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*Article*

# Mathematical Problem-Solving Strategies Among Elementary School Students

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**Abstract**

*Background: This Study aimed to identify the strategies employed by elementary education students in solving mathematical problems, as well as students' abilities to solve the problem in a variety of ways. Method: To accomplish this, a qualitative approach was used. The instruments for the study were built, and their validity and reliability were tested. The instruments included a semi-structured interview, and two sorts of questions: mathematical problems, questions asked while students solve problems, along with structural code to analyze the semi-structured interviews. Six students; 3 from Grade 4 and 3 from grade 5, participated in this study. The findings revealed that while some students understand the problem, they do not understand the mathematical problem components; giving and requirements, and they do not follow Polya's problem-solving steps. Students have difficulty in solving mathematical problems, for example, they have difficulty solving problems with large numbers and unrealistic problems. Results: According to the findings, students utilized the trial-and-error strategy the most, followed by finding a pattern strategy, logical reasoning strategy, making a drawing or a diagram strategy. The findings also revealed that students used a variety of strategies to solve one mathematical problem.*

*Conclusions: The study provided various recommendations, the most important of which was to urge and encourage teachers to teach their students Polya's problem-solving steps.*

***Keywords*** *Mathematical Problem, Strategies, Elementary School, Polya's problem-solving.*

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## Introduction

Problem-solving is a crucial cornerstone in mathematics teaching and learning because it helps learners enhance their ability to think correctly, allowing them to deal with the contemporary world successfully and professionally (NCTM, 2000; Nahrowi et al., 2020). Problem-solving enables students to apply the procedural and conceptual knowledge using thinking-based ways, which increases thinking by requiring students to devise solutions that can be applied in different contexts (Ben-Ben-Hur, 2006; Bergsten et al., 2017). Mathematical problems are grouped into numerous types, including arithmetic, algebraic, and geometric, which are further subdivided into routine and non-routine problems, as well as verbal and nonverbal problems (Sayaili, 2017; Tao, 2006).

The mathematical problem is characterized as a mathematical situation in which the student does not have a ready-made answer (Polya, 1971); it also demands that the students link conceptual and procedural knowledge, which helps them to develop their thinking processes (Ben-Hur, 2006). Besides, it also allows them to put strategies, skills, and concepts into practice in a way that depends on their understanding and enables them to apply what they learned in real-life situations (Romberg, 2016).

Understanding the problem, devising a plan, carrying out the plan, and then looking back to check the solution are the four steps Polya outlined for solving mathematical problems (Finan, 2006). The language used in writing the problem and the students' knowledge of it determine how well the problem is understood. Here, the teacher's role is to help students grasp the problem by utilizing familiar language, correctly identifying the given and requirements, and establishing a plan for solving the problem (Lenchner, 2005). The solution plan is a road map that students follow by employing one of the strategies that aid in the de-mystification of the problem, such as finding a pattern strategy, guessing strategy, working backwards strategy, making a drawing or a diagram strategy, and a more straightforward problem-solving strategy (Albarracin & Gorgorio, 2014). To solve a problem, students can employ multiple strategies. This flexibility in applying strategies can be learned and developed by the learner being exposed to various problems and using them to solve them and apply what they learnt to other problems (Posamentier & Krulik, 2009; Lenchner, 2005).

The third step of Polya's problem-solving steps, carrying out the solution, depends on the plan that the student devises in the second step and his prior cumulative knowledge of mathematical concepts and ability to carry out the mathematical procedures that are appropriate for the solution plan. In this phase, the teacher must inform the students that they can amend their solution plan if it fails to solve the problem, and they must revise each step before moving on to the next one. The fourth and last step is to review the solution by working backwards through it, substituting the answer, or using other ways the student chooses (Lenchner, 2005; Finan, 2006).

