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Exploring Secondary Students' Algebraic Thinking in Terms of Intuitive Cognitive Style

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abstract

Algebraic thinking has the important role to improve the students' understanding in solving real-world problems, especially in algebraic forms. The aim of this study is to explore the students' algebraic thinking in terms of intuitive cognitive style. This research used the qualitative approach with case study method. 61 Grade-8 students in one of public secondary schools in Ngawi District, East Java, Indonesia were participated in this study. Three intuitive subjects were selected for interviewed. This study used algebraic thinking test, questionnaires, and interview protocol for collecting the data. Researchers adopted ten questions from *TIMSS 2011 8th-Grade* to examine the students algebraic thinking abilities. All questions were validated by three experts in mathematics education and piloted before used. In this study, three algebraic thinking components: generalization, analytic thinking, and dynamic thinking were used to analyze the students algebraic thinking abilities. The finding showed that the intuitive students can solve number pattern problems using picture and number patterns in generalization component. In analytic thinking component, students can solve problems related to equations using trial-error strategies and substitution methods. The students can also carry out dynamic thinking component about equivalent proportion by determining the median value and proportion concept. Thus, it can be concluded that the intuitive students are able to demonstrate the three algebraic thinking components properly.

Keywords:
Algebraic thinking, Intuitive style, Generalization, Analytic thinking, Dynamic thinking

INTRODUCTION

Kieran (1996) defined algebraic thinking as a quantitative approach that emphasizes relational aspects not only related to written symbols, but also can be used to support cognitive abilities. Amerom (2002) explained that algebraic thinking is a process that includes undefined reasoning, generalization, and formalization of the relationship between quantities and variable concepts. Algebraic thinking by Kaput (2017) is defined as a conceptual framework used to solve problems. According to him, the theory of algebraic thinking contains two different aspects: generalization and symbols, which include arithmetic, functions, and modeling.

Algebraic activities by Kieran (1996) are categorized into three: generalization, transformational, and global meta-level activities. Generalization is defined as an activity that involves the formation of algebraic expressions and equations. Transformational is an activity related to changing the form of an expression or equation to maintain its equality. Global meta-level activities include problem solving, modeling, generalization, linkage analysis, proof, even activity predictions that can be done without even using algebra. The components of algebraic thinking according to Lew (2004) are classified into six components: generalization, abstraction, analytical thinking, dynamic thinking, modeling, and organizing. Generalization is a process of finding patterns or shapes. Abstraction is the process of extracting objects and mathematical relations based on generalizations. Analytical thinking is defined as the process of solving a problem. Dynamic thinking can be developed by deducing hypotheses and trial and error strategies to monitor and control actions on each variable that changes. Modeling is a process for representing complex situations using mathematical expressions, for investigating a condition with a model and drawing conclusions from the activity. Finally, organizing is the process of sorting and organizing data using tables about problem conditions, the relationship between problem conditions, and the relationship between the independent variables and the dependent variable. Kriegler (2007) stated that thinking consists of two main components: development of mathematical thinking instruments and fundamental algebraic ideas. Mathematical thinking covers three topics: problem solving, representation, and quantitative reasoning skills. Then, fundamental algebraic ideas consist of three main points: algebra as general arithmetic, language, and function and mathematical modeling.

The formulation of algebraic thinking components by experts are vary. In this study, researchers use the formulation from Lew (2004) as a framework to explore the student's algebraic thinking abilities. The component criteria by Lew are clearly presented in the algebraic thinking sub-component. It's help the researchers to compose questions, evaluate the results of student answers and analyze the strategies used in solving problems.

Permatasari and Harta (2018) states that algebraic thinking is important for students to develop mathematical concepts. Understanding the basic concepts of algebra is important according to Agoestanto et al (2019) because it is required for students' prior knowledge when they will learn the next subjects that involves algebra. The importance of algebraic thinking is to increase students' skills to understand and solve problems in everyday life, especially with regard to algebraic forms Farida and Hakim (2021). The development of algebraic thinking from an early age is important for developing mathematical reasoning processes in tool-mediated learning processes Wettergren (2022).

