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REVEALING THE CAUSES OF STUDENTS' ERRORS IN INTEGER ARITHMETIC OPERATIONS: COGNITIVE AND GENDER PERSPECTIVES

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Abstract: The low understanding of integer arithmetic operations often leads students to make mistakes when solving math problems. This study aims to identify various types of cognitive errors experienced by students based on Nolting's theory, and to analyze their relationship to gender differences. The research method used is descriptive qualitative, with data collection conducted through diagnostic tests on 58 students and in-depth interviews with 10 grade VII students of MTs N 1 Sarolangun. According to Nolting, the five categories of errors analyzed in this study include: Misread-Directions Errors, Careless Errors, Concept Errors, Application Errors, and Test-Taking Errors. The research findings show that the most common errors are Careless Errors and Concept Errors, with female students making more errors in each category than male students. These findings emphasize the importance of analyzing comprehensive errors and the need for a learning approach that considers cognitive and gender factors to improve the quality of mathematics learning.
Keywords: student error; nothing theory; integers; gender

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Introduction

Integer arithmetic operations are the basis for understanding mathematics easily (Khalid & Embong, 2019). Integer operations focus on arithmetic skills such as addition, subtraction, multiplication, and division, so that they can solve mathematical problems correctly (Rosyidah *et al*., 2021). Therefore, students must understand basic integer operations to solve problems (C. Dela Rosa *et al*., 2023). However, students still struggle to learn the integer operations material *(Zainudin et al*., 2022). This is because the understanding and knowledge of each student are different (Salimul Farhan *et al*., 2019). So that students face challenges in understanding questions presented in authentic contexts. Students have difficulty changing problems into mathematical models and focus on formulas without understanding the underlying concepts (Anisa *et al.*, 2023). As a result, errors occur when solving problems. This error is because students cannot analyse the information provided (Rahma Muharam & Rahayu, 2024).

In addition, gender differences also affect solving problems, especially problems that require precision (Kumala Sari & Wulantina, 2024). This is because male and female students do things differently during the mathematics learning process (Nikmah et al., 2020; Amin & Hariyadi, 2021). So, they have different mathematical problem-solving patterns (Zhu, 2007). Therefore, the gender aspect is essential to pay attention to in mathematics learning (Latief *et al*., 2019).

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Student error analysis is vital for teachers (Safitri *et al*., 2023). Nolting's theory is one of the theories that can analyse cognitive errors in solving problems. Thus, Nolting's theory can contribute to helping teachers map the types of student errors and plan further learning improvements (Fitri & Tantri, 2023). Nolting's theory can see student errors comprehensively and emphasises the analysis of conceptual errors (Asih *et al*., 2023). Many students fail to solve math problems because they do not understand the concept (Ulpa *et al*., 2021). Nolting's theory helps analyse errors in mathematics by focusing on Misread-Directions Errors, Careless Errors, Concept Errors, Application Errors, and Test-Taking Errors (Luna *et al*., 2024).

Research related to the analysis of student errors based on Nolting's theory has indeed been conducted, as reported in (Luna *et al*., 2024; Fitri & Tantri, 2023; Ulpa *et al*., 2021). However, these studies have not considered gender aspects, used limited diagnostic test samples (fewer than 30 students), and involved fewer than 10 students. In addition, the materials used in these studies differ from those discussed in this study. Nolting's theory was chosen because it is the newest among other error theories (Ridha *et al*., 2023). This theory can also help understand the difficulties experienced by students so that learning strategies can be adjusted to improve student understanding. This study aims to answer the following questions: (a) What cognitive errors often occur when students work on integer arithmetic operations? (b) How does applying Nolting's theory help identify and overcome students' cognitive errors in solving integer arithmetic operations? (c) Which gender of students makes the most errors?.