Based on the information presented above, we conclude that understanding the problem and using an appropriate strategy to arrive at a solution are the keys to solving a mathematical problem. This idea demonstrates the importance of the strategy and that he can select the best strategy for the given requirements of the problem, which comes from practice, training, and exposure to enough mathematical problems, and often a deep and broad understanding of various problem-solving strategies (Szabo et al. 2020; Ozrecberoglu & Caganaga, 2018).

Based on the importance of teaching mathematical problem-solving strategies, these strategies vary in complexity and appropriateness to the student's age. The student has innate strategies used without teacher instructions, such as trial-and-error or guessing strategies. The student attempts speculative responses to see if they are valid, then decides whether to accept or reject them based on their results. The teacher's role is to encourage his students to use a smart guessing strategy, which involves deciding which efforts to make based on the results of prior tries; this decreases the number of trial-and-error efforts and allows students to acquire the correct answer in less time (Posamentier & Krulik, 2009).

One of the most prevalent strategies among students is finding a pattern strategy. This strategy is characterized as looking for connections between the problem components. For example, in a sequence of digits, the student is requested to finish, and he tries to find a connection between the most recent digit and predict the next digits. The significance of this strategy is that it makes mathematical sequences easier for young students, which aids in the foundational comprehension of these concepts later (Spangenberg & Pithmajor, 2020).

Making a drawing or a diagram strategy is one of the strategies that is frequently used in solving geometric mathematical problems. However, it can also be used in solving non-geometric problems to organize and clarify the giving and requirement of the problem, which helps in visualizing the problem and makes misunderstood words visual and understandable, thereby enhancing logical thinking and obtaining the solution, particularly, while solving problems that involve more than one step (Posamentier & Krulik, 2009; Guzman Gurat, 2018).

When learners have difficulties solving problems with large numbers, they may try to solve them by simplifying the digits to make them more meaningful, known as the *"simpler equivalent problem-solving"* strategy. This strategy aids students in visualizing the steps required to solve the original problem. Simplifying is not limited to digits; in other circumstances, students simplify the given context inside the problem. For example, if the problem is compounded, they solve it by breaking it down into numerous problems, solving each separately before combining the solutions of the original problem (Lockwood, 2015; Posamentier & Krulik, 2015).

One of the most challenging strategies among students is working backwards. In this strategy, the student begins with a known step and works backward until arriving at the desired answer, following which he solves the problem after learning the conditions and steps. This strategy is widely utilized, particularly in proofs (Ramful, 2015; Katz et al., 2016).

Since the elementary stage is the foundation for how a student deals with mathematics, it is significant and vital in establishing mathematical concepts and promoting proper mathematical thinking among students. On one hand, students either struggle with mathematics or excel at it from the start, and on the other hand, developing their problem-solving skills is one of the most essential tasks that teaching and learning mathematics aim to achieve. Several studies were carried out to examine how well students understood the components of the mathematical problem and how difficult it was for them to solve. The findings of a study conducted in Thailand (Phonapichat et al. 2014), which used the descriptive approach and content analysis, highlighted the presence of obstacles among students in understanding the problems and their inability to extract the given requirements from them. A total of 98 students from fifth and sixth grades, as well as 10 of their teachers, participated in the study. A structured interview was used as a study tool for teachers, while a written exam was used for the students in the sample. In the same context, Wulandari et al. (2018) emphasized the importance of the language used to write a text and understand it, and their significance in understanding the problem and finding a solution. The study was carried out on a sample of third-grade students with varying reading abilities. While reading the problem aloud, the researchers counted how many mistakes students made. Then their problem-solving ways were put to the test. According to the study's findings, there was a connection between the students' reading aptitude and problem-solving abilities. It was discovered that students with low reading abilities had significant difficulties solving mathematical problems and were unable to justify their solutions or explain the significance of the problem.

In contrast, students with strong reading abilities were able to solve the mathematical problem quickly. Many studies investigated the strategies students use to solve non-routine mathematical problems, and the results differed depending on the grade level of the study participants. A six-problem test was used in the study of

Celebioglu et al. (2010), which targeted a sample of 170 Turkish first graders to identify the strategies they use to solve non-routine mathematical problems. The findings of this study revealed that the most used strategy was finding a pattern.