Everyone has differences in receiving and processing information. Jena (2014) explains that cognitive style is an attempt to define problems based on personality and interrelated conditions. Arina and Lukito (2019) interpreted cognitive style as the way people to receive, process, and respond the information. Martin (1998) distinguishes cognitive styles into two catagories, systematic and intuitive. Student who has a systematic style usually uses a planned approach as a whole to solve problems. In contrast, student with an intuitive style tends to use unexpected analytical steps in solving problems.

The study related to the student's algebraic thinking skillss based on cognitive style has previously been carried out (Agoestanto et al., 2019; Arina & Lukito, 2019; Esti et al., 2020; Kusumaningsih et al., 2020; Maharani et al., 2018). Maharani et al (2018), in his research explained that students with an impulsive-reflective cognitive style were able to fulfill the indicators of algebraic thinking according to Lew. However, reflective students tend to better understand about the problems in the questions compared to impulsive students. Arina and Lukito (2019) conducted research related to the algebraic thinking skills of junior high school students in solving number pattern problems in terms of intuitive systematic cognitive style. They found that the systematic students tried to deconstruct numbers to determine the series of certain terms. It's different with intuitive students who tend to use *trial-error* strategies to solve the problem. Agoestanto et al (2019) conducted the research related to the position and causes of algebraic thinking errors in terms of field dependent and field independent cognitive styles. Other research was also carried out by Esti et al (2020) which explained that students with a reflective cognitive style were able to meet five indicators of algebraic thinking, namely generalization, abstraction, dynamic thinking, analytical thinking, and modeling. Kusumaningsih et al (2020) in his study discussing students' algebraic thinking in terms of cognitive reflective impulsive style based on gender. Based on previous research, the study on algebraic thinking in terms of cognitive style has been carried out. However, the research related to algebraic thinking in terms of intuitive cognitive style is still limited.

Previously, research on algebraic thinking related to intuitive systematic style had been carried out by Arina and Lukito (2019). However, their research was only focused on exploring students' intuitive systematic algebraic thinking skills on the generalization component. In this study, researchers extend the exploration of the students' intuitive algebraic thinking abilities on the three components, namely generalization, analytical thinking and dynamic thinking. So, the problem of the research is how are students' algebraic thinking skills intuitive in solving mathematical problems. The results of this study are expected to help the teachers for designing the learning approach or model to facilitate the students for developing algebraic thinking skills according to the characteristics of their individual differences such as cognitive styles.

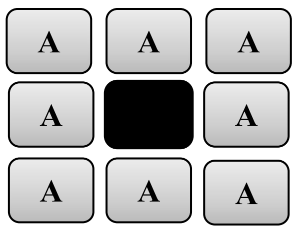
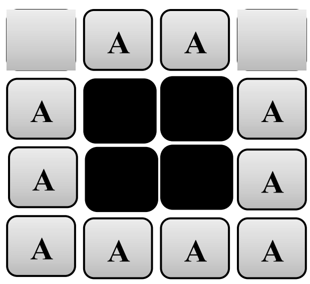
METHODS

This type of research is a case study qualitative research that aims to explore students' algebraic thinking skills based on intuitive cognitive style. This research involved 61 Grade-8 students at one of public secondary schools in Ngawi District, East Java, Indonesia. The data were collected by algebraic thinking skills test, *Cognitive Style*

Inventory (CSI) questionnaries, and interview protocol. The algebraic thinking test instruments were adopted from the *TIMSS 2011 8th-Grade Mathematics Concepts and Mathematics Items* (TIMSS & PIRLS, 2013). The researchers selected ten questions which included two questions in each component of algebraic thinking: generalization, abstraction, analytical thinking, dynamic thinking, and modeling. The instrument questions were first validated by three experts in mathematics education. In addition, the researchers also piloted the intrument to 20 students who were not included as the research subject. Based on the validation and pilot process, the researchers eliminated one question on generalization and dynamic thinking components, respectively. So, the researchers set eight questions to reveal students' algebraic thinking skills. To find out the classification of students based on cognitive style, the researchers adopted *The Cognitive Style Inventory (CSI)* questionnaire was developed by Martin (1998). To further explore the students' algebraic thinking skills, the researcher interviewed the selected subjects. The interview protocol was first validated by two experts before being used.

