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A Newman Error Analysis of Grade 11 Students' Adaptive Reasoning in Solving Composition-of-Function Problems

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Abstract

Adaptive reasoning is one of the five strands in mathematical proficiency. It reflects students' capacity to think logically and justify their reasoning when solving mathematical problems, particularly in the topic of composition of functions. This study aims to analyze students' errors in solving adaptive reasoning problems on the topic of composition function based on Newman's Theory. The type of research used is qualitative research using a diagnostic test and interviews as instruments. The subjects of this study were 16 eleventh-grade students at a high school in Berau Regency in Kalimantan Timur Province. The results of this study show that students' errors occur at the understanding stage, transformation stage, process skills stage, and the solution process stage. In the argumentation indicator, students experienced errors at the comprehension stage by 100%. In the inference indicator, errors occurred at the transformation stage by 43.75% and the process skills stage by 37.5%. Furthermore, on the validation indicator, students' errors in the process skill stage at 6.25% and the completion process stage at 18.75%. The type of errors that majority of students experienced was the comprehension stage on the argumentation indicator.

Keywords: Adaptive reasoning; Composition of functions; Mathematical proficiency; Newman's error analysis

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INTRODUCTION

Mathematics learning aims to improve and develop students' abilities, especially in critical, logical, innovative, and creative thinking. Adaptive reasoning ability was introduced by the NRC (National Research Council) as part of the five strands of mathematical proficiency. Adaptive reasoning is an important skill in mathematics learning, which is a combination of inductive and deductive reasoning. Adaptive reasoning not only involves using formulas correctly but also reasoning using patterns, analogies, and information as a basis for making conclusions (Kilpatrick, Swafford & Findell, 2002).

Adaptive reasoning is the human ability to think logically and behave appropriately in a situation or environment by using existing experience but adapting to changes in information and circumstances (Putri & Warmi, 2024). Indicators of adaptive reasoning are argumentation, inference, and validation (Kilpatrick et al., 2002). Argumentation refers to students' logical reason in applying mathematical procedures and conditions, while inference is the students' ability to drawing logical conclusions or constructing the solutions based on the given information, and validation involves evaluating and confirming the proper answer. Such reasoning can help students understand a concept deeply and its relationship with other concepts. In mathematics learning, adaptive reasoning allows students to solve problems not only by memorizing procedures but also by understanding how to choose procedures or create alternative solutions that are appropriate for the given situation. Students are expected to be more flexible in solving various types of problems, both those they have encountered before and those that are different from previous problems.

One of the objectives of the Mathematics subject in the Merdeka Curriculum is to equip students with the ability to reason through patterns and properties, generalize, construct proofs, or explain mathematical ideas and statements (Kemdikbudristek, 2022). In this case, adaptive reasoning skills play an important role because they enable students to understand mathematical patterns and properties in depth and also use them in various different contexts. The essence of adaptive reasoning, which is flexible thinking and adapting to new contexts, is significant in facing broader and more complex mathematical challenges.

However, in reality, students generally do not yet have adequate adaptive reasoning skills. The lack of adaptive reasoning skills is due to students' inability to identify the relationships between concepts and communicate abstract ideas in a more concrete form (Magfirah et al., 2020). Most students are only able to solve familiar problems according to the examples given by the teacher in the classroom. Students tend to only be able to repeat the steps to solve the problem without understanding how and why the solution works, so that if the form of the problem given changes even slightly, students are no longer able to provide the correct solution.

One of the learning outcomes that need to be achieved in mathematics is that students are able to determine composition of functions. Composition of functions $f \circ g$ is defined as $(f \circ g)(x) = f(g(x))$ for all x in the domain g, with the condition that $g(x)$ is in the domain f (Susanto et al., 2021). Employing the indicator of adaptive reasoning argumentation means that students can present logical reasons, both in writing and orally, regarding the process, sequence, and results of function composition operations, inference reflects in the ability to draw conclusions based on patterns or relationships identified in the process of function composition, and validation means students are able to check and evaluate the accuracy of the results of function composition they have obtained. From previous research, one of the mistakes made by students is the assumption that function composition is the same as the multiplication operation between two functions (Kolins, Wahyuningsih, Safrudin & Rusdin, 2020). In line with the results of interviews with mathematics teachers at a high school in Berau Regency in Kalimantan Timur Province, learning outcomes for the topic of composition of function are still far from expectations, especially in solving adaptive problems.