Method

This study used a qualitative approach with an exploratory descriptive design. This design aims to describe in depth the types of students' cognitive errors in solving integer arithmetic operations problems based on Nolting's theory, and to analyse them from a gender perspective. Data was collected through two main techniques: diagnostic tests and in-depth interviews. The test instrument, in the form of mathematical story problems, was validated before being given to students. The test results were then analysed to identify the types of errors according to Nolting's theory categories, namely Misread-Directions Errors, Careless Errors, Concept Errors, Application Errors, and Test-Taking Errors.

Participants in this study consisted of 58 seventh-grade students of MTs Negeri 1 Sarolangun who took the diagnostic test. From the test results, the researcher selected 10 students as interview subjects using a purposive sampling technique (Creswell, 2012)The selection of subjects considered the representation of each type of error according to Nolting's theory and gender, as well as students' communication skills, so the data obtained from the interviews were in-depth and informative. This approach allows researchers to comprehensively explore the causes of errors and the factors influencing students' thinking processes in solving mathematics problems.

The first instrument is a diagnostic test of mathematical story problems that tests students' ability to complete integer arithmetic operations. A validator validated this instrument before use. The questions are as follows.

> To enter the final of the Mathematics Olympiad, participants must obtain a minimum score or value of 165. The questions are in the form of multiple choice, consisting of 50 items with the following provisions:
> • Correct answers get a score of 4
> • Wrong answers get a score of -2
> • Unanswered questions get a score of -1

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Table 1. Final results of the selection participants

No	Name	Correct	Incorrect
1	Andre	45	5
2	Sofwan	43	1
3	Jihan	46	3
4	Sofia	44	2

Based on the final scores, who made it to the finals?

The validator has also validated the interview guideline. This guideline is used to explore students' mathematical understanding and problem-solving abilities. This guideline is divided into several components. For details on the structure and content of the interview guideline, see Table 2. However, the questions can be developed according to the needs of the analysis.

Table 2. Interview guidelines

No	Error Type	Question
1	*Misread-Directions Errors*	What information do you know from the question? Please mention it?
2	*Careless Errors*	Pay attention to your answers! Why did you choose those steps and operations?
3	*Concept Errors*	1. Do you know the arithmetic operations of integers? 2. Mention what arithmetic operations are in the given problem?
4	*Application Errors*	1. Pay attention to your answer! What steps did you take to solve the problem? 2. How did you solve the problem?
5	*Test-Taking Errors*	1. Is your answer based on the question given? Give reasons! 2. Please state the conclusion of the problem.

A detailed description of the errors experienced by students can be seen in Table 3. This table outlines the various cognitive errors that can occur at each stage of Nolting's theory, particularly in completing integer arithmetic operations.

Table 3. Student Error Indicators

No	Error Type	Student Error Indicators
1	*Misread-Directions Errors*	Students do not understand the information from the questions given, or they do not write anything down.
2	*Careless Errors*	Students' inaccuracy in performing integer arithmetic operations
3	*Concept Errors*	Students do not understand the concept of integer arithmetic operations.
4	*Application Errors*	Students do not know how to apply the correct arithmetic operations to solve the problems.
5	*Test-Taking Errors*	Students do not complete the questions until they are finished or draw conclusions.

The next step is triangulating (Hayashi Jr et al., 2019) by comparing the test and interview results. Then, the researcher formulates conclusions based on the triangulation results. The findings of this study will likely include various causes of errors made by students, as well as techniques that can be used to

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reduce the mistakes that may occur. The percentage of types of errors made by students using the formula:

$$EP = \frac{a}{N} x\ 100\%$$

EP = Error Percentage

ɑ = Many students make mistakes ɑ

N = Many students

Results and Discussion

The following is a recapitulation of the percentage of student errors grouped based on the type of error, according to Nolting and gender.

