Difficulties in Solving Non-Routine Problems in Mathematics Learning

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***ABSTRACT**--Problem-solving requires students to apply and incorporate many mathematical concepts and skills. However, students were found to be having difficulty solving mathematics problems, especially non-routine problems. The present study will search the student's error in mathematics skills and cognitive abilities that caused the difficulties in non-routine problems-solving among high-achieving students. A problem-solving test (PST) that comprises six non-routine problems distributed to the 83 high-achieving students. Then, eight students with most errors in the PST were interviewed to gain a clearer understanding of how that errors influence difficulties in non-routine problem-solving. Descriptive analyses of students' scripts on PST and students interview revealed that visual-spatial skills and information management skills were the most critical factors that caused students failed to understand and solve the problems.*

***Keywords**-- Problem-Solving; Non-Routine Problems; Mathematics; Difficulties*

I. INTRODUCTION

One of the key aspects of the math curriculum is to produce individuals who are skilled in problem-solving and decision making. Problem Solving is a very important skill for students to master in everyday life, whether it is at a higher level of learning or in the future (Krulik & Rudnick, 1996). There are two types of problems observed in literature: routine problems and non-routine problems(Arslan & Altun, 2007). Approaches, strategies, formulas can solve routine problems, or known formulas (Polya, 1957) that help to establish links between mathematical knowledge and real-life (Xin, Lin, Zhang, & Yan, 2007), while non-routine problems develop skills, this is at the highest level. However, a significant number of students reported having difficulty learning mathematics, especially in solving non-routine problems. Mohd Nizam & Rosaznisham (2004) report that many students do not succeed in solving problems because they do not have the basic skills they need in math(Mohd Nizam & Rosaznisham, 2004).

Since higher-order thinking skills (HOTS) included in the national examination papers in 2014(Kementerian Pendidikan Malaysia, 2018), analysis of the national examination results shows that the percentage of candidates who failed the exam has increased every year. It is even more frustrating when PISA 2012 shows that Malaysian students miss three years of learning in math proficiency compared to their counterparts in other participating countries(OECD, 2014b). 60% of 15-year-old Malaysian students who participated in PISA 2012 failed to achieve a minimum level of proficiency in mathematics(OECD, 2014a).

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The Malaysian Examination Board also reported that many factors have caused students to face difficulties in problem-solving. The students are not only had a misconception or incomplete mastering the concept, but they are also uncertain about which strategies to use. The Ministry of Education, in its report (Ministry of Education, 2015), expressed concern that teaching and learning in schools in the past did not pay enough attention to the development of HOTS and problem-solving skills. If the teaching and learning process is not equally effective for all students, the difficulties in acquiring mathematic skills by the students could get worse. Understanding students' difficulties in mathematics skills needed in problem-solving are one of the ways to assist this group of students.

The above situation shows that students are still struggling with problem-solving and need great math skills. The difficulty in acquiring students' mathematical skills will become worse if the implementation of the teaching and learning process in the classroom not effective. One way to help this group of students is to understand students' difficulty in math skills needed in problem-solving. By understanding students' difficulty in acquiring the math skills needed in problem-solving, better programs can be provided to help those still struggling with math.

II. LITERATURE REVIEW

2.1 Non-Routine Problem-Solving

Non-routine problems viewed as ill-defined problems (Brunning, Schraw, & Ronning, 1999), and there is no predictable approach to deal with the question. Non-routine problems are problems that replicate real-life situations and do not provide keywords to solve using known procedures or standard methods(Arslan & Altun, 2007) but, using some unique strategies, they may provide some possible solutions accepted(Brunning et al., 1999). Finding solutions to non-routine problems requires the development of techniques and challenges one to think to understand the concepts involved (Jacinta, Abdul Halim, Mohd Salleh, Mahani, & Noor Azean, 2017).

In general, non-routine problems can develop problem-solving skills and develop those skills for use when dealing with real-life problems(Polya, 1957; Schoenfeld, 1992a). Therefore, non-routine problem solving needs to be included in mathematical learning to develop critical and creative thinking (Mabilangan, Limjap, & Belecina, 2011; Polya, 1981) as non-routine problems require a combination of several problem-solving strategies to be used. A non-routine problem-solving process is not a straightforward process as it requires creative thinking to apply some strategies in understanding and finding the best way to solve a problem.

Non-routine problem solving involves many processes and requires higher-order thinking skills. After mastering the basic concepts and solutions of the routine problems(Schoenfeld, 1992a), only then HOTS can be acquired. In solving non-routine problems, how the results achieved, the strategies used, and the logical thinking about the solution is more important aspects of attention than just reaching the right answers(Hegarty, Mayer, & Monk, 1995).

Students need to have a strong mathematical knowledge base, sufficient experience in learning how to solve problems, knowledge of various mathematical models or representations, and the ability to model or represent situations mathematically by constructing or drawing conclusions to succeed in solving non-routine problems(Lester, 2013). However, a study by Arslan & Altun (2007) found that students lacked the skills and lack of confidence to choose and use strategies to solve problems and then encountered difficulties in solving non-routine problems. According to Schoenfeld (1992), difficulties in solving non-routine problems may be due to students' failure to learn and apply some heuristics, such as making diagrams or using simpler cases.