The focus of this study is to analyze three questions included generalization, analytical thinking, and dynamic thinking as presented in Table 1. The researchers explore students' skills in determining the total number of tiles and the number of gray tiles in a particular square shape using generalization questions. Analytical thinking questions are used to explore students' ability to determine the value of a particular equation. Finally, dynamic thinking questions are used to explore students' ability to determine the length of a bush's shadow at a certain height.

Table 1
Algebraic Thinking Test Questions

No	Question Type	Question
1	Generalization	Several pieces of tiles are arranged into a square shape as follows: A 3 x 3 square shape consists of 8 gray tiles and 1 black tile.  A 4 x 4 square shape consists of 12 gray tiles and 4 black tiles.  The table below shows the number of tiles arranged into a square shape of various sizes. Complete the table below to find out the number of tiles that make up the square!

Form	Number of Black Tiles	Total Gray Tiles	Total Tiles
3 × 3	1	8	9
4 × 4	4	12	16
5 × 5	9	16	25
6 × 6	16		
7 × 7	25		

2	Analytical Thinking	a + b = 25 What is the value of 2a + 2b + 4 ?
3	Dynamic Thinking	Pay attention to the table below!

Check height (cm)	Shadow Length (cm)
20	16
40	32
50	
60	48
80	64

The table above shows the shadow lengths of four bushes at different heights at 10 am. If the bush is 50 cm high, then determine the length of the bush's shadow!

Based on the results of *The CSI* questionnaires, the classification of 61 students' cognitive style are presented in Table 2.

Table 2
Cognitive style grouping data

Cognitive Style Classification	The number of students
Intuitive Style	3
Integrated Style	12
Undifferentiated Style	9
Split Style	37
Systematic Style	0
Total Students	61

Subsequently, researchers select all subjects in the intuitive cognitive style category based on the data in Table 2. The selection of subjects was based on the results of filling out the *CSI* questionnaires which showed that of the 61 students, three students in the intuitive cognitive style category and no students in the systematic cognitive style category. Then, researchers coded the three subjecst by S1, S2, and S3 to simplify for researchers to analyze the data.

The researchers used four steps to analyze the data. Firstly, the students' answer sheet documents of the results of the students' algebraic thinking skills test were analyzed focus on the solution steps and strategies used by students to solve problems. Researchers use the assesment rubric as shown in Table 3 to analyze the document.

Table 3
Assessment Rubric

Assessment criteria	Score
The solution steps and the answers are correct	3
The solution steps are correct but the answer is incorrect	2
The partial of solution steps are correct but the answer is incorrect	1
The solution steps and the answers are incorrect	0

Secondly, researchers conducted deep interviews to reveal the students understanding in explaining their steps and strategies to solve the problems. In this steps, researchers used semi-structure interview protocol for more flexible in asking the questions. Thirdly, the results of document analysis and interview were triangulated for checking the conformity. Finally, researchers sintesized and summarized the students' pattern in solving problems and formulate the conclusion. The procedure of this study is presented in the figure 1.

