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Students' Analogical Reasoning Errors in Solving Mathematical Analogy Problems: Differences in Abstract Sequential Thinking Styles

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Abstract

Students' ability to construct analogical thinking is an important skill in solving mathematical problems, as it allows them map knowledge from familiar mathematical concepts to new mathematical concepts. Unfortunately, many students make errors in constructing analogies, especially when faced with abstract and complex problems. Individuals with an abstract sequential thinking style, known for their ability to analyze ideas and describe logical sequences are interesting subjects for research on how they solve mathematical analogy problems and what types of analogical reasoning errors emerge during the process. This study aims to identify and analyze analogical reasoning errors made by students with an abstract sequential thinking style when solving mathematical analogy problems. This case study qualitative research was analyzed using the Miles and Huberman model. The research subjects were Tenth-grade senior high school students. Based on the questionnaire, 31 students with an abstract sequential thinking style were identified from 183 students, from which two students were selected as samples. Based on the analysis of the two research subjects, it was found that students with an abstract sequential thinking style experienced analogical reasoning errors at the Applying stage, in the form of errors in the use and construction of concepts. Both subjects also completed the inferring stage before returning to the encoding stage of the target problem. The results study indicated that even students with strong logical abilities can still struggle to apply mathematical concepts, particularly when dealing with analogies, suggesting that teachers can develop more effective instructional strategies.

Keywords: Analogy Reasoning, Abstract Sequential, Mathematical Analogy Problem

1. Introduction

Students' errors in solving mathematical problems can be examined from various perspectives. One perspective for analyzing student errors is the causative factor. Identifying the factors that cause students' errors is important because by uncovering these causes, we can work to prevent such errors, so that they can be avoided in future mathematical problem-solving.

Research studies that have been conducted on students' errors in solving mathematical problems is numerous, both in relation to the factors causing the errors and the types of errors made by students. Several factors that contribute to students' errors in solving mathematical problems include limited comprehension of mathematical concepts, insufficient practice, and perceived difficulty of mathematics (Rahma & Khabibah, 2022; Subaidah & Nuryanti, 2022). Students also struggled with word problems and identifying appropriate formulas (Fauziah & Astutik, 2022; Mafruhah & Muchyidin, 2020).

One of the factors causing errors is a limited understanding of mathematical concepts. This limitation in understanding mathematical concepts occurs due to several factors, one of which is the difficulty of learning through mathematical thinking. Leatham et al., (2015) found that one of reason why learn using mathematical thinking so really hard to do by students is because the complexity to recognize and interpret teachers mathematical thinking.

Besides these factors, the other factor causing misunderstanding in students mathematical thinking is the conceptual construction error. Conceptual construction error often happened when students solving a mathematical problem. Students often struggle with concept interpretation, reasoning, and connecting mathematical knowledge (Kusno & Sutarto, 2022). Misplaced concepts and mis analogy, also have contribute to errors in constructing mathematical concepts (Setiawan et al., 2023).

Subanji, (2015) divided concept construction errors into four types: pseudo-construction, construction gaps, logical construction errors, and analogical construction errors. Analogical construction errors are closely related to students' analogies. Analogy is the process of identifying similarities or a structural relationship between two or more objects. Furthermore, analogy is viewed as a process of mapping a relationship between two problems, referred to as the source problem and the target problem. (Meagher, 2006). Because of that, analogical construction errors is an error that students make when they try to make a relation between the new learning material they have just learned and the material they have already learned.

Students' ability to construct analogical thinking is an important skill in solving mathematical problems, as it allows them to make relation or mapping knowledge from familiar mathematical concepts to new situations or unfamiliar mathematical concepts. Unfortunately, although analogical thinking is considered a valuable skill in supporting mathematics learning, many students make errors in constructing analogies effectively, especially when faced with more abstract and complex problems. Errors in analogical construction or analogical thinking can be influenced by various factors, one of which is the student's thinking style, which affects how they process information and solve problems.