2.2 Difficulties in Mathematics Skills and Non-Routine Problem-solving

In Malaysia, studies showed that students felt difficult in mathematics because, they had difficulty in understanding and retrieving concepts, formulas, facts, and procedure (Zahrah, Jamaliah, Rohana, Badariah, & Jaafar, 2003) and lacked the ability to visualize mathematics problems and concepts (Rohani, 2017; Tarzimah, 2005). To better understand the difficulty of problem-solving, it is important to understand the process of its solution. The four-phase problem-solving process consists of; i) understand problems, ii) planning strategies, iii) implement plans, and iv) looking back(Polya, 1957) used in this study. Each phase involves a combination of different mathematics skills and cognitive abilities. Heong (2005), argues that difficulties in solving problems are due to weakness in understanding concepts, logical thinking, and strategic knowledge. However, not many studies emphasise the difficulty of solving non-routine problems related to the mathematics skills deficit. If the difficulties in the mathematics skills involved are understood, the teacher can organise a better program for solving the difficulties. Also, if the learning approach and teaching strategies used do not meet students 'intellectual needs, students' difficulty in learning mathematics will worsen. Therefore, Meese (2001) argues that when teachers understand the problems and difficulties of learning and their students' potential, effective teaching and learning strategies can be implemented to produce meaningful learning among their students.

Although many students struggle with problem-solving(Garderen, 2006; Tarzimah & Thamby Subahan, 2010), they still need to learn math because of its importance in everyday life. The primary and secondary mathematics curriculum emphasises the skills of arithmetic, communication, construction, and technology application skills (Bahagian Pembangunan Kurikulum, 2015, 2016; Kementerian Pendidikan Malaysia, 2013), which are important to apply in problem-solving. Hill (2008) argues that deficiencies in any of these skills can lead to difficulties in math skills among students. The main reason for this difficulty is because solving non-routine problems requires a lot of skills to be used together.

The ability to use cognitive abilities in problem-solving is crucial. However, many students use these cognitive abilities ineffectively. Tarzimah & Thamby Subahan (2010) report that they have difficulty in making accurate perceptions and interpretations, taking facts, giving conclusions, and using their logical thinking. Errors in the comprehension of the text, the inability to create a suitable mathematical model and errors in the solution phase may cause difficulties in problem-solving. (Abdul Halim, Nur Liyana, & Marlina, 2015), share some student’s errors in solving HOTS problems. Newton analysis was used in their study to assess comprehension errors, transformation errors, process skills errors, and encoding errors.

Lack of mathematical skills leads to difficulties in solving problems(Tarzimah & Thamby Subahan, 2010). Garderen (2006) adds that deficiencies in visual-spatial skills may lead to difficulties in differentiating, relating, and managing information meaningfully. During the decision-making and problem-solving process, students need to apply and integrate many mathematical concepts and skills. This study examines four types of mathematical skills: i) numerical skills and mathematical concepts; ii) arithmetic skills iii) information management skills; iv) language skills; and v) visual-spatial skills to illustrate mathematical concepts, manipulate geometric shapes and space meaningfully.

Difficulties in understanding problems may be due to incomplete mastery of number facts, weaknesses in computation, difficulty in making meaningful connections between information, inability to convert information mathematically, incomplete understanding of mathematical language and terms, difficulty in understanding, and visualising concepts mathematics. These weaknesses can lead to many mistakes and misunderstandings in the problem-solving process.

Knowledge of procedures and conceptual understanding are essential to problem-solving(Geary, 2004). However, these skills should be supported by cognitive systems that control the focus and intervention of information processing. Also, interpreting and manipulating information effectively in working memory requires language and visual-spatial skills. Any obstacle at any level can lead to difficulties in the problem-solving process. Early understanding and identification of difficulties are important for any intervention(Tarzimah & Thamby Subahan, 2010).

III. METHODOLOGY

This study is a descriptive study that used a quantitative and qualitative approach. Data was obtained through a problem-solving test (PST) and interview to identify the types of student's errors and gain a better understanding of how that errors led to difficulties in non-routine problem-solving. The sample for this study consisted of 83 high-achieving forms of four students in a secondary school of the district Batu Pahat, Johor.

*3.1 Instrumen*t

The first instrument used for this study was a set of test questions to identify the types of errors made by students to reach a solution. The test had six non-routine problems that allow students to apply the mathematics learned in school to solve the problems. The test items were real-life problems with the expectation that students had not previously encountered and solved similar problems set. Many different approaches and strategies can solve these problems. As such, students were to search for and apply strategies they think could solve the problems. Students were also encouraged to provide rough work and alternative solutions.

Problem 1, Problem 3, and Problem 4 were geometry problems involving area or perimeter. Problem 2 was on simple proportion and required logical reasoning that can be solved by mathematical modeling. Problem 5 and problem 6 were problems that require the use of rules provided in the solution process. Table 1 shows the items and possible strategies that can be used to solve them.