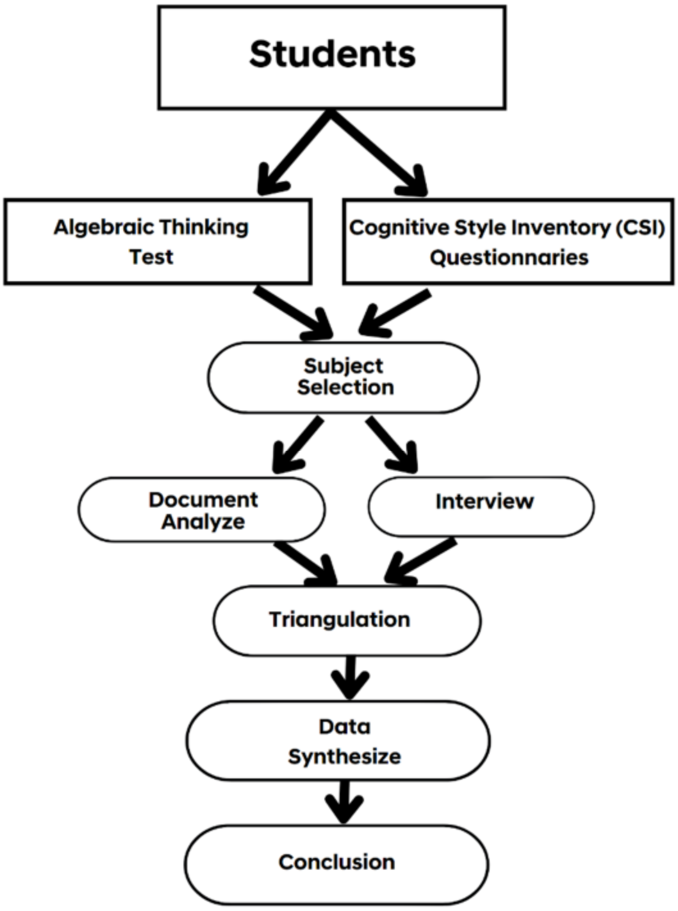


Figure 1
The study prosedure

RESULT AND DISCUSSION

Result

In this section, the results of document analysis and interviews with three subjects of intuitive cognitive style in solving generalization, analytical thinking, and dynamic thinking problems are presented.

Generalization

Generalization questions are used to explore students' algebraic thinking abilities in carrying out generalization activities, namely pattern recognition and number series relationships. Based on the results of the algebraic thinking skills test, S1 and S3 were able to solve problems with the correct steps and results. However, S2 has unable to solve the problem using the correct steps to solve it.

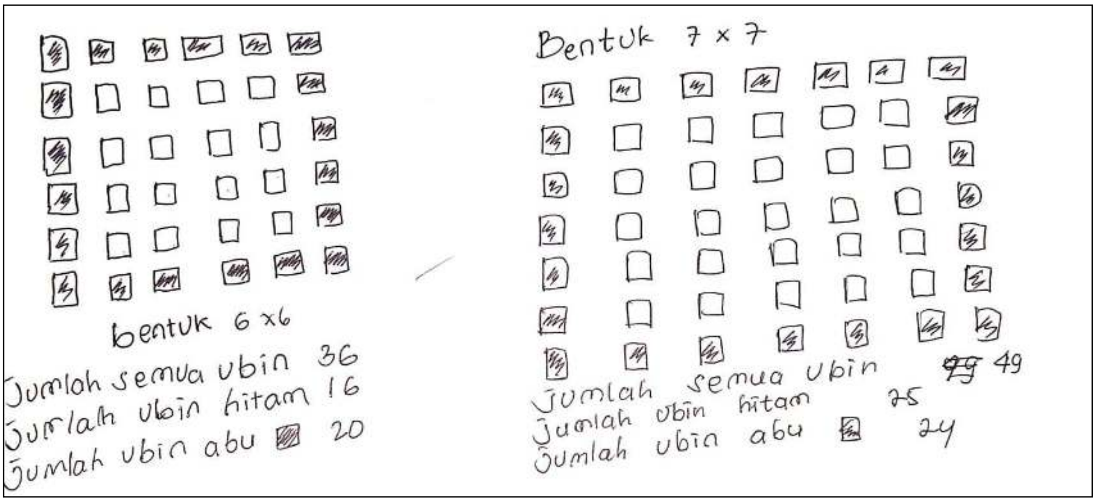


Figure 2
Answers to S1 generalization question

Based on Figure 2, it shows that the solving strategy used by S1 to answer generalization questions is by drawing 6 x 6 and 7 x 7 shape tiles. Then provide shading on the tile images to show the differences between gray and black tiles. S1 determines the total tiles by counting all the tiles drawn. The subject determines the number of gray tiles by counting the edges of the image while the rest is the number of black tiles. Based on this analysis it can be concluded that S1 is able to use picture patterns to solve problems. S3 also used the same strategy, namely solving problems using picture patterns.