The quantitative approach was employed in another study (Ratnasari & Safarini, 2020), which used a sample of 20 eighth-grade students in Jakarta. A test with two non-routine algebraic problems was presented to the students. To learn more about the study, six participants were interviewed. The most widely used strategies were a drawing or a diagram strategy and a guessing strategy. Yazgan's study (2016) in Turkey aimed to discover the non-routine problem-solving strategies of fourth graders. The study sample included a total of 240 male and female participants. According to the findings, the strategies assist 84% of students reach the solution. These strategies were in the following order, based on their importance in arriving at the proper solution: finding a pattern, working backward, establishing a systematic inventory, drawing, guessing, checking, and simplifying the problem strategies. In Charlotte, Freeman (2013) conducted a study to explore the influence of problem-solving strategy on problem-solving skills among eighth-grade students with learning difficulties. The sample consisted of 6 eighth-grade students, both male and female. The findings revealed that all the participants understood the steps of problem-solving and that there was a connection between utilizing a problem-solving strategy and having better success in solving the problem of all six targeted students.

## Methodology

This study adopted the quantitative approach. Three fourth-grade students and three fifth-grade students with various academic levels based on their mathematics scores in the previous semester were chosen as a purposive sample. Table 1 explains the distribution of students by school grade, academic level, and student code.

*Table 1. The distribution of participating students in the study sample is based on school grade, academic level, and each student's code.*

| **Grade 5** | **Grade 4** | |
|---|---|---|
| Student (S4) | Student (S1) | Excellent |
| Student (S5) | Student (S2) | Moderate |
| Student (S6) | Student (S3) | Low |

The study's instruments were created to answer the study questions, and they are as follows:

1. How well do students grasp the concept of mathematical problems, the ways they solve them, and the difficulties they face?
2. What problem-solving strategies do students employ?

A semi-structured interview was designed to address the study questions. Questions, including four mathematical problems, were asked during the semi-structured interview to determine the student's understanding of the significance of the problem and the steps for solving it according to Polya's. Even the types of difficulties students encounter when solving the problem, if any. The problems and the questions are explained in Appendix (1). The interviews were analyzed using a structural code based on the quantitative research literature (Saldana, 2013), which is shown in Appendix 2. The validity of the instruments' content was verified by referring them to several qualified arbitrators in the field of mathematics curriculum, as well as measurement and assessment. The instruments were modified in response to the feedback of the arbitrators. The interviews were conducted and videotaped so the researchers could analyze them correctly. They also reanalyzed them two weeks later to guarantee the analysis's reliability; the reliability rate was 98%.

## Results and Discussions

The study's first question is:

*How well do students grasp the concept of mathematical problems, the ways they solve them, and the difficulties they face?*

According to the findings of the interviews, three students understood the problem. However, they do not know the components of the mathematical problem through its giving and requirements, which they defend by claiming that their elementary school mathematics teachers did not teach them the mathematical problem components.

Then, some of the students (50%) had only a rudimentary understanding of the mathematical problem components, as evidenced by a student's response to offering the researcher the correct answer during the semi-structured interview, as indicated in the following quote:

Researcher: *"Identify the giving and requirements in the mathematical problem?"*
S (2): *"What does that mean?"*
Researcher: *"Didn't you learn the giving and requirements in school?"*

S (2): *"No, the teacher did not teach us the giving and requirements."*

The student cannot extract the text's giving and requirements when considering the quote. This means that students will be unable to finish one of the most crucial steps in problem-solving: understanding the problem. According to Polya, understanding helps the student later in other steps. In the lack of formal planning for the solution, the students carry out Polya's second step to solving the problem mentally, asking themselves, *"Can we do it this way?"*, or they try to identify a relationship between what is given in the problem. It can be illustrated by the students (S1) to solve the fourth problem; he thought mentally, *"What is the connection between the number of the medicine pills and the time it takes to be finished?"* He multiplied the number of hours by the number of pills. Figure 1 shows his answer.