Table 1: Problems Used in the Study

Number	Problem	Strategies
1	Two circular pieces of equal radii and maximum area, touching each other, are drawn on a rectangular cardboard of dimension 14 cm x 7 cm. Then, it cut from the cardboard. Find the area of the remaining cardboard.	Drawing diagrams Manipulation of variables

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2	Ahmad and Nurul have some money each. If Ahmad spent RM 45 and Nurul spent RM 15 every day, Ahmad would still have RM 300 while Nurul had spent all her money. If Ahmad spent RM 15 and Nurul spent RM 45 every day, Ahmad would still have RM 420 while Nurul had spent all her money. How much money was each of them has initially?	Logical reasoning Mathematical Modelling
3	A well of diameter 150 cm has a stone parapet around it. If the length of the other edge of the parapet is 616 cm, find the width of the parapet.	Drawing diagrams Manipulation of variables
4	Your company is going to make frames as part of a new product they are launching. The frame is of a piece of steel. The inside of the frame has to be 11 cm by 6 cm, so that the final area should be 38 cm^2. What should the width of the metal be?	Algebraic method (quadratic equation) Systematic trial and error
5	The access code to a locked door was a 4-digit number. The number is the smallest integer that can write as the sum of two positive cubes in two different ways, and the number is between 1000 and 2000. What is the access code?	Systematic Listing
6	Farish and Hakimi had some money each. The amount of money that Farish had was a whole number. Farish wanted to buy a watch using all her money, but he was short of RM 90.50. Hakimi wanted to buy the same watch using all his money, but he was short of RM 1.80. The total amount of money that both of them had was still not enough to buy the watch. How much was the watch?	Mathematical Modelling Reasoning

Semi-structured interviews were also carried out among eight students with most errors in the process of solving mathematics non-routine problems. Then, the data was analysed, and the semi-structured interview used to probe issues that emerged.

3.2 Procedure

At the end of the school year, during night study hours, PST was conducted to 83 students. In a quiet atmosphere, students were given 40 minutes to finish all the problems individually. Also, the researcher made some explanations when needed and observed the procedure, but she did not give any assistance to students. Then, eight of them, with most errors in the PST, were interviewed to gain a clearer understanding of how that errors influence difficulties in non-routine problem-solving. Each interview recorded and transcribed.

3.3 Data Analysis and Scoring

As this study was descriptive, data for the errors that are made by students were scheduled based on the category. Based on solution processes from the writings of students on test sheets, every question in the test awarded as 0 (wrong or no answer), 1(partly correct answer), and 2 (correct answer). Mathematically correct workings were duly credited.

IV. RESULTS AND FINDINGS

Table 2 shows the frequency and percentage of each score per question. From table 2, no one can answer questions 2 and 5 correctly. Both questions are under the Numbers and Operations fields. While these questions do not require complicated calculations, students need to understand every bit of information provided to understand the question. They do require information management skills such as manipulating information, making connections between each information, stating mathematical sentences, and deciding which operations or formulas to use. However, manipulating information and formulating situations mathematically are found to be a major subset of information management skills that influence difficulty in problem-solving (Tarzimah & Thamby Subahan, 2010).

Table 2: Frequency and Percentage of Each Score

Number of Problems	**Score**						**Blank Sheet**	
	2		1		0			
	f	%	F	%	F	%	f	%
1	58	70	7	8	9	11	9	11
2	0	0	0	0	57	69	26	31
3	27	33	4	5	19	23	33	40
4	14	17	8	10	38	46	23	28
5	0	0	2	2	49	59	32	39
6	19	23	0	0	29	35	35	42

As mention earlier, a four phases problem-solving process, which consists of; i) understanding the problem, ii) planning strategies, iii) performing the plan, and iv) looking back, was adapted for the study. This section discusses the errors made by the students in each phase that led to difficulties in solving non-routine problems.

4.1 Understanding Problem

In the problem-solving process, there are 4 phases of the solution that students need to go through. However, many students find it difficult to do the first phase of the task, understanding the problem. One of the difficulties encountered in this phase is the misinterpretation of the information provided. This misunderstanding leads to uncertainty about what to do with the problem. For example, in Problem 2, there are 31% of students did not answer the questions, while 66% of students failed to make appropriate mathematical representation and could not find a solution. The other 3% did not understand the question by giving the number of days in response to the money needed. Students interviewed stated that they had never solved such a problem and did not understand that

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question. Moreover, they do not know what to do and what strategies can be used to solve the problem. **Figure 1** below shows examples of the student's answer to Problem 2.