Composition of function like every other algebra concept have very practical utility in budgeting, engineering, analysis while also serve as foundation for more advanced mathematical concepts (Asomah et al., 2026). The issues that students face in solving these problems indicate a systematic deviation (Ardiawan, 2015). Difficulties that occur in the learning process are normal, but errors in solving mathematical problems mean that learning objectives are not optimally achieved, due to a lack of understanding of concepts or basic calculations (Ningsih, Hariyanti & Fayeldi, 2019; Putri, Priatna & Kusnandi, 2023; Sunardiningsih, Hariyani & Fayeldi, 2019). Students' competence to understand mathematics can be reflected in their abilities and the difficulties they experience in solving math problems (Putri et al., 2023). Therefore, it is necessary to analyze the difficulties experienced by students to provide meaningful diagnosis for educators, allowing practical interventions and relevant with Indonesian’s mathematics curriculum.

Analyzing the difficulties experienced by students can be done by examining the mistakes made in solving problems (Happy, Alfin & Handayanto, 2019). There are many error analysis theories that can be used to identify the difficulties experienced by students, one of which is Newman's theory (White, 2010). Newman's theory, often referred to as Newman's Error Analysis (NEA), is commonly used because it is suitable for the type of questions used, namely essay questions (Neef, 2003; Suyitno & Suyitno, 2015). In addition, Newman's Error Analysis stage is best used to analyze students' thinking process when solving mathematical word problem (Zulyanty & Mardia, 2022; Lestari et al., 2018; Darmawan et al., 2018). According to Clement (Khairani & Kartini, 2021), there are five types of errors based on Newman's Theory, namely (1) reading error, (2) comprehension error, (3) transformation error, (4) process skill error, and (5) encoding error.

Several studies have explored students' errors in mathematics learning using Newman's Error Analysis. However, most of these studies only focused on specific topics such as algebra (Erni, 2021; Kaligis, Tuerah & Pulukadang, 2023; Maulana & Pujiastuti, 2020) or the type of problems posed separately (Badriani, Wyrasti, Tanujaya, 2022; Toha, Mirza & Ahmad, 2018). These studies successfully identify error stages but rarely relate them to specific reasoning constructs. Meanwhile, studies on adaptive reasoning focus on students' ability to justify and infer mathematically, yet they often investigate reasoning performance without diagnostic categorization of errors. This separation suggest a lack of integration between reasoning theory and structured error analysis. This study, therefore, seeks to address this gap by applying Newman's Theory to identify students' difficulties in solving adaptive reasoning problems on the topic of composition of functions. This study address this research question: What errors do students make in adaptive reasoning problems in the topic of composition of function?

METHOD

Research design

This study used a qualitative method to describe the types and causes of students' errors when solving adaptive reasoning problems on the topic of composition-of-function. In qualitative research, the researcher is the main instrument of research (Sugiyono, 2023). Since the research focused on understanding students' reasoning processes and interpretations rather than measuring learning outcomes quantitatively, a qualitative method was considered appropriate.

Participant

The research was conducted on 16 eleventh-grade students at a public high school in Berau Regency in Kalimantan Timur Province who had studied the composition function material. The participants were selected using purposive sampling by choosing a single class with a relatively homogeneous learning context, intended to minimize external variations in external variations or learning experiences aiming for rigor over breadth (Vasileiou, et al., 2018). The purposive sampling was considered to be appropriate to ensure that the selected participants could provide rich and relevant data for the study to identify and analyze different types of students' errors. Then, data reduction was carried out to select research subjects for in-depth interview based on their errors and their potential to provide sufficient data.