During the interview, S3 was also able to explain another solution strategy, namely using number patterns. S3 identify the relationship between the shape of the tiles, the number of black tiles, the number of gray tiles, and the total tiles to find patterns. S3 solves the problem by first determining the total tiles. S3 found the total tiles of the shape 6 x 6 from the multiplication operation 6 x 6 = 36. S3 calculated the difference between the total tiles and the known number of black tiles to find the number of gray tiles. The same way was done to find a 7 x 7 square shape solution. This is shown through the following interview results.

P (Researcher)	:	For this number question, what is known in the question?
S3	:	A square formed from black and gray tiles, then for the same number the total is written in the table, sis.
P (Researcher)	:	How to find the number of gray tiles and their total in the empty part of the table?
S3	:	Look at the pattern, sis, that's 3 x 3, the total is 9, so it means that 6 x 6, the total is 36. To find out the number of ash tiles, you just need to find what number, if you add 16, equals 36, which means 20, right, miss. The 7 x 7 is also the same way.

There are two solving strategies used by the subject to answer generalization problems. The strategy used is the picture pattern and number pattern. Solution of using a picture pattern means that the subject answers the question by illustrating the problem in the form of an image. The solution strategy using number patterns shows that the subject solves the problem by identifying the relationship among data in the problem. Based on the steps and problem-solving strategies, the intuitive subject uses an approach that tends to be non-programmed and uses alternative steps or fast methods, namely by visualizing problems in the form of pictures.

Analytical Thinking

Analytical thinking questions are used to explore students' algebraic thinking abilities in carrying out analytical thinking activities, namely solving equations with inverse operations. Based on the results of the algebraic thinking skills test, S1 was unable to work on analytical thinking questions on the answer sheet but was able to explain during the interview. S2 were able to answer with partly correct and wrong answers, but were able to explain precisely during the interview. Meanwhile, S3 were unable to answer the questions, either on the answer sheet or during the interview.

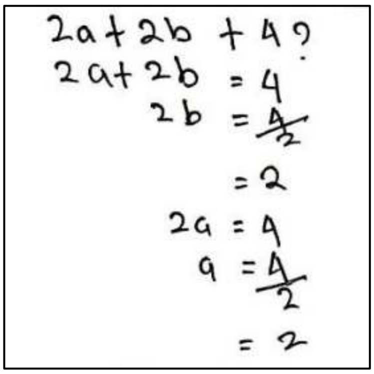


Figure 3

Answers to S1 analytical thinking question

Figure 3 shows that the solving strategy used by the S1 to solve the problem is not appropriate. The strategy presented by S1 in solving problems does not relate questions to known equations in the problem. S1 did not understand the concept of solving problems related to a system of two-variable linear equations. Based on document analysis, it means that S1 have not been able to carry out analytical thinking activities in solving problems in the system of two-variable equations.

Even though they were unable to answer the questions on the answer sheet, S1 were able to explain the appropriate settlement strategy during the interview. S1 completed the problem by taking arbitrary values a and b and then entering these values into the problem, so that the answer was 54. This statement is supported by the following interview results.

P : For question number 4, try to state what is known in the question?

S1 : There is an equation a + b = 25, miss. Then for the question asked to find 2a + 2b + 4.

P : How do you find the value of 2a + 2b + 4?