Anthony Gregorc identified that there are 4 types of thinking styles that are influenced by 2 factors, which is perception and the ability to organize information processing. A person's perception of an object consists of 2 things, which is concrete and abstract. A person's ability to organize information processing is also divided into 2 things, which is sequential (linear) and random. Thus, there are 4 thinking styles, namely concrete sequential, abstract sequential, concrete random, and abstract random.(Munahefi et al., 2023)

Abstract sequential thinkers excel in analyzing ideas, describing logical sequences, and using facts to prove theories (Andini & Masduki, 2022; Rahmah et al., 2021). They demonstrate strong mathematical communication skills, particularly in written text, drawing, and mathematical expressions (Utami et al., 2020). However, research shows that students with this thinking style can also experience errors in analogical thinking, especially when they fail to accurately map the relational structure between the source problem and the target problem. This may be due to limitations in the ability to identify relevant structural similarities or a tendency to focus on irrelevant surface similarities. (Lailiyah et al., 2018)

As an example, research conducted by Fazrianti et al. (2022) found that students with an abstract sequential thinking style have lower mathematical analogical thinking abilities compared to students with a concrete sequential thinking style. In their research, it was found that students with an abstract sequential thinking style had an average mathematical analogical thinking score of 31.50 out of 100, while students with a concrete sequential thinking style had an average score of 46.25 out of 100. This indicates that there are analogical thinking errors exhibited by students with an abstract sequential thinking style, although it is not yet clear where the errors lie in the construction of their analogical reasoning.

Therefore, further research is needed to gain a deeper understanding about types of errors students make when they constructing analogical thinking or when they do the analogical reasoning, particularly among students with an abstract sequential thinking style. Accordingly, this study aims to identify and analyze the analogical thinking errors made by students with an abstract sequential thinking style in solving mathematical analogy problems.

2. Methods

This research on students' errors in analogical reasoning was conducted using a qualitative case study research method. A qualitative approach was chosen because the study aims to understand the case of how the research subjects made an error during the construction analogical thinking or analogical reasoning in solving mathematical analogy problems. In this study, the data obtained consisted of students answer sheet and verbal explanations intended to describe how the errors made during the analogical reasoning and which stages of analogical reasoning experience errors.

This study was conducted with 10th-grade students at SMA Negeri 2 Banjarmasin, selected for its diverse student population, which provided an appropriate context for identifying individuals with an abstract sequential thinking style. A total of 183 students participated in the initial phase. Using purposive sampling, the researchers aimed to select participants who met the specific criteria relevant to the study's objectives. All participants completed a thinking style questionnaire developed by John Le Tellier, adapted from Gregorc's model, and validated by a professional psychologist to ensure its reliability and appropriateness (DePorter & Hernacki, 2015). Based on the questionnaire results, students were classified into four categories of thinking styles, and 31 students were identified as having an abstract sequential thinking style. From this group, two students were selected as primary research subjects based on their ability to articulate their thinking processes during interviews, which was essential for in-depth qualitative data collection. The classification results from the questionnaire are presented in Table 1 below.

Table 1 .
Thinking Styles' Distribution from Class X Students of SMA Negeri 2 Banjarmasin

Nu.	Thinking Style Type	Students
1	Concrete Sequential (CS)	34
2	Abstract Sequential (AS)	31
3	Abstract Random (AR)	88
4	Concrete Random (CR)	30

Data collection in this research used several techniques include tests, interviews, and questionnaires. The test consisted of analogical reasoning problems in the form of source and target mathematical problems. The mathematical problems in the test consisted of a quadratic equation problem as the source problem and a logarithmic equation problem as the target problem as seen on figure 1 below. Interviews were conducted to gain a deeper understanding of the students' analogical reasoning processes and their error in solving the given analogy problems. The questionnaire administered was a thinking style questionnaire used to identify the students' thinking styles. The questionnaire consisted of 15 items. Each item contained four descriptive terms, and students were asked to select the two terms that best represented themselves. Each of the four choices corresponded to one of the four thinking styles. After completing the questionnaire, students' responses were recorded in a table and totaled. The highest total among the four thinking styles indicated the student's most dominant thinking style.

Figure 1
Test Instrument Analogical Reasoning

Instrumen Tes Penalaran Analogi Soal Persamaan Logaritma

Bacalah petunjuk berikut!
Soal tes penalaran analogi ini dibuat berpasangan.

a. Baca dan pahami soal terlebih dahulu sebelum menjawabnya!
b. Tuliskan jawabanmu dilembar jawaban yang telah disediakan!
c. Jika merasa ada kesalahan, jangan gunakan tipe-ex, coret saja jawabanmu kemudian tuliskan lagi dibawahnya!
d. Dilarang membuka buku paket atau buku catatan, kerjakan sebisanya saja!
e. Dilarang mencontek atau berdiskusi dengan teman!

1. Sumber

Diberikan fungsi h yang dinyatakan sebagai:

$$h(t) = t^2 + t - 30$$

Tentukan pembuat nol fungsi tersebut!