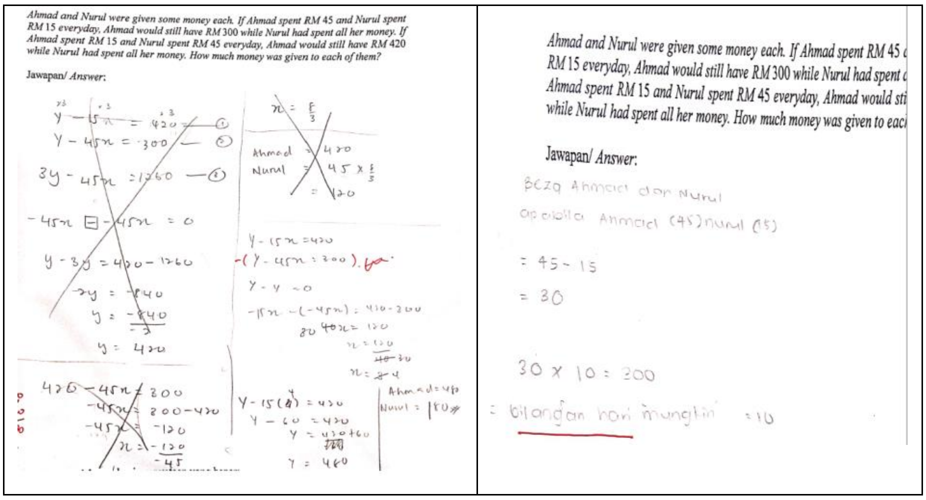

Figure 1: Examples of students' answers for misinterpretation of information in Problem 2.

Understanding problems is an important aspect of problem-solving. Questions must be understood first before they can be solved(Montague, Warger, & Morgan, 2000; Polya, 1957; Schoenfeld, 1992b). However, because non-routine problems usually in long paragraphs and a lot of information are involved, students are confused about the purpose of the problem. They are so confused that they cannot understand what the story is behind the problem, they are confused about what is meant by each piece of information at hand and ultimately do not know what to do with all the information provided in the question. All of these mistakes may lead to mistakes in the next phase.

According to Tarzimah & Thamby Subahan, (2010), the confusion that students face is due to difficulties in understanding the mathematical terms used or making incorrect connections between each information. As a result, it takes longer to understand the question, resulting in more time to solve the problem. Therefore, the timeframe given may not be enough for students to solve all the problems. Tarzimah & Thamby Subahan (2010), adds that the process of understanding problems requires language skills and visual-spatial skills to understand the goals. However, the lack of these skills in many students makes it difficult for them to identify the goals and objectives mentioned in the problem. As a result, they cannot decide how to resolve the issue. In other words, students do not know how to plan and implement a problem-solving strategy without understanding the goals to be achieved. For example, in problem 5, 2% try to answer by simply listing the cube numbers, but they also do not seem to understand the information 'written as the sum of two positive cubes in two different ways.' In the end, they put down any number they liked for no apparent reason. Figure 2 shows examples of the student's response to Problem 5.

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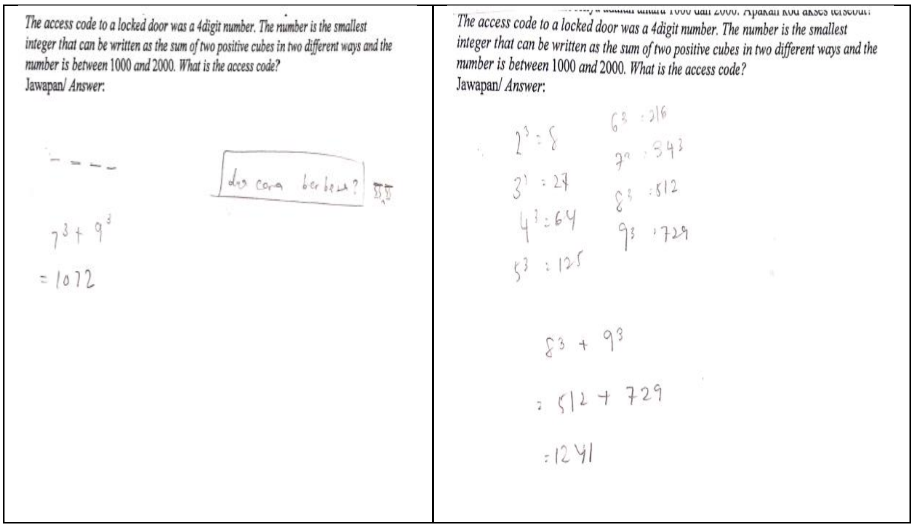

Figure 2: Examples of students' response to Problem 5

In Problem 3, 10% had a misconception of the length of the parapet (616) given. They consider the length of the parapet as the height of the well instead of the outer circumference of the well. The other 8% used the wrong formula, which is the formula of volume or area. 5% were able to draw the diagram with the correct label (Figure) but did not continue the proper calculation step. Students seem to understand the problem but do not know the strategies that can be used to solve the problem. Only 27 students can answer this question correctly.