S1 : You have to look for the value of a and b using that substitution first, miss, but I forgot how. For example, you can, for example, a = 12 then b = 13, so that means correct a + b = 25. That means finding 2a + 2b + 4, all you have to do is replace a with 12 and b with 13 so later (2 x 12) + (2 x 13) + 4 the result is 54. It seems like whatever the value of a is the same as b as long as it fulfills a + b = 25 the result is also the same 54, sis.

P : Ok, try to prove that whatever the value of a is the same as b, as long as it satisfies a + b = 25, the result is also the same as 54 with another example!

S1 : Okay, for example, sis. So, let's try to put it back into the problem, OK, (2 x 10) + (2 x 15) + 4, which means that 20 + 30 + 4 results are the same, Ms. 54. It means that the answer is correct.

In contrast to the S1, the S2 based on document analysis was able to present some of the appropriate solution steps. S2 completed the problem inaccurately because the problem that should have been solved was 2a + 2b + 4 but S2 wrote 25a + 2b = 4. However, when observed the frame of mind used by S2 was not completely wrong because the initial mistake made by the subject was related substitution problem. S2 wrote down several correct operating steps, this was seen in the solution of the first to fourth lines, but for the fifth line there were still errors. In the following, the results of completing the subject will be presented on the answer sheet.

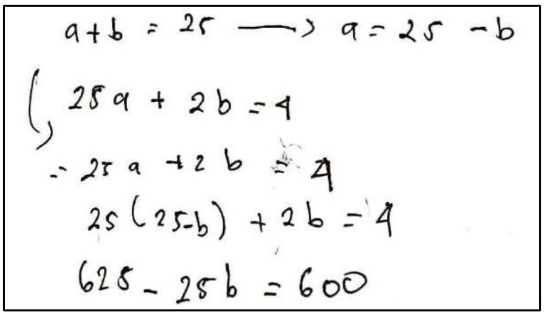


Figure 4
Answers to S2 analytical thinking question

Although unable to answer the questions correctly on the answer sheet, S1 was able to explain the appropriate solution strategy during the interview. The results of the interview showed that S2 solved the problem of a system of two-variable linear equations using a substitution method where S2 first changed the equation a + b = 25 becomes a = 25 – b, then substituted in 2a + 2b + 4 to obtain a result of 54. Referring to the analysis of the interview results, it can be concluded that S2 is able to carry out analytical thinking activities appropriately by using the value substitution step for the problems presented. This statement is supported by the following interview results.

P : Now try to explain the information you got when reading the questions?

S2 : It is known that a + b = 25, then asked to find the value 2a + 2b + 4, sis.

P : Okay, so from the known information you can solve the problem, right? How do you go about solving it?

S2 : First, change a + b = 25 to a = 25 – b so that later the “a” in 2a + 2b + 4 can be replaced with a = 12 – b so that later the symbol will only be b, sis. So that means later it will be 2a + 2b + 4 = 2 (25 – b) + 2b + 4, so all of that is calculated, miss, so the result is 50 – 2b + 2b + 4 = 54. The result is 54, is that right or not sis?

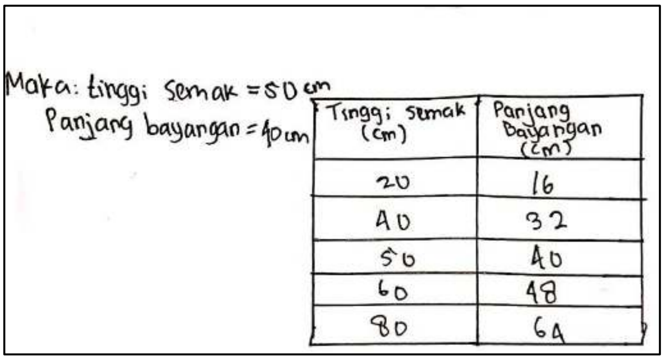
P : Well, yes or no?

S2 : Yes, that's right.