Instruments

The data were collected through a diagnostic test and interviews. The test instruments used were related to the composition function material designed in accordance with adaptive reasoning indicators. Meanwhile, interviews were conducted to obtain additional information using unstructured guidelines but adjusted to the amount of information needed (Sugiyono, 2023). The research instruments were validated by experts, including a mathematics education lecturer and the classroom teacher to ensure the suitability of the instruments with the students' characteristics.

Data analysis

The data analysis techniques used were data condensation, data presentation, and conclusion drawing/verification (Miles, Huberman & Saldana, 2014). The models mentioned in this study include data condensation in the form of 1) data reduction, which involves examining test results and selecting research subjects according to the types of errors in each question indicator, then 2) data presentation in the form of tables to classify the errors of each subject, and 3) drawing conclusions and verification by comparing test results and interview results. Student work results will be classified based on Newman's Theory, with the following indicator descriptions.

Table 1. Description of Newman's Theory Indicators

Indicator	Description
Reading Error	a) Students can read but do not understand the meaning of problems or mathematical symbols. b) Does not use the information in the question.
Comprehension Error	a) Does not know/incorrectly write down what is known from the question. b) Does not know/incorrectly write down what is asked in the question.
Transformation Error	a) Unable to determine the appropriate mathematical formula, operation, and procedure.
Process Skills Error	a) Unable to perform mathematical calculations correctly. b) Failure to complete the calculation process.
Encoding Error	a) Unable to show the correct answer. b) Does not provide a conclusion.

Table 1 presents the description of the indicators used in this study, elaborating the focus of each indicator and typical student errors. These indicators described serve to categorize student's reasoning errors.

RESULTS AND DISCUSSION

Based on the results of the essay test consisting of 3 adaptive reasoning questions on the topic of composition of functions, the percentage of errors for each indicator of Newman's theory is as follows.

Table 2. Total of Newman's Error Analysis Indicators

Indicator	Question 1	Question 2	Question 3
Reading	0	0	0
Comprehension	16	0	0
Transformation	0	7	0
Process Skills	0	6	1
Encoding	0	0	3

Based on Table 2, the only stage where students did not make errors is the reading stage, this align with prior research that indicating reading errors rarely happened in higher educational level (Jha, 2012; Seng, 2020; Lubis et al., 2021; Fatawu et al., 2023). However, students' mistakes in other stages showed a concerning fact that majority of the students have a poor problem-solving ability (Zulyanty & Mardia, 2022). Furthermore, students had difficulties in solving each question, especially question number 1, where all students had difficulties. Next, in question number 2, only a few students were able to solve it correctly, then in question number 3, the majority of students solved the question correctly, but there were still some students who encountered difficulties. Each question was compiled based on adaptive reasoning indicators so that the number of difficulties in each indicator could be presented in the Table 3.

Table 3. Total of Errors in Adaptive Reasoning Indicators

Question Number	Question Indicators	Percentages of Errors
1	Argumentation	16
2	Inference	13
3	Validation	4

Table 3 indicates that the percentage of students experiencing the most error is in the argumentation indicator, which indicates that all students were unable to solve the problems correctly and provide explanations. The next indicator, inference, shows that most students were unable to solve the problems correctly and draw conclusions. Then, on the validation indicator, some students were still unable to solve the problems correctly and provide validation. Thus, it can be concluded that most students still made errors when solving adaptive reasoning problems on the topic of composition of functions.

In order to determine the cause of these errors, data reduction was carried out by selecting three subjects, namely Subject A, B, and C, taking into account the types of errors made on each question indicator. The following is a discussion of each question.

Question Number 1:

> Given two functions$f(x) = \sqrt{x} + 5$, and $g(x) = -\left|\frac{1}{x}\right|$. Determine the composition of function $(f \circ g)(x)$ if defined, and provide reasons for each step!