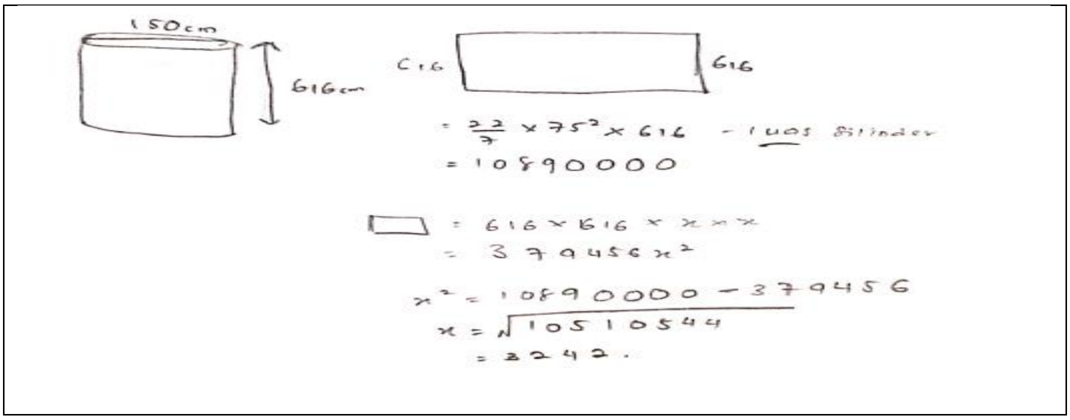

Figure 3: Examples of student's response to Problem 3

From the interviews, they are most difficult when trying to make a connection between each of the information provided in the question. They failed to build the appropriate mathematical representation and thus ended up falling apart without solving it. Ibrahim (1997) declares that transforming a problem into a mathematical sentence is a difficult thing to do, maybe because of the students' ability to create a clear vision. Deficiencies in visual-spatial skills may cause difficulties in relating, comparing, and managing information that ultimately influences effectiveness in problem-solving(Garderen, 2006). ***Figure 4*** shows the examples of student's responds for Problem 1 and Problem 3 that indicate lacking in visual-spatial skills.

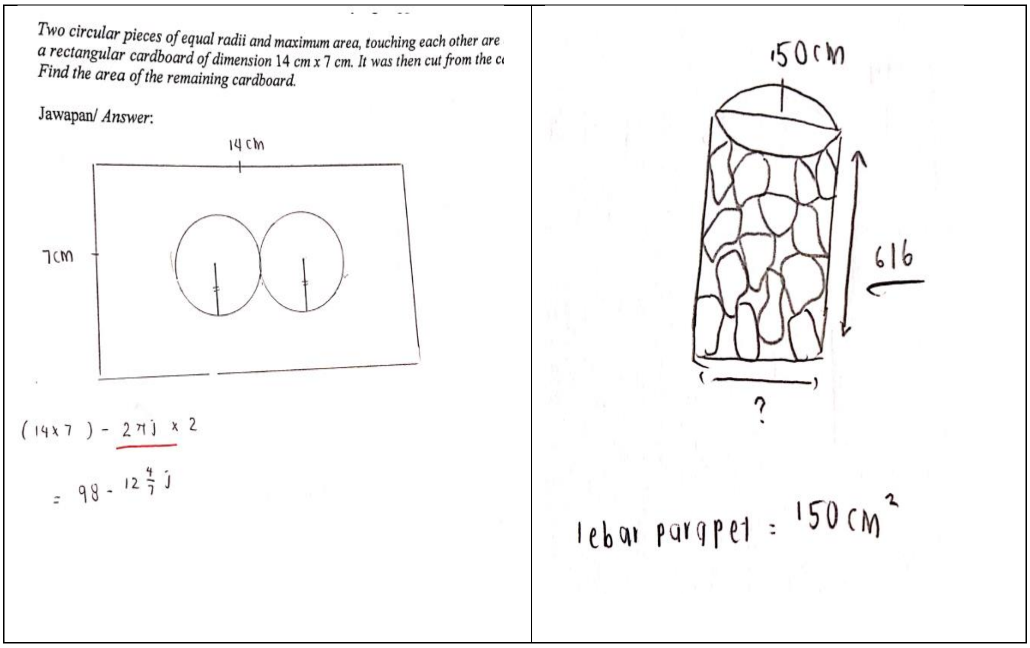

Figure 4:Examples of lack in visual-spatial skills

4.2 Planning Strategies

Understanding the problem alone does not guarantee that a student can solve the problem. Often, when a student understands a problem, they still cannot determine what to do to solve the problem. The students' responses in Figure 5 below indicate that they understand the question but cannot plan the appropriate solution strategy and cannot solve the problem.