Thus there are 2 solving strategies used by the subject to answer analytical thinking problems. The strategy used is by*trial and error* and substitution. Solution using *trial and* *error* means that the subject answers the question by taking any values a and b. The solution strategy using substitution shows that the subject solves the problem by substituting the value of one of the variables with an equivalent value. Based on the steps and problem solving strategies, the subject is intuitive approach*trial and error* to solve the problem.

Dynamic Thinking Questions

Dynamic thinking questions are used by researchers to explore students' algebraic thinking abilities in carrying out dynamic thinking activities, namely solving problems using direct proportions. Based on the results of the algebraic thinking skills test, S1 and S2 were able to answer with the correct steps and results on the answer sheet. The S3 was unable to answer with the right steps and results. But able to explain at the time of the interview.


Maka: tinggi semak = 50 cm
Panjang bayangan = 40 cm

Tinggi semak (cm)	Panjang Bayangan (cm)
20	16
40	32
50	40
60	48
80	64

Figure 5
Answers to S1 dynamic thinking question

Based on Figure 5, S1 completes the problem by writing the results of the solution directly on the answer sheet. Solution on the answer sheet shows the subject is able to find the right solution. S2 also used the same strategy, namely writing the results of the solution directly on the answer sheet.

At the interview stage, S1 and S3 explained the same settlement strategy. Both solve the problem by applying the concept of comparison of worth. The subject explained that the solution to the problem related to the length of the bush's shadow can be solved by looking for the pattern in the table where for every bush that has a height of 20 cm, the length of the shadow is 16 cm, meaning that for every 10 cm the bush has a shadow of 8 cm. Furthermore, to determine the shadow of a bush that has a height of 50 cm, it can be obtained by adding up the previous shadow lengths, namely 32 cm and 8 cm, so that a bush shadow length of 40 cm is obtained. The following is one of the results of an interview with the subject.

P	:	What is known in question number 6 what do you think?
S1	:	The height of the bush and the length of the shadow are right at 10 am, Miss. The data is in the table, Miss.
P	:	Then what was asked about?
S1	:	Determine the length of the shadow of a bush that is 50 cm high

P : So, from the data in the table, how do you determine the shadow of the bush, how come you can get the answer 40 cm?

S1 : The height of the bush is 40, right, the shadow is 32, that is added 8 so the result is 40

P : 8 where can it come from?

S1 : From 16 divided by 2, because if the difference in height is 20, the length of the shadow is 16, so from height 40 to 50, the difference is only 10, so to calculate the length of the next shadow, add half of 16.

In contrast to the strategies and solving steps used by S1 and S3, S2 solved the problem by identifying the patterns contained in the second to fourth order bush height data until it was obtained that the difference in the height of the 3 bushes was 10 cm each. Furthermore, S2 thinks that means the difference in the length of the shadow will also have such a pattern. To find out the length of the shadow of a bush when the height of the bush is 50 cm, S2 writes down the numbers 32 to 48 according to the data in the table then determines the length of the shadow on a bush that has a height of 50 by finding the median between 32 and 48 so that the result is 40. This is shown in the interview draft. following.

P : OK, for question number 6, what information is known in the problem?

S2 : The data for the height of the bush and its shadow at 10 am, sis.

P : OK, from the answer sheet you wrote down yesterday's answer 40. How do you solve it, how come you get 40?

S2 : Oh, I forgot.

P : Nothing to remember at all? Take a look at the problem first!

S2 : Oh, just like this, the easy way is like that, sis, but I don't know whether it's true or not. Right, between the heights of 40 to 50 and 50 to 60, the distance is the same, Ms. 10, right? It means that between the 32 and the empty column and the 48th empty column, the distance will also be the same. It means that we just write down the numbers starting from 32 to 48. Now, we can see which number is in the middle position. This means that 40 is the same difference, which is 8.

P : OK, great solution idea.