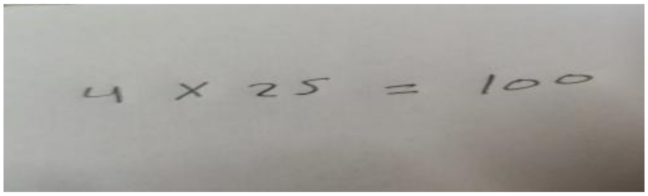


*Figure 1. The solution of (S1) for the fourth problem*

The researchers discovered that all students follow Polya's third step of problem-solving, which is to apply the solving way, while none of them follow the fourth step, which is to check all students' solutions.

Many students (50%) will struggle to analyze the mathematical problem since they have not completed the first step of Polya's problem-solving steps. It will therefore perplex the students in terms of following a way to solve the problem sequentially. If some students can find a solution, they will have no justification for utilizing that way or using the error and trial strategy (Choice and intelligent guessing) to solve the mathematical problem.

As can be seen in the following quotes, the students' responses during the semi-structured interview emphasized this point:

Researcher: *"Explain why you used this method to solve the problem."*
Student (S2): *"I do not know, but I believed I had to do this."*

This question was not answered in some cases.

Researcher: *"Explain why you used this way of problem-solving?"*

Student (S1): *"Honestly, I cannot resolve any problem at school. I solve it at home, I try numbers."*

Based on the foregoing, it is evident that the student's lack of understanding of the concept of giving and requirement, as well as their failure to understand the reason for employing this way in solving the problem, is consistent with Phonapichat and his colleagues' findings (Phonapichat et al. 2014). Their study found that students could not recognize the giving and requirement in a mathematical problem, so when they do not understand the mathematical problem, they tend to guess the answer rather than rely on mathematical reasoning to solve the problem. It contradicts Freeman (Freeman, 2013), who stated in his study that all participating students could understand the process. The researchers believe that this is because students in the current study are fourth and fifth graders, whereas they are different from students in Freeman's study (2013). It is because logical and analytical thinking develops later, allowing students to break down a problem into its components, understand it, and choose the best problem-solving strategy appropriate for the situation.

During problem-solving, students face challenges. For example, S5 faced difficulty in solving the first problem because of its large numbers, as stated in the following quote:

Researcher: *"Do you still have the same difficulty if you replace the numbers with smaller ones?"*

Students (S5): *"No, I will find the answer more easily."*

For some students, the problem's inconsistency with their reality is challenging. Student (S6) believed that the problem of dividing the pie was illogical, as evidenced by the following quote:

Researcher: *"Did you face any challenges during problem-solving?"*

Student (S6): *"Yes, it was difficult."*

Researcher: *"Is the final answer that you got logical? Why do you think that?"*

Students (S6): *"No, because when we bring a pie and want to divide it, we do not divide it equally, whatever we try."*

Researcher: *"Explain how you overcame this challenge."*

Students (S6): *"I tried to imagine."*

Considering the preceding quote, we can see that some students connect the problem to real life, as they find it difficult to solve any problem that they cannot relate to reality or solve in a realistic context. It is consistent with what Elia and her colleagues found in their study (Elia et al. 2009). According to the findings, some students (33.3%)

struggle with non-routine (unfamiliar) problems. Table 2 shows the type of difficulty, the number, and the percentage of students who faced it.

*Table 2. The difficulties in solving problems*

| Type of difficulty | No. of students | Percentage |
|---|---|---|
| Difficulty in analyzing the problem. | 3 | 50% |
| Difficulty of solving non-routine problems. | 2 | 33.3% |
| Difficulty in solving a significant number of problems. | 1 | 16.7% |

The study's second question was as follows:

*What problem-solving strategies do students employ?*

As shown in Appendix (2), the structural code was used to analyze students' responses. The results of this analysis are explained in Tables 3 and 4.