Alternative Solution:

> Determine the possibility of composition of function $f(x)$ and $g(x)$
>
> a. Determine domain and range of $g(x)$
> Domain $g(x) = \mathbb{R}, x \neq 0$
> Range $g(x) = x < 0$
>
> b. Determine domain of $f(x)$
> Domain $f(x) = x \geq 0$
>
> c. Checking whether the range of $g(x)$ included in the domain of $f(x)$
> $$R_g \cap D_f = \emptyset$$
>
> Because the range of $g(x)$ is not in the domain of $f(x)$ then $f(x)$ dan $g(x)$ can not be defined in $(f \circ g)(x)$

Subject A

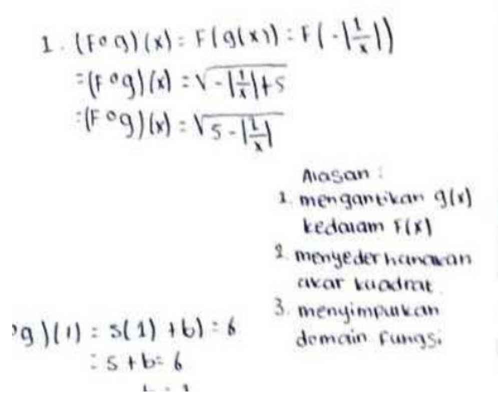

Figure 1. Subject A's answer to question number 1

Figure 1 shows that Subject A made an error in understanding the question by directly composing the two functions without checking the initial conditions. Subject A did not understand that before composing the functions, it was necessary to check to ensure that the intersection between the result area of $g(x)$ and the origin area of $f(x)$ was not an empty set. This mistake shows that Subject A had difficulty understanding the meaning of the question.

On the answer sheet, Subject A wrote down the reason, but the reason did not match the intent of the question and more reflected the technical steps for performing the composition function. The interview results also reinforce this; when asked to state what the question was asking, Subject A replied that the question asked for the composition of the functions $f(x)$ and $g(x)$. When asked to explain the steps, Subject A only repeated the reasons they had written down without mentioning the conditions and rules of the composition function.

From this analysis, it can be concluded that Subject A had difficulty understanding the question and therefore chose the wrong strategy to solve it. This difficulty was caused by a lack of understanding of the basic concepts of composition functions, especially the conditions and rules before performing composition functions. As a result, Subject A provided a solution and reasoning that did not match the question.

Subject B

Subject B did not attempt to answer question number 1. Based on the interview results, Subject B admitted to did not understand the question because subject had difficulty using functions containing absolute value signs. Subject B found the absolute value signs confusing and did not know how to use them. In addition, Subject B did not understand what the question was asking. Subject B assumed that all functions could be defined if they were composed, so the question caused confusion.

This difficulty indicates a misconception related to composition of functions, particularly in understanding the conditions that must be met in composition of functions. This misconception was one of the main reasons Subject B did not attempt to solve the question. This finding indicates that conceptual understanding of composition of functions is still lacking, especially in identifying initial information and determining the appropriate steps for solving the problem.

Subject C

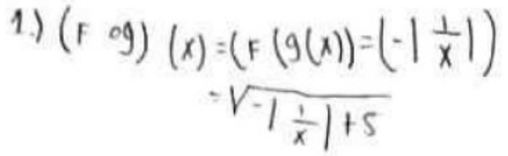

Figure 2. Subject C's answer to question number 1

Referring to Figure 2, it can be seen that Subject C made an error by directly performing the function without checking the domain and range of each function. Subject C had difficulty understanding the question, assuming that the function was defined because it could be composed and could be worked out by directly substituting the function $g(x)$ into the function $f(x)$. However, when asked to state the conditions for the composition function, Subject C was able to state them correctly.

The interview results show a gap between theoretical understanding and conceptual application. Subject C did not fully understand the question, so the steps taken to solve it were incorrect. This indicates that Subject C tends to understand concepts verbally but has difficulty applying them procedurally. One of the causes of this difficulty is a lack of practice in integrating theory with practice.