2. Target

Diberikan fungsi f yang dinyatakan sebagai:

$$f(t) = (\log_2 t)^2 + \log_2 t - 30$$

Tentukan pembuat nol fungsi tersebut!

The stages of analogical reasoning used in this study that used to analyze the error of students' analogical reasoning and observe how students engage in the analogical reasoning process when solving mathematical analogy problems, based on English (2004) can be seen as table 2 below:

Table 2.
Description of Analogical Reasoning Stages

Analogical Reasoning Stages	Students' Activity
Encoding	Subject identifies the elements in the source problem and target problem by writing them in symbolic form (encoding).
Inferring	subject determines the relationships between the elements present in the source problem or solve the source problem
Mapping	Subjects identified relationship between the source problem and the target problem in order to select an appropriate solution method.
Applying	subject solves the target problem by referring to the solution method used in the source problem.

After all the data on analogical reasoning errors were collected, the data were then analyzed using interactive data analysis techniques for qualitative data. The interactive analysis model used was the model of Miles, Huberman, and Saldana. This analysis model involves three activities: data condensation, data display, and conclusion drawing (Miles et al., 2014).

Data condensation carried out in this research is the process of selecting and categorizing the analogical reasoning errors made by the research subjects into four stages of analogical reasoning. This process begins with collecting students' answer documents related to the mathematical analogy problems they have completed. After collection, the students' answers are then sorted according to the research focus needed by the researcher.

Data display in this research was carried out through the organization and consolidation of information. This research focused on displaying the students' answers to the mathematical analogy problems they had completed, which had been categorized into four stages of mathematical analogical reasoning to facilitate analysis. All student answer data were presented and then divided and focused according to the aspects of analogical reasoning to be discussed, with a deeper analysis of the errors that occurred in each stage.

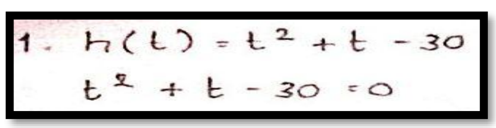
Conclusion drawing in this study began during data collection, such as identifying patterns of analogical reasoning errors made by students and categorizing them into specific groups based on the type of error. Conclusions were also drawn throughout the data analysis process, particularly in relation to the four stages of analogical reasoning identified from the research subjects.

3. Result and Discussion

3.1 Analogical Reasoning First Subject (S1)

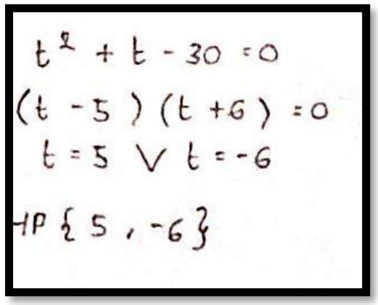
The analogical reasoning demonstrated by S1 shows that S1 was already able to carry out the encoding, inferring, and mapping stages well for the pair of problems. However, it's not happened in applying stage, as the subject made an error by omitting an additional step that should have been included in solving the target problem. As a result, S1 did not arrive at the intended outcome of the target problem in the problem pair. The problem pair consisted of two problems, the source problem represented by question number 1 and the target problem represented by question number 2.
S1's success in performing the encoding stage began with their understanding of the source problem. In solving the analogy problem pair, S1 carried out encoding after identifying the known and asked elements of the problem. The first encoding was done on the source problem, or question number 1. The encoding carried out by S1 can be seen in Figure 1 below.

Figure 2
S1 Encoding Source Problem



After performing encoding on the source problem, S1 did not proceed immediately to encoding the target problem, but instead chose to solve the source problem first. Since S1 solved the source problem first, they entered the inferring stage. The inferring stage carried out by S1 involved identifying the relationship between the known and the asked elements in the source problem. From S1's answer sheet, it can be seen that S1 performed factoring on a quadratic equation obtained by equating the given function to zero. This was done to answer the question posed in the source problem. This process is shown in Figure 2 below.

Figure 3
S1 Inferring Stage



S1 was able to conclude that the relationship between the known element (the function) in the source problem and what was being asked in the source problem is the strategy of factoring a quadratic equation, where the equation is obtained by setting the function equal to zero. The interview excerpt presented in Dialogue Box 1 illustrates how S1 arrived at this conclusion.

R (Researcher): So, after identifying what is known and what is being asked, what did you do after getting that information?
S1: I set the function equal to zero, then I factored it and got the result, Sir.
R: Oh, I see. So what strategy do you think you used to solve question number 1?
S1: Factoring.
R: Is that all?
S1: Yes, Sir.