*Table 3. The strategies used by fifth and fourth-graders.*

| Student | Strategies used in the first problem | Strategies used in the second problem | Strategies used in the third problem | Strategies used in the fourth problem |
|---|---|---|---|---|
| S1 | Trial and error strategy (Choice and intelligent guessing) | Logical reasoning strategy | Making a drawing or a diagram strategy | Making a drawing or a diagram strategy |
| Another way | Finding a pattern strategy | Making a drawing or a diagram strategy | | |
| S2 | Trial and error strategy (Choice and intelligent guessing) | Trial and error strategy (Choice and smart guessing) | Trial and error strategy (Choice and intelligent guessing) | Making a drawing or a diagram strategy |

| | | | | |
|---|---|---|---|---|
| Another way | Finding a pattern strategy | Logical reasoning strategy | | |
| S3 | Trial and error strategy (Choice and intelligent guessing) | Trial and error strategy (Choice and smart guessing) | Making a drawing or a diagram strategy | Logical reasoning strategy |
| Another way | | | | |
| S4 | Trial and error strategy (Choice and intelligent guessing) | Trial and error strategy (Choice and smart guessing) | Making a drawing or a diagram strategy | Logical reasoning strategy |
| Another way | Finding a pattern strategy | Working backwards strategy | Logical reasoning strategy | |
| S5 | Trial and error strategy (Choice and intelligent guessing) | Trial and error strategy (Choice and smart guessing) | Working backwards strategy | Trial and error strategy (Choice and intelligent guessing) |
| Another way | Finding a pattern strategy | Working backwards strategy | | |
| S6 | Finding a pattern strategy | Logical reasoning strategy | Finding a pattern strategy | Finding a pattern strategy |
| Another way | | | Logical reasoning strategy | |

*Table 4. Cumulative table for used strategies.*

| **Strategy** | **How often is it used?** |
|---|---|
| Trial and error (Choice and intelligent guessing) | 11 |
| Finding a pattern | 7 |

| | |
|---|---|
| Logical reasoning | 7 |
| Making a drawing or a diagram | 7 |
| Working backwards | 2 |

Tables (3) and (4) show that the most common strategy employed by students was trial and error strategy (intelligent guessing), followed by finding a pattern strategy, logical reasoning strategy, and making a drawing or a diagram strategy, this indicates that these are the most helpful and effective strategies for students in solving a mathematical problem, which is consistent with the prior study's findings (Celebioglu et al. 2010; Ratnasari & Safarini, 2020; Yazgan, 2016).

When looking at the tables, you will see that students utilize different strategies to solve the same problem. For example, in the fourth problem, students (S1) and (S2) used the drawing or a diagram strategy, while students (S3) and (S4) used the logical reasoning strategy. The smart guessing strategy was utilized by student (S5), while the finding a pattern strategy was utilized by student (S6). The researchers also noted that the students' strategies vary in mathematical problem-solving situations. Some students have a greater diversity in using strategies than others, implying that they are more capable of solving mathematical problems. It allows future research to focus on the causes of this diversity and how to improve it among other students. Students have also been observed using a trial-and-error strategy when they are having difficulty solving the problem because they know that this strategy leads them to a solution to the mathematical problem. In contrast, other strategies do not, as in the case of student (S1) when solving the first problem. Figure 2) explains the student's (S1) solution to the first problem.