Table 4. Recapitulation of Percentage of Student Errors and Gender

No	Error Type	Percentage of Error	Gender	
			Male	Female
1	*Misread-Directions Errors*	24%	6	8
2	*Careless Errors*	53%	9	22
3	*Concept Errors*	48%	8	20
4	*Application Errors*	44%	8	18
5	*Test-Taking Errors*	44%	9	17

Based on Table 4, the highest percentage of errors is Careless Errors, followed by Concept Errors, and female students make the most errors in each type of error. This result is consistent with previous research that shows that female students make many errors (Rahayu *et al.*, 2024). This problem can be associated with psychological and social factors influencing students' thought patterns and emotional responses. Previous research found that cognitive distortion is more related to internalising problems, such as anxiety and depression, which are more common in female adolescents (Kuijper, 2023). In addition, female students have higher levels of cognitive distortion than male students, which can be caused by social pressure and cultural expectations of gender roles (Aydin & Ay, 2023). These factors can make female students more susceptible to negative and irrational thought patterns, such as overgeneralisation and dichotomous thinking. Thus, the interaction between psychological and sociocultural factors plays an essential role in explaining why female students are more susceptible to cognitive errors in learning.

Next, 10 subjects were selected according to specific criteria set to facilitate further exploration of the errors made. The selection of these subjects aimed to collect in-depth information about the mistakes made by students. This approach allows a comprehensive analysis of inevitable misunderstandings and cognitive processes that contribute to students' difficulties in completing integer arithmetic operations. Ultimately, the information obtained will be the basis for designing a learning model that supports students in understanding mathematics better, especially in overcoming cognitive barriers identified from the perspective of Nolting's theory.

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Misread-Directions Errors

a. S1 is male

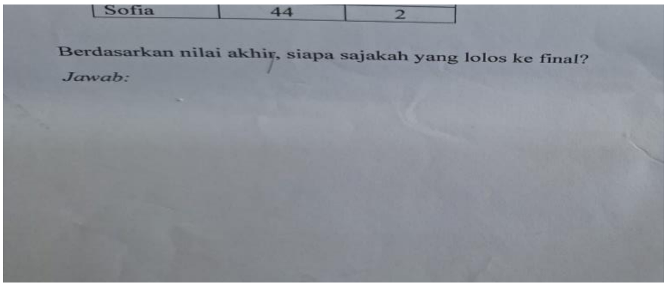

Figure 1. S1 work results

Figure 1 shows that S1 did not write anything on the answer sheet. This indicates that S1 did not understand the information from the questions given. The interview results showed that S1 did not write the answer because he forgot how to do it, was afraid of being wrong, and was unsure what to write.

b. S2 is female

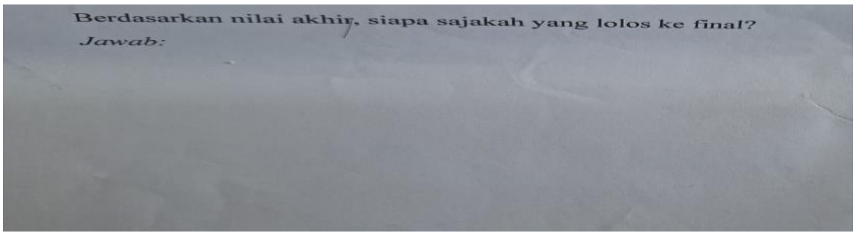

Figure 2. S2 work results

Based on the results of S2's work, it can be seen that S2 did not write anything on the answer sheet. The interview results found that S2 was confused about where to start and did not know how to solve the problem or the formula used. In addition, S2 also revealed that he did not understand the material on integer arithmetic operations.

One phenomenon often seen in mathematics learning is when students do not write anything on the answer sheet when asked to solve a problem. This phenomenon is not always caused by a lack of motivation to learn, but is more related to cognitive and affective factors. On the mental side, students often feel confused when determining the initial steps to solve a problem, especially if the problem is complex or requires deep conceptual understanding. The inability to break down the problem into smaller parts often makes them stop and not continue (Polya, 1988). In addition, stressful situations, such as exams, can interfere with students' working memory, making it difficult for them to remember formulas or procedures that have been previously learned (Sweller, 1988).