Dialogue Box 1

After completing the inferring stage, S1 then began working on question number 2, or the target problem. S1 proceeded to perform encoding on the target problem. As shown in Dialogue Box 2 below, S1 had already understood the given problem. Therefore, S1 was also able to carry out encoding, as illustrated in Figure 3 below.

Figure 4
S1 Encoding Target Problem

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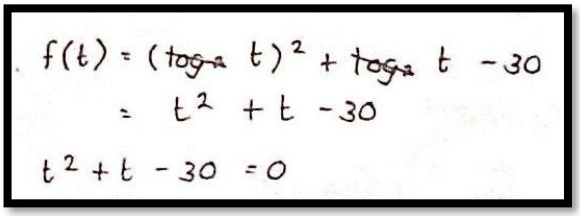


R : Okay. So, in question number 2, what is given?
S1: There's a function, Sir. It's similar to the function in question 1, but there's a logarithm in front of the variable.
R: Oh, okay. And what is being asked in that problem?
S1: Also the zero(s) of the function, just like in question 1, Sir.

Dialogue Box 2

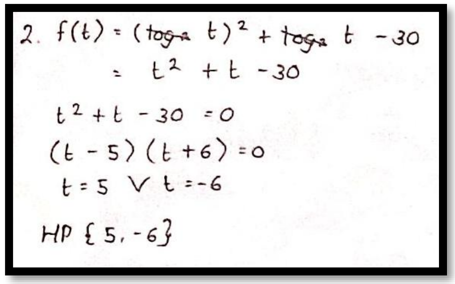
After performing encoding, S1 then mapped the rules from the source problem to the target problem, or conducted the mapping stage. S1 stated that there were similarities between question number 1 and question number 2. S1 considered the given functions to be similar and noted that what was being asked was also the same, so the method used would also be the same. However, interestingly, S1 also assumed that the result for question number 2 or the target problem would be the same as in question number 1 or the source problem. This can be seen in Dialogue Box 3 below.

R: In your opinion, is there anything similar between question number 1 and question number 2?
S1: Yes.
R: If so, what are the similarities?
S1: The functions are similar, Sir, and what's being asked is also the same. The method is the same, and the result is the same too, Sir.

Dialogue Box 3

After completing the mapping stage, S1 proceeded to the applying stage. This stage was carried out by factoring a logarithmic quadratic equation, which was obtained by setting the function in question number 2 equal to zero. Unfortunately, an error occurred during S1's applying stage. Instead of substituting with a variable or directly factoring the logarithmic quadratic equation, S1 incorrectly eliminated the logarithmic part, leaving only the variable. This mistake is shown in Figure 4 below. S1's explanation regarding this error can be seen in Dialogue Box 4.

Figure 5
S1 Applying Stage



R : Now, try to explain how you solved question number 2. *S1: So, since I was looking for the zero of the function, I first set the function equal to zero, then I crossed out the logarithm and factored it, Sir.* *R: Okay, and what was the result?* *S1: 5 and -6.* **Dialogue Box 4**

The error made by S1 was not realized by S1. This was evident from the interview conducted by the researcher. S1 believed that their answer was correct. An excerpt from the interview transcript related to this can be seen in Dialogue Box 5 below.

R : In your opinion, did the method you used provide the correct solution? *S1: Yes, it's correct, Sir.* **Dialogue Box 5**

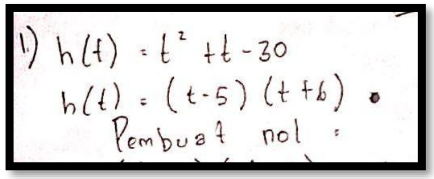
3.2 Analogical Reasoning Second Subject (S2)

The analogical reasoning demonstrated by S2 in the analogy problem pair shows that S2 was able to perform the encoding, inferring, and mapping stages well. However, this did not apply to the applying stage, as the subject made an error by misinterpreting the logarithm into its exponential form, resulting in an incorrect final answer. The analogy problem pair consisted of two problems, the source problem represented by question number 1, and the target problem represented by question number 2.

In performing the encoding stage on the source problem, S2 began by understanding the form of the function presented in the source problem. Additionally, S2 understood what was being asked, enabling them to create a coding of the known and the asked elements, as shown in Figure 5. This is consistent with the results of the researcher's interview with S2. An excerpt from the interview regarding S2's understanding of the source problem can be seen in Dialogue Box 6 below.

