermore, a study by Ningsih (2016) stated that students' thinking processes in solving problems could be considered as learning anxiety. The results of this study showed that the students with low learning anxiety tended to think divergently in understanding problems. In selecting the problem-solving strategy step, the students had different answers. In using problem-solving strategies, the students showed fluency, including: varying ideas and answers, using different solving methods, and thinking about more than one answer. In the final step of solving the problem, the students had a convergent thinking process because they tended to say that their answer was correct. This result is consistent with the studies conducted by Apriyani & Imami (2022); Irfan (2017); Ismawati et al. (2015).

Based on the elaboration, problem-solving behavior is important for students. Previous studies concluded that with problem-solving behavior, students can decide to choose the right strategy or process to solve problems (Attali, 2015; Fernández et al., 2015; Jitendra et al., 2014; Kadir, 2023; Quezada, 2020).

CONCLUSION

The mathematical problem-solving behavior of the first-grade students of senior high school students in solving mathematical problem on the topic of trigonometry ratios can be categorized into apathetic, semi-routine, routine, semi-sophisticated, and sophisticated. Apathetic is the behavior of manipulating numbers in problems. Routine is the behavior of using mathematics in a structured way, and sophisticated is the behavior of using one's own strategy in solving problems. Meanwhile, semi-routine behavior is behavior between apathetic and routine. As for the semi-sophisticated behavior, it is a behavior between the routine behavior and the sophisticated behavior category. In order to improve students' problem-solving behavior, it is recommended that teachers pay attention to the processes students use in solving problems. In the learning process, teachers can use teaching methods that can help students find the right strategy for solving problems. Teachers should focus not only on the result, but also on the process of completing it. By improving students' problem-solving behavior, expected that students' mathematical problem-solving ability will also improve. This study implies that teachers should develop student worksheets that are appropriate to students' respective problem-solving behaviors.

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