On the affective side, the fear of making mistakes and doubts about the answers students give also play an important role in hindering students' courage to write down their thinking processes. Low academic Self-Efficacy can impair students' active participation in learning activities (Bandura, 1997). Students who tend to be perfectionists may choose not to write at all rather than write answers they consider wrong. From the perspective of constructivist theory, students' failure to build knowledge independently can occur when the learning environment does not support exploration and the courage to try (Vygosky, 1978). Therefore, the role of teachers is crucial in creating a safe learning climate by providing space for students to try and make mistakes and providing the proper scaffolding to help them start solving problems gradually (Wood *et al*., 1976).

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Careless Errors

a. S3 is male

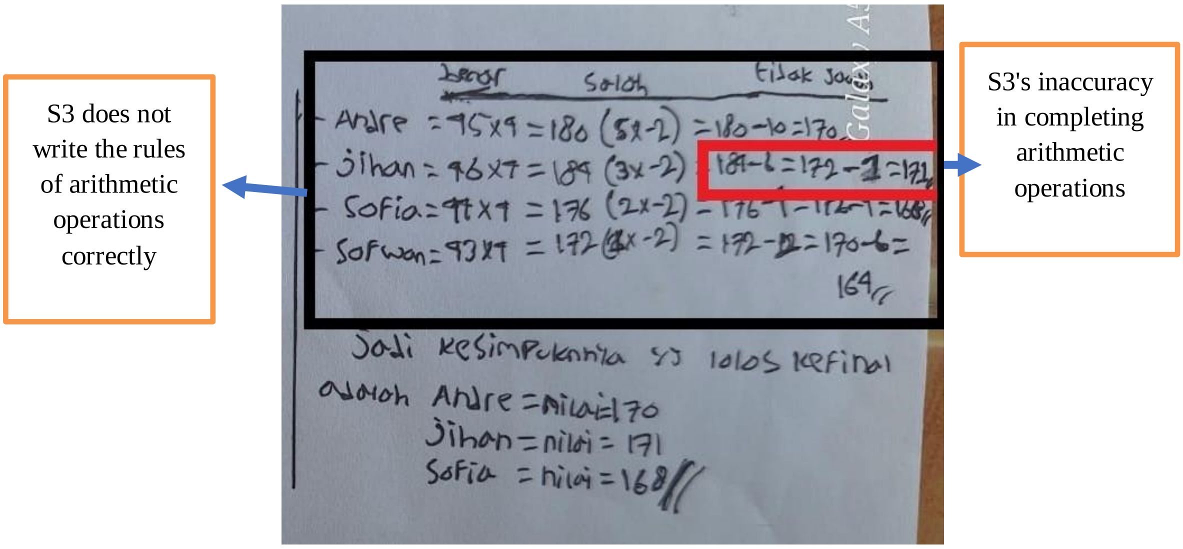

Figure 3. S3 work results

The interview results revealed that this inaccuracy was caused by S3's desire to immediately complete the problem without correcting the answers that had been worked on. Furthermore, when asked why S3 did not correctly write the rules of arithmetic operations or choose the steps and operations in the work results, S3 explained that S3 only remembered the arithmetic operations needed to solve the problem. S3 also chose these steps and operations because he thought this method was easy to understand and could speed up the problem completion.