Figure 6

S2 Encoding Source Problem



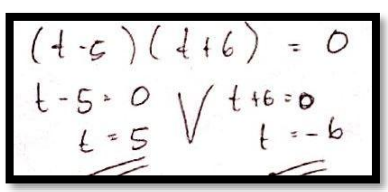
R: So, from question number 1, what do you know about the problem? *S2: There is a quadratic function, Sir, and we need to find its zeros.* *R: From that problem, what is being asked?* *S2: We need to find the zeros of the function, Sir.*
Dialogue Box 6

After performing encoding on the source problem, S2 did the same as S1 by not immediately proceed to encode the target problem but instead solving the source problem first. This is consistent with the results of the interview conducted by the researcher with S2. An excerpt from that interview transcript can be seen in Dialogue Box 7 below.

R : When you were working on questions number 1 and 2, did you finish question number 1 first, or after knowing what was known and asked in question 1, did you then look for what was known and asked in question 2? *S2: I finished question number 1 first, Sir.*
Dialogue Box 7

Since S2 completed the source problem first, S2 entered the inferring stage. The inferring stage carried out by S2 involved identifying the relationship between what was known and what was being asked in the source problem. From S2's answer sheet, it can be seen that S2 performed factoring. Factoring was even done during the encoding stage, so that during inferring, the function set equal to zero was no longer a quadratic function but already in its factored form. Therefore, when set equal to zero, S2 was able to easily identify the values of the variable t that satisfy the zeroes of the function. This process is shown in Figure 6 below.

Figure 7
S2 Inferring Stages



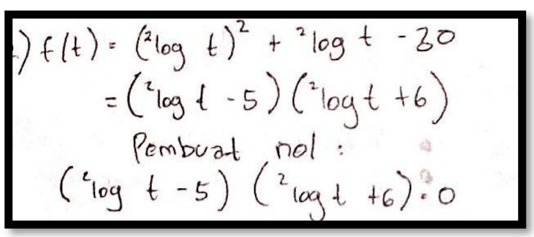
S2 concluded that the relationship between the known element (the function) in the source problem and what was being asked is the strategy of factoring a quadratic equation. Although during the process, S2 had already factored the given quadratic function beforehand, so that when it was set equal to 0, it was no longer in the form of a quadratic equation but rather a product of its factors. An excerpt from the interview presented in Dialogue Box 8 shows how S2 arrived at this conclusion.

R: So, after knowing what you knew and asked, what did you do after getting that information?
S2: The function was set equal to 0, then it was factored, and I got the result t equals 5, and also t equals -6, sir.
R: Oh, I see. So, what strategy do you think you used to solve question number 1?
S2: Factoring.
R: Why did you choose to factor it?
S2: Because it's a quadratic equation, sir.
R: Is that all?
S2: Yes, sir.
R: So, what are the steps to solving it using factoring like you mentioned earlier?
S2: The function is set equal to 0, then it's factored, then the factors are set equal to 0, and then we find the value of t, and that's the result, sir.

Dialogue Box 8

After do the inferring stage, S2 then began working on question number 2 or the target problem. S2 performed encoding on the target problem. S2 was already able to understand the given question and thus was able to perform encoding as shown in Figure 7. S2 identified the known and unknown elements in the problem and created mathematical symbols to represent the situation in the target problem.

Figure 8
S2 Encoding Target Problem

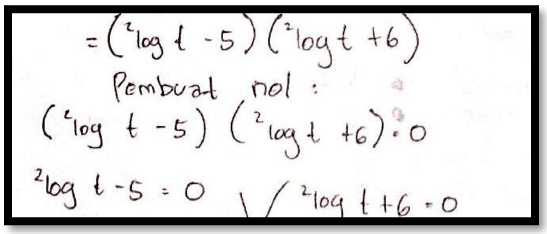


After performing encoding, S2 then mapped the rules from the source problem to the target problem, or mapping. S2 stated that there were similarities between question number 1 and question number 2. S2 considered the two questions to be the same, except that the form of the function was different, because in question number 2, the quadratic function was a logarithmic function. However, S2 believed that factoring could still be used to solve question number 2. This can be seen in Dialogue Box 9 and Figure 8 below.

R: In your opinion, is there anything similar between question number 1 and question number 2?
S2: Yes, there is.
R: If so, what are the similarities?
S2: Everything is the same, sir, except that in question number 2 there are logarithms.
R: Then how about the method to solve it?
S2: It's the same, sir — factor it as well.