Thus there are 2 solving strategies used by the subject to answer dynamic thinking problems. The strategy used is the concept of value comparison and looking for the median value. Solving using the concept of worth comparison means that the subject answers the question by comparing the height value of the bush and the value of the shadow. The solution strategy for finding the median value shows that the subject solves the problem by finding the middle value between the length of the image before and after it. Based on the steps and strategies for solving problems, intuitive subjects tend to be unstructured in presenting solving steps. Intuitive subjects more often explore strategies in their minds and immediately present the results of their solution on the answer sheet.

Discussion

There are two solving strategies used by the subject to answer generalization problems, picture and number pattern. On the picture pattern, the subjects represent the problem in the form of image. The subjects draw all tiles to calculate the numbers of tiles based on the different color. Furthermore, the solution strategy using number patterns shows that the subject solves the problem by identifying the relationship among data in the problem. The subjects used the number pattern on the table to find the number of tiles on the previous pattern. Based on the problem-solving strategies, the intuitive subject solve the generalization problem by visualizing in the form of pictures. The results of this study are in line with the research by Kristanto and Manoy (2021) which states that students with a cognitive-intuitive style tend to use visual and symbolic representations in solving problems. The visual representation is shown through the pictures presented to solve the problem. Meanwhile, the symbolic representation is shown by the subject through the variables used by the subject to answer the questions.

For the analytical thinking problems, there are also two solving strategies used by the subject to answer the questions, namely *trial-error* and substitution. On the trial-error strategy, the subjects used any values a and b to find the unknown variable. The solution strategy using substitution shows that the subject solves the problem by substituting the value of one of the variables with an equivalent value. Based on the problem-solving strategies, the intuitive subject solve the analytic thinking problem by *trial and error* and subtitution. This results in line with study by Arina and Lukito (2019) which states that students intuitively tend to use trial-error to solve problems, namely by choosing any number that satisfies the known equation in the problem. The results of the study by Miftaqurohmah and Hayuhantika (2020) also states that intuitive students often use try and error and skip steps (not sequential).

For the dynamic thinking problems, there are also two solving strategies used by the subject to answer the problems, namely the concept of direct proportion and median value. On the direct proportion strategy, the subjects answers the question by comparing the height of the bush and it shadow. The solution strategy with median value shows that the subjects solve the problem by finding the middle value between the two length of the bush's shadow. Based on the problem-solving strategies, the intuitive subjects tend to be unstructured steps in solving problem. They immediately present the solution stategies in their minds to the answer sheet. In the dynamic thinking activity of intuitive students, the answer sheet does not present the solution steps clearly, and directly writes down the solution. This character corresponds to an intuitive personality that tends to be spontaneous and not sequential when answering a problem, Syuhriyah et al (2021).

The finding showed that the intuitive subjects generally able to perform algebraic thinking activities in generalization, analytical thinking, and dynamic thinking components. In addition, the strategies in determining the solving problem are vary. The characteristics highlighted by the intuitive subject include solving problems by trial and error, representing problems visually, unstructured, and spontaneously. This is consistent with a statement from Martin (1998) which states that someone with an intuitive cognitive style uses a visual approach and trial and error strategies to solve problems.

CONCLUSION AND IMPLICATION

Conclusion

The students with a cognitive-intuitive style are generally able to perform algebraic thinking activities in generalization, analytical thinking, and dynamic thinking components. In generalization activities, subjects able to solve problem using picture patterns and number patterns. In analytical thinking activities, subjects were able to solve problem using trial-error and substitution strategies. Then, in dynamic thinking activities, subjects were able to solve problem using the concept of value comparisons and determining the mean value.

The limitation in this study is that it only focuses on analyzing intuitive cognitive styles. So it has unable to compare the students algebraic thinking skills in exploring mathematical problem solving strategies with other cognitive styles. The researchers recommend for future research to expand the analysis of student's algebraic thinking skills on the other cognitive styles.

Implication

The results of this study are expected to be the attention for teachers to carry out the learning process, especially at the junior high school level. The diversity of student's cognitive styles is a challenge for teachers to design the learning models or strategies in the classroom to facilitate the individual differences. The differentiated learning is one of learning strategies that able to facilitate student learning according to individual abilities.

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