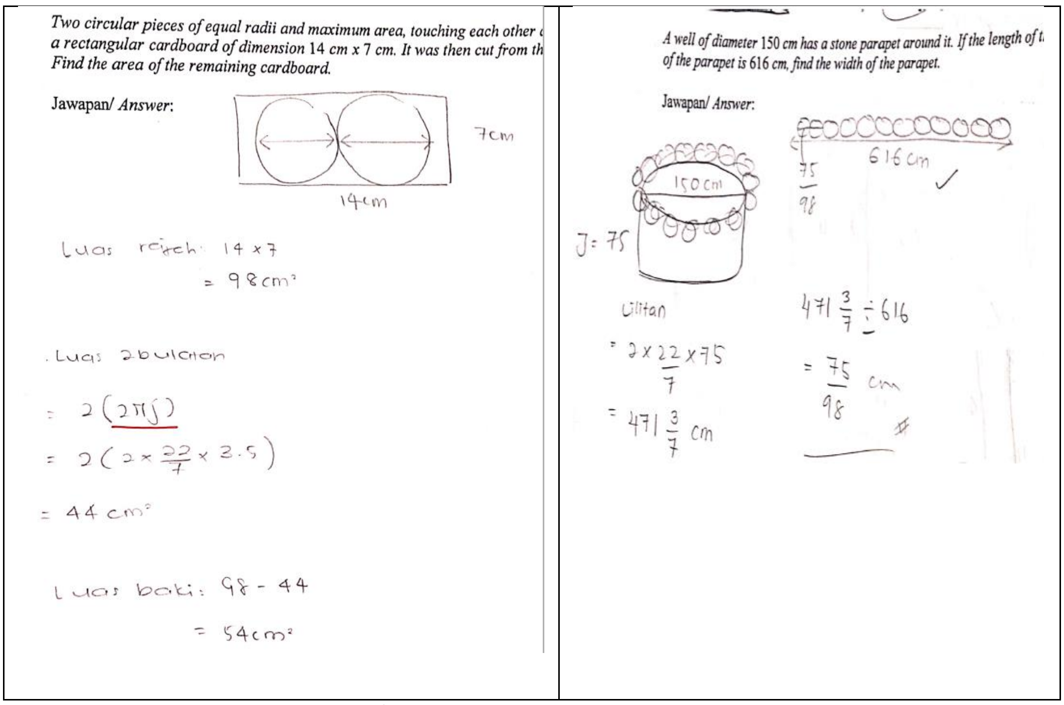

Figure 5: Example of a student's response to Problem 1 and Problem 3

This difficulty may be due to a lack of numerical skills and information management skills. The relationship between inaccurate information and facts or the relationship between inaccurate facts and formulas can cause students to misinterpret information in reaching a solution. Also, this lack of skills can lead to inappropriate planning and then creates an error and confusion in the problem-solving process. Many types of mathematical skills difficulties may arise from the inability to connect and transfer mathematical, conceptual aspects to the knowledge and incomplete mastery of numbers.

During the second phase, students have to work out strategies to solve the problem and get the answer. In this process, students must be able to make the right decisions and decide what to do. They need to have skills in managing information and managing problem-solving strategies. Because the problem-solving process is hierarchical, obstacles in the first phase will fail in other phases.

4.3 Performing the Plan

To execute the strategy, arithmetic skills and numerical skills are important. With these skills, students can apply correct concepts and facts and can make accurate calculations. However, most students are not proficient in all of these skills. For Problem 4, students are required to find the width of a rectangular frame with the final area of 38cm^2 after 11cm by 6cm inside the frame were cut off. However, 8% of the students involved in this study considered the area (38cm^2) as the area of the whole frame. Another 17% made incorrect mathematical representations by writing the wrong equation and using the wrong operation, as shown in Figure 6.

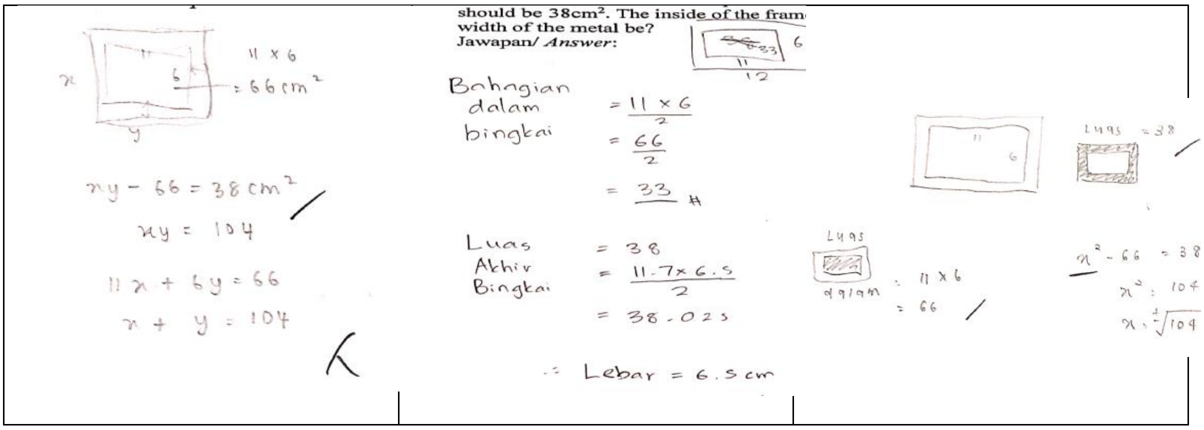

Figure 6: Examples of student's response to Problem 4

For problem one and problem 3, even though both involved a circle, the per cent failed to answer question 3 was higher because problem 1 is easier to understand than problem 3. Students misuse the formula; they use a formula of circumference rather than formula of area (Figure 7). Some still have operational errors even though they have used the correct formulas. They make the wrong substitution of the radius or the wrong calculation (Figure 7). The error in this calculation is due to the negligence of the student for not reviewing the answer.