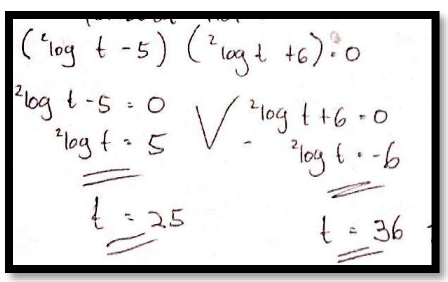
Dialogue Box 9

Figure 9
S2 Mapping Stage



After performing the mapping, S2 proceeded to the applying stage. The applying stage was carried out in the same way as in the solution for question number 1. The given function was first factored so that the equation could be set equal to 0, and the zero values could be found from the multiplication of the function's factors. Unfortunately, the applying stage carried out by S2 was not perfect, due to an error in interpreting the logarithmic form into exponential form. This can be seen in Figure 9 below.

Figure 10
S2 Applying Stage



S2 was actually recognized his errors. This was evident from the interview conducted by the researcher. S2 felt that his answer was still not correct because he was still unsure about the conversion from logarithmic form to exponential form, especially in producing the variable t. This aligns with S2's incorrect response in converting the logarithmic expression to its exponential form in order to find the value of the variable t. A quote from the interview transcript can be seen in Dialogue Box 10 below.

R: In your opinion, did the method you used provide the correct solution? *S2: I think it's still wrong, sir.* *R: Why do you feel it's still wrong?* *S2: I'm not confident about the conversion from the logarithm to the variable t, sir.* **Dialogue Box 10**

Based on the results of analogical reasoning demonstrated by the two research subjects, there are three findings that show similarities between the two subjects with an Abstract Sequential thinking style. The first finding shows that both subjects first solved the source problem—in this case, by performing the Inferring stage in analogical reasoning—before proceeding to the Encoding stage on the target problem. The condition experienced by both subjects with an Abstract Sequential thinking style, namely S1 and S2, aligns with findings from other studies, which indicate that students who have already understood the source problem tend to solve the source problem first before working on the target problem (Pradita et al., 2021; Sakinah & Lukman Hakim, 2023). This also aligns with research findings that highlight the characteristics of students with a Abstract Sequential thinking style who tend to work through math problems systematically and complete all problem solving steps (Rahmah et al., 2021).

The second finding shows that both subjects were able to solve the source problem well. The source problem given was a quadratic equation. This is in line with findings that show students students with abstract sequential thinking styles demonstrate good critical and creative thinking abilities in solving mathematical problems (Ludfiana et al., 2024). Nevertheless, in another study specifically on solving quadratic equation problems, it was found that students with abstract sequential thinking styles struggle to solve quadratic equation problems compared to other thinking styles (Rosiyanti et al., 2020). This indicates that there are other factors related to students with a Abstract sequential thinking style that distinguish this study from the other research.

The third finding shows that both subjects made errors during the applying stage. The error made by S1 indicates a mistake in the Applying stage of the analogical reasoning process, specifically a conceptual error regarding logarithms. On the other hand, S2 made a similar error by solving a logarithmic equation using exponential concepts. This aligns with previous research findings which state that students can make errors during the Analogy stage when performing analogical reasoning to solve problems. (Elgiyan & Wijayanti, 2024; Kristayulita et al., 2018). On the other hand, errors in the Applying stage when solving problems—especially logarithmic quadratic equations as the target problem in this analogy—can occur due to several factors such as lack of understanding of fundamental concepts, insufficient problem-solving strategies, and carelessness in calculations (Islamiyah & Suryadi, 2023; Mone et al., 2024; Yodiatmana & Kartini, 2022).

The results study indicated that even students with strong logical abilities can still struggle to apply mathematical concepts, particularly when dealing with analogies. This result also suggest that teachers can develop more effective instructional strategies to make sure students can apply mathematical concepts correctly and dealing with analogies to improve students' mathematical ability.

4. Conclusion

Based on the results of the research conducted, it was found that students with an Abstract sequential thinking style only made mistakes in the Applying stage of the analogical reasoning process when solving mathematical problems. The errors that occurred in this stage were due to misunderstandings of concepts, either mistakes in applying logarithm concepts or in choosing concepts—where some subjects chose to use exponential concepts to solve logarithmic problems. Students with an Abstract sequential thinking style also tend to skip stages in the analogical reasoning process, as they prefer to perform the Inferring stage by solving the source problem first before returning to perform the Encoding stage on the target problem.

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