From the results of the work and interviews of the three subjects, it can be concluded that all students experienced difficulties with the argumentation indicator, namely providing explanations regarding the rules and conditions of composition functions. In this indicator, students' experienced errors in comprehension stage where they can read the problems but unable to interpreting and understand the problem (Duru & Koklu, 2011; Prakitipong & Nakamura, 2006). This is the most common errors made in this study where all of the participants mistranslating the intent of the question similarly related to study by Agustin et al

(2023). Students did not fully understand these rules and conditions, especially in the context of their use. Wu and Adams (2006) argue that this type of error made it impossible to answer correctly as comprehension is the core of solving problems. Indriani et al (2017) also discussed the common cause in low adaptive reasoning abilities is errors in understanding the problems or condition presented that later leading to inappropriate problem-solving strategies.

One of the reasons for this was the lack of variety in the questions given. Students tended to be given questions where all composition functions could be defined, so there was no need to check the initial conditions, resulting in the omission of the initial steps. In addition, the conditions and rules of composition of functions are only explained theoretically at the beginning of the material, but are not consistently integrated into the practice questions. As a result, the conditions and rules of composite functions, which are important and vital part, become a part of the material that is often forgotten. Students are not accustomed to applying these concepts in more complex contexts. This difficulty highlights the need to provide questions with varying levels of difficulty and emphasize the importance of checking the conditions for composition functions in each solution.

Question Number 2:

If $(f \circ g)(1) = 6$,$(f \circ g)(2) = 11$,$(f \circ g)(3) = 16$, and$(f \circ g)(4) = 21$. Determine$(f \circ g)(x)$!

Subject A

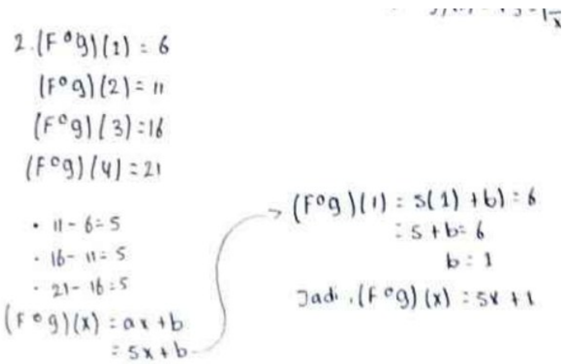

Figure 3. Subject A's answer to question 2

As shown in Figure 3, Subject A successfully completed question number 2 correctly without difficulty. Subject A was able to construct the general form of the composition of function using the values of several composition of functions whose values were known. This success demonstrates a good understanding of the basic concepts of composition of functions and their application in various contexts. From the interview results, Subject A explained the steps to solve the problem accurately and provided appropriate reasons to support the chosen solution. This shows Subject A's ability to use adaptive reasoning, such as drawing conclusions and providing logical and valid arguments.

Subject B

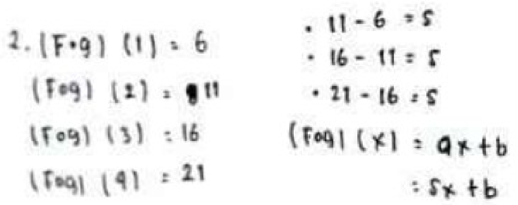

Figure 4. Subject B's Answer to Question 2

It can be observed from Figure 4 that Subject B made error in the process skill stage. Although the steps used to solve the problem were correct, Subject B did not continue the calculation process to obtain the final answer. This difficulty was evident in the substitution stage, where Subject B was unable to determine which function values could be substituted to obtain the correct value of b. Through interviews, it was found that Subject B did not fully understand the relationship between the values given in the question and the function that needed to be used in the calculation. This difficulty indicates a lack of comprehensive understanding of the basic concepts of functions and the steps to solve them, especially in integrating known information to reach the final solution. Therefore, practice involving a variety of more complex questions is needed.