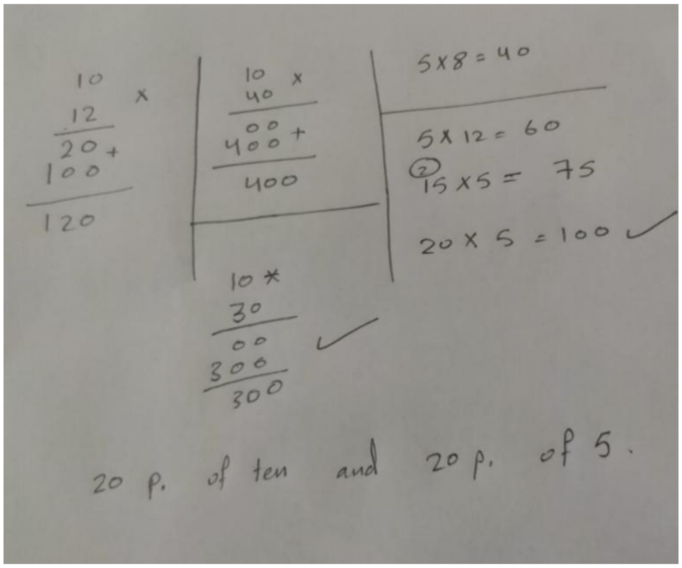


*Figure 2. Student's (S1) solution to the first problem.*

It is consistent with the findings of (Elia et al. 2009), which found that students who use multiple strategies while solving mathematical problems are more capable of solving mathematical problems than students who use only one strategy, and that the trial-and-error strategy can lead to success. It was the sole strategy that got students to the correct answer, but this contradicts the findings of the current study, which show that students rarely use problem-solving strategies. The study's findings revealed that students employ various strategies while solving mathematical problems, although most are unaware of Polya's steps for problem-solving or their sequence. That is because elementary school teachers focus on diversifying problem-solving ways and encouraging students to think in multiple ways. We can also see from the table that some students who were unable to answer some problems in more than one way could indicate that they are content with one way of solving the problem and are bored or unable to think differently. It is reinforced by the answer of the student (S6) to the first problem:

Researcher: *"Is it possible to solve the question another way?"*
Student (S6): *"I got tired and do not know."*
Researcher: *"Try to use another way to solve it."*
Student (S6): *"There is no need since I got the answer."*

We see that students lack motivation and need to increase their motivation to think in different ways. We recommend informing them about the ways of solving problems used by other students, as this will expose them to other ways of solving problems, allowing them to develop their own ways, motivate their thinking, and teach them that a mathematical problem can be solved in multiple ways. It will positively impact their performance in mathematical problem-solving and deductive reasoning.

## Conclusions

As the ultimate objective of teaching and learning mathematics, many researchers have long investigated why students have low skills and abilities to solve mathematical problems. This study aimed to determine the strategies students use when solving mathematical problems and their ability to solve the problem using more than one way. According to the findings of this study, fourth- and fifth-grade students do not follow Polya's steps when solving a mathematical problem, and they also cannot extract the given and required information despite their capacity to obtain the proper solution. Additionally, they often use ways to get the solution without comprehending the reason, beyond adopting this way to solve a mathematical problem. The study concluded that students confront challenges in solving mathematical problems, such as the difficulty of solving problems with large numbers, and those that they cannot correlate to reality. The findings also suggested that when students cannot identify the best way to solve the problem, they employ a trial-and-error strategy. It is worth noting that this strategy is the most prevalent strategy among students.

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Appendix (1)

Mathematical problems:

First problem:

Samah has 50 coins, some of which are 10 Shekels and the others are 5 Shekels. If Sama's total amount is 400 Shekels, how many coins of each type does she have?

Second problem:

In front of the school canteen, Khaled and Ali stand in a queue. When counting from the beginning of the queue, Khaled's order is number five, and Ali's order is number twelve when counting from the end. How many students stand between Khaled and Ali if you know the number of students in the queue is 25?

Third problem:

If five girls share a pie evenly, and seven boys share two pies equally

- How much does each girl get?
- How much does each boy get?
- Who gets more, boys or girls?
- Suggest a way to equalize the proportion of boys and girls.

Fourth problem:

Every four hours, Amani must take a medication pill. How long does Amani need to finish her medication if she has 25 pills?