b. S4 is female

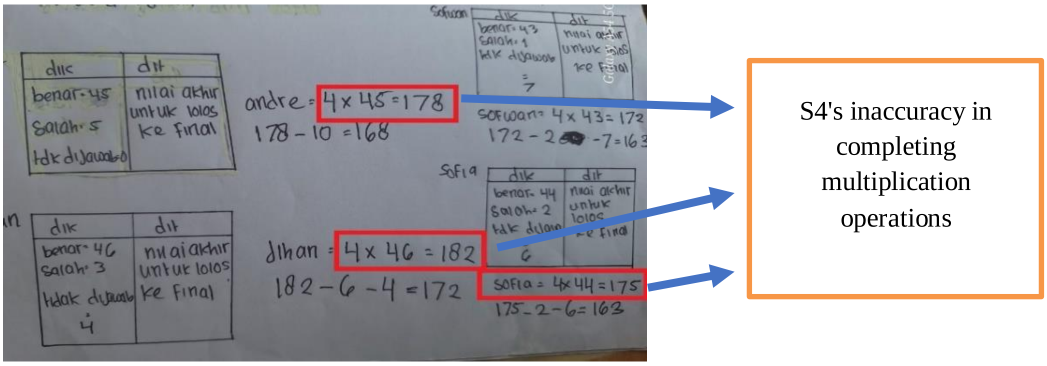

Figure 4. S4 work results

The interview results revealed that S4 lacked concentration when working on the questions, was in a hurry, and did not re-check his work. However, S4 realised the importance of time management in avoiding rushing when completing the questions. S4 stated that this experience was a lesson to improve accuracy and concentration when working on questions.

The results of interviews with S3 and S4 found that inaccuracy was caused by, firstly, a lack of concentration. This lack of focus can cause students to make mistakes in understanding and solving problems, even skipping essential steps. Previous research has shown a relationship between students' lack of concentration in learning mathematics and low learning motivation, passive attitudes during learning, and low intelligence abilities of students (Anggeriani & Ain, 2024). Other research also revealed that learning concentration significantly impacts students' ability to solve mathematical problems (Simorangkir & Napitupulu, 2022) and students' mathematics learning outcomes *(Maharani et al.*, 2024). This shows that concentration is crucial in achieving optimal learning outcomes.

Second, the desire to quickly complete the problem without verifying can increase the possibility of errors. This hasty attitude often hurts the accuracy and precision in solving the problem. When students ignore essential steps such as rechecking calculations, re-understanding the problem, or evaluating the logic of the answer, the risk of errors increases significantly (Santrock, 2011). Meanwhile, the verification process is integral to reflective thinking, which can improve conceptual understanding and prevent unnecessary mistakes (Slavin, 2014). Therefore, teachers must instill the habit of thinking carefully and not in a hurry as part of an effective learning strategy.

Concept Errors

a. S5 is male

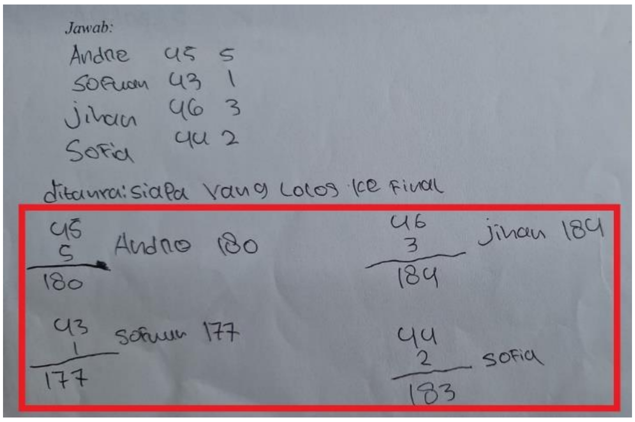

Figure 5. S5 work results

The results of S5's work showed that S5 could not identify the arithmetic operations used in the problem and did not multiply integers correctly. Based on the interview results, it was found that S5 did not mention all the arithmetic operations used in the problem and felt confused about how to apply them to solve the problem given. In addition, it turned out that S5 did not memorise the multiplication of 1 to 10 and found it difficult in mathematics lessons.