Subject C

Subject C did not attempt to answer question number 2 even though they had no difficulty understanding what was known and asked in the question. However, Subject C did not know the appropriate procedure for this question. The main difficulty lay in Subject C's lack of ability to connect concepts between materials, making them unable to solve the question. Through this analysis, it can be found that Subject C failed in the transformation stage, which is the stage where students should be able to translate the information provided into a procedure or solution steps. This difficulty indicates that their conceptual understanding of the relationship between concepts is not yet adequate. Generally, this is because the questions provided only focus on the material being studied and do not sufficiently explore the ability to connect between materials.

From the results of the assignments and subject interviews, it was found that several students made errors when completing problems in the inference indicators, especially at the transformation stage and process skills. Errors at the transformation stage were evident in the students' inability to determine the appropriate procedures or rules. Kaligis, Tuerah, and Pulukadang (2023) argue that students even if able to discover what known and asked, still need help to choose the formula to solve the given problems. This was due to the need for connections with other material concepts and not limited to composition functions. Similar result also found by Aulia, Cholily, Ummah, and Mustakim (2024) where students are used to follow procedures that commonly used to complete the assignments but lacked in problems that needs relational thinking. Students' experience in solving problems also playing a vital role as it can strengthen students' ability to perform the mathematical procedures (Rohana & Ningsih, 2019).

In addition, several students showed errors in process skills, particularly in procedural ability. In this question, this weakness was evident in the inability to substitute is correctly to obtain the solution. The cause of this error was that students were accustomed to solving problems by repeating the steps taught by the teacher, so they were unable to change the solution steps based on new information. This error shows that students not only need conceptual understanding but also practice focused on applying procedures that involve the integration of concepts between materials.

Question Number 3:

If it is known that $f(x) = 2x^2$, $g(x) = x + 2$, then $(f \circ g)(x) = 2x^2 + 4x + 4$. Check the validity of this statement.

Subject A and Subject B

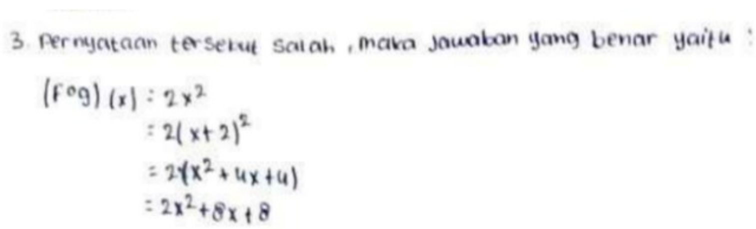

Figure 5. Subject A's Answer to Question 3

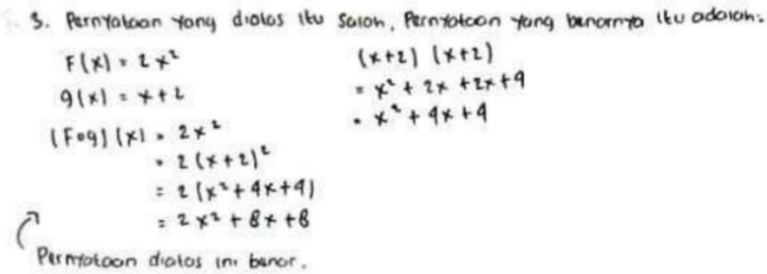

Figure 6. Subject B's Answer to Question 3

Figures 5 and 6 show that Subject A and Subject B made no error in solving question number 3. Both subjects were able to provide the correct solution and demonstrated a good understanding of the concepts being tested. Moreover, the subjects validated their answers by providing relevant conclusions, which demonstrated excellent adaptive reasoning skills. This success also indicates that Subject A and Subject B not only understood the procedural steps in solving the problem, but also had the reflective ability to ensure that the solutions provided were appropriate to the context of the question. This shows the importance of a deep understanding of concepts and experience in validating answers as part of adaptive reasoning indicators.