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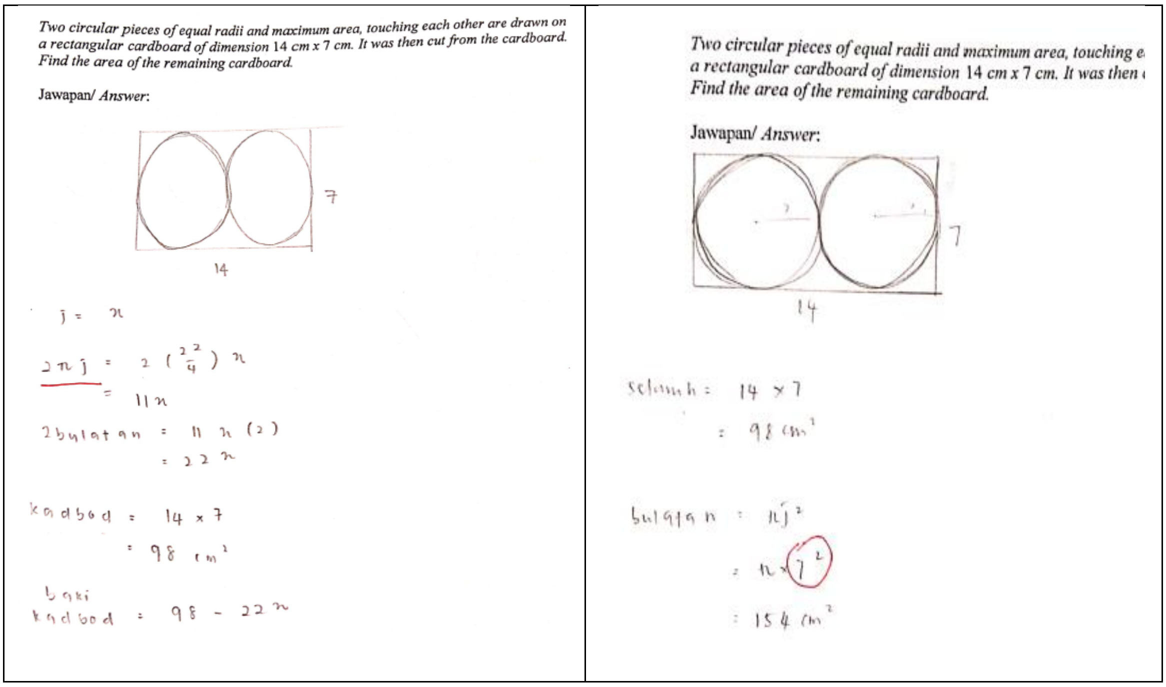

Figure 7: Examples of Student's Response for Problem 1

4.4 Looking Back

Students often ignore the fourth phase. They find this phase unnecessary since the first three phases are quite challenging for them. For them, if they have been successful through the first three phases, it is considered successful. However, this opinion is incorrect because misunderstandings of the problem may occur or accidental errors have been made during the problem-solving process, as shown in Figure 8 below.

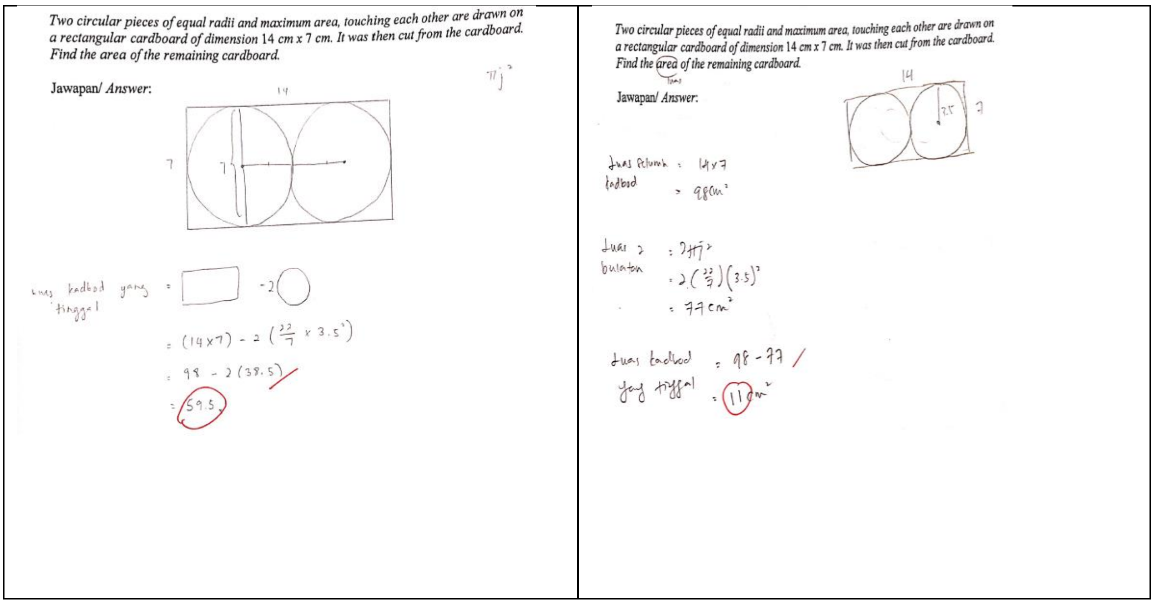

Figure 8: Example of Student's Response for Arithmetics Error

Some students stated that they were bored when they reached an answer because it took time. This time-consuming process has made them less interested in seeing the same problem again. At the same time, they are running out of time to move on to the next question, which also requires a long thought process. Therefore, they cannot concentrate on a task for a longer time. Furthermore, integrating all of their mathematics skills to explain the answer is a challenge for them. As a result, not many students complete the entire problem-solving process by going through this fourth phase.

V. DISCUSSION

This section discusses mathematical skills and cognitive skills that led to difficulties in solving non-routine problems. Geary (2004) argues that conceptual understandings and procedural knowledge influence achievement in problem-solving. The phases of the problem-solving process are interrupted if students lack math skills such as facts, concepts, and arithmetic skills.

5.1 Mathematics skills

Visual-spatial skills are another critical skill for students. Since the diagrams are not attached for the six questions, students should imagine and construct diagrams by themselves based on the information and conditions provided in the problem. Many students are found to be lacking in shape orientation and unable to build connections between problems with diagrams. According to Garderen (2006), deficits in visual-spatial skills may cause difficulties in comparing, relating, and managing information. Tarzimah (2005) adds that students who cannot visualise problems and mathematical concepts face difficulties in solving problems.

Besides that, lack of language skills such as understanding mathematical terms and languages can hinder understanding of problem objectives and may affect the ability to solve problems. In helping to interpret and manipulate information effectively in working memory, language, and visual-spatial skills are essential (Geary, 2004). In addition to students lacking in conceptual understanding, students also have difficulty in systematically demonstrating work procedures and ensuring the accuracy of their work procedures. This skill is a key skill in arithmetic skills that results in students' difficulty in solving problems. Heong (2005), states that weaknesses in conceptual understanding and lack of strategic knowledge have led to difficulties in solving problems. Therefore, there may be interactions between all of these skills.

5.2 Cognitive Abilities

The main cognitive ability to learn that may cause students to encounter difficulties in solving problems is the ability to access existing knowledge and to recall facts related to making connections in their thinking. This ability indirectly affects the efficiency of critical math skills in problem-solving ability. Students may have trouble retrieving the facts involved and recalling past learning experiences. This deficit can lead to difficulties in information management skills. As a result, students are unable to bring meaning to the problem and thus have difficulty in finding the right concepts, formulas, facts, and procedures in solving the problem (Zahrah et al., 2003). To implement more effective and explicit learning strategies, teachers need to understand students' difficulties and their learning processes for the meaningful learning of their students (Meese, 2001). The ability to focus well, to make meaningful perceptions, and to think logically and to use memory effectively are important factors in learning skills and problem-solving (Stendall, 2009). Therefore, if teachers understand students 'difficulties, they can make changes to create meaningful learning based on students' intellectual needs as these skills can be learned and practised.

Many students believe that the difficulties they face in preventing mathematical achievement come from difficult, tedious math problems, which require a lot of knowledge, work procedures, and time. However, the real obstacle is not the mathematical problem but rather the deficit of all the mathematical skills in the student that cause difficulties. Math problems will no longer be a hindrance if students can master the skills they need. Therefore, one way to help students realise their weaknesses and to try to overcome them is to diagnose the skills involved. The findings could help in the planning of an approach to teaching this group of students more effectively. Teaching mathematics concepts and skills using a contextual approach with logic can be adapted for this group of students. However, further research is essential.

VI. CONCLUSION

This study concludes that the lack of cognitive skills and incapacity in acquiring many mathematical skills are the reasons for students having difficulty in solving non-routine problems. Information management skills are considered to be the most critical math skills; without information transfer skills, they are unable to understand and make effective connections to the information in the problem, even though students acquire other mathematical skills. Generally, the majority of students do not have this skill. The ability to recall, memorise, and evaluate is a cognitive ability in learning that influences problem-solving efficiency.

Difficulties in students' mathematical skills are a challenge to overcome. The efficiency of the problem-solving process was interrupted by a lack of language skills, information management skills, and mastery of number fact skills. Because of these shortcomings, students become confused and unsure of the relationship between the information, eventually making the wrong decision, which in turn leads to error in solving the problem. The efficiency of each phase in problem-solving depends on the ability to remember, especially problems involving facts. Students find it difficult to make meaningful connections to problems and influence the efficiency of the next phase of the solution. Therefore, the ability to manage information is a key factor in determining the smoothness of the problem-solving phase.

This study shows that students' difficulties due to their weaknesses in math skills and their ability to solve problems can occur at any level. One of the strategies to overcome this problem is to understand the problems that students face at each level. Guidelines for teachers to plan better approaches and effective teaching methods can be provided based on this understanding. To create a more meaningful teaching and learning process, development modules, instrument diagnostics, and approaches are essential to assist students. However, further research needs to be done to understand better students' ability to apply those skills. Difficulties in solving non-routine problems may be overcome by Identifying the required mathematical skills. Understanding teachers' issues, knowledge, skills, and commitments are key to helping students succeed now and in the future. These efforts can help students improve their skills in solving math problems, especially non-routine problems.

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