b. S6 is female

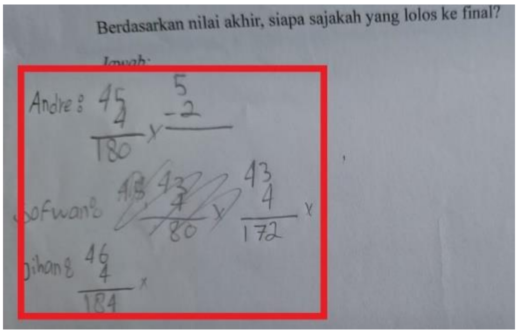

Figure 6. S6 work results

The results of S6's work show that S6 did not complete all the arithmetic operations needed to solve the problem, only multiplication. Based on the interview results, it is known that S6 does not really understand the concept of integer arithmetic operations and only memorises the steps to solve the problem without understanding the reasons. As a result, when the numbers change or the form of the problem is different, S6 is immediately confused.

Students' difficulties in solving math problems, especially integer arithmetic operations, indicate weak conceptual understanding and procedural skills. The inability to identify arithmetic operations and

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not memorising basic multiplication 1-10 indicates weak mastery of basic math facts (basic fact fluency). This impacts students' confusion in applying the solution steps when the form of the problem changes, because they tend to rely on memorising procedures rather than understanding concepts (Kilpatrick *et al.*, 2001). Students' habits of only memorising steps without understanding their mathematical meaning make them susceptible to errors when the problem is packaged in a different context. Students who do not understand the basic concepts of integers and arithmetic operations will have difficulty solving problems correctly, especially if a combination of operations is required (Reys *et al*., 2015). This is also related to low metacognition and mathematical problem-solving skills.

To overcome students ' difficulties in integer arithmetic operations, it is necessary to strengthen conceptual understanding through concrete media, such as number lines. Memorising basic multiplication 1-10 must be improved with interesting methods, such as games or songs. Questions are given contextually and in various ways so that students memorise steps and understand the application of concepts. Metacognitive exercises are also important, such as reading questions carefully and reflecting on solutions. In addition, remedial learning individually or in small groups is needed to overcome specific difficulties and build students' confidence in mathematics.

Application Errors

a. S7 is male

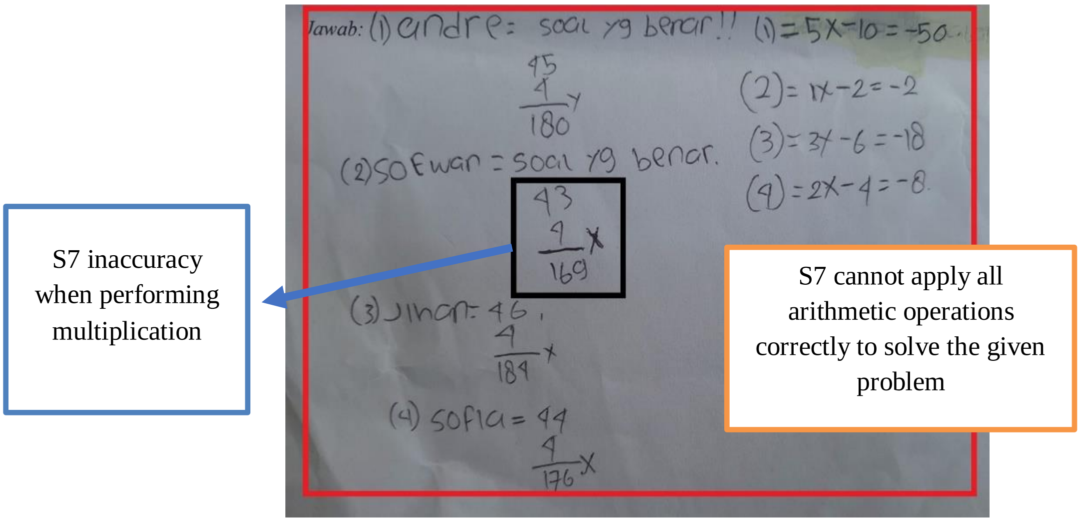

Figure 7