Subject C

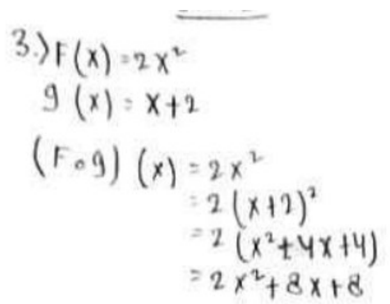

Figure 7. Subject C's Answer to Question 3

Figure 7 displays an error that occurred in the solution process by Subject C. The subject was able to solve the problem but did not provide the required validation of the problem. Although Subject C was able to solve the problem and obtain the final answer, the subject did not provide a conclusion as part of the validation process. From the interview results, it was found that Subject C thought it was unnecessary to provide a conclusion because the final answer already showed the difference from the question. This shows that Subject C did not fully understand the importance of the validation step as an important part of solving the question, not just as a supplement but to ensure a logical and systematic thinking process. This type of findings consistently happened especially in word problem-solving problems (Badriani et al., 2022; Ramadhani et al., 2024; Zulyanty & Mardia, 2022)

In terms of validation indicators, error rarely occurred, except in process skills and the completion process. Difficulties in process skills were caused by a lack of accuracy in the calculation process, namely algebraic operations. Meanwhile, in the completion process, difficulties were caused by students not providing a concluding statement. Although the students had proven the results of the composition of two functions, they tended not to consider it necessary to provide a validation. In accordance with this result, several studies also presented similar findings, Purnama and Rahardjo (2024) and also Erni (2021) as well declare that students unable to conclude the final results referred to by the question. However, in questions such as number 3, validation is key to ensure that the solution provided is accurate and correct according to the context of the question. It is imperative to emphasize the importance of the validation stage to show reflection or reasoning that supports the final result (Toha et al., 2018). Without this validation, the answer cannot be considered complete.

CONCLUSION

Based on the results of this analysis, several errors identified in students' ability to solve adaptive reasoning problems on the subject of composition of functions. Students made errors in the indicators of argumentation, inference, and validation, with the most errors experienced with the indicator of argumentation. In the argumentation indicator, students were unable to solve the problems correctly and provide appropriate reasons, as indicated by their difficulty in understanding the problems due to a lack of understanding of the basic concepts of the conditions and rules of composition of functions caused by a lack of integration of the context of their use in the solution steps. Then, in the inference indicator, students were unable to conclude from the information provided to make the correct and complete solution steps. Some students experienced difficulties in the transformation stage, namely not being able to determine the appropriate procedures or rules. Other errors arose in this indicator were seen in the process skills stage, where students did not continue the calculation process to obtain the final answer. The errors in this indicator were closely related to the students' lack of procedural skills, as most of them were only able to repeat the solution steps that had been taught by the teacher previously. Furthermore, on the validation indicator, students were able to solve the problems correctly but did not provide the validation in the form of statements requested by the questions. This error occurred at the solution process stage, where students tended to ignore the provision of validation, which would actually complete the answer to make it a complete and correct thought process.

RECOMMENDATION

For future research, it is recommended to focus on the development and implementation of instructional designs that can reduce the potential errors found in this study while improving students' adaptive reasoning skill. Furthermore, research can focus on an in depth study of students' cognitive processes in constructing arguments, drawing inferences, and performing validation at each stage of problem solving. In addition, further research can examine the role of classroom discourse and teachers' pedagogical practices in supporting the continuous development of adaptive reasoning.

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AUTHOR CONTRIBUTIONS STATEMENT

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Noviana Antaria	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓		✓	✓
Sufyani Prabawanto	✓	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓	

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Ruswan Dallyono		✓			✓					✓	✓	✓		

CONFLICT OF INTEREST STATEMENT
Authors state no conflict of interest.

DATA AVAILABILITY
The data that support the findings of this study are available from the corresponding author, NA, upon reasonable request.

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