On each mathematical problem, the questions below were asked:

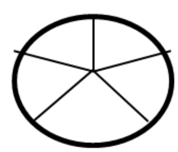
1. Identify the giving and requirement. How did you come up with the solution?
2. Explain why you used this problem-solving way. Is there a different way to solve the problem? Think, then answer this question.
3. Is your final answer logical?
4. Did you face any challenges when attempting to solve the problem? Explain how you overcame this challenge.

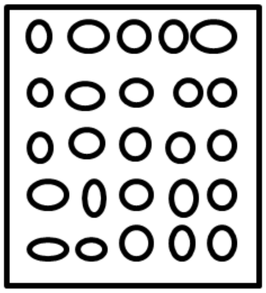
Appendix (2)

The structural code for analyzing the interview

Constructing this structural code referred to the studies on problem-solving strategies (Posamentier & Krulik, 2009).

| Strategy | Description | Example |
| --- | --- | --- |
| **Finding a pattern strategy** | **The problem comprises codes that follow a particular pattern; this pattern leads us to the solution rule.** | *He solved the first problem by adding the tens and fives to get to the output 400<br><br>10+10+10+10+10+10+10+10+10<br>+10+10+10+10+10+10+10+10+<br>10+10+10+10+10+10+10+10+10<br>5+5+5+5+5+5+5+10+10+10+10+<br>400=5+5+5+5+5+5+5+5+5+5+5+5+5+<br><br>Then the solution is 30, 10, 20, and 5 pieces. |
| | | *He solved the first part of the problem by adding the fractions, stating that ½ +½ =1. It means the pie is divided into two pieces, and each girl gets a half.<br><br>If there are five girls, the solution will be: 1/5+1/5+1/5+1/5+1/5=1<br>Then each girl gets a fifth. |
| **Error and trial strategy (Choice and intelligent guessing)** | It is the simplest way to solve a mathematical problem. The requirement is found after numerous attempts to apply all conceivable processes. Deductive trial and error and | *He solved the first problem by multiplying some numbers by 10 and 5, then he added the outputs to find the solution<br>120=12×10<br>400=40×10<br>300=30×10 |

| | | |
|---|---|---|
| | organized trial and error strategies are two examples. | 40=8×5<br>300+40=340 (Wrong answer)<br>60 =12×5<br>300+60= 360 (Wrong answer)<br>100 =20×5<br>100<br>400 =300+<br>Then the solution is 30 coins of tens, 20 coins of fives. |
| | | *He solved the second problem by adding 12 and 5 to the output 25, the total number of students.<br>$25 \neq 6 + 5 + 12$<br>$25 = 8 + 5 + 12$<br>Then, eight students are standing between Khalid and Ali. |
| **Making a drawing or a diagram strategy** | It represents the problem in a geometric form to illustrate the connections between the components of the problem to arrive at a solution. | *He solved the first part of the second problem by drawing a circular pie, then he divided it into five sections and gave one piece to each girl, that is, one-fifth for each girl (5÷1=1/5)<br> |

| | | |
|---|---|---|
| | | *To solve the fourth problem, he drew a pillbox; he claimed that the solution is 25×4=100 hours to finish the entire medicine.  |
| **Working backwards strategy** | Using the given in a sequence backwards, the starting points for solving the problem are the last given input in the problem, and so on. | *He solved the second problem by beginning at the end of the question. The total number of students was 25; he subtracted Ali's and Khalid's ranks to get the students between Ali and Khalid. 25–12–5=8 |
| **Logical reasoning strategy** | The process of employing the logical sequence in conjunction with a problem-solving explanation. | *He solved the second problem by stating that if there are five students at the beginning of the queue and 12 students at the end of the queue, the total number of students is 17. The number of students in the queue is 25, so 17+8=25, and then eight students stand between Khalid and Ali. |
| | | *He solved the fourth problem by calculating that if one medicine pill is taken every 4 hours, the total number of pills is 25, then 25×4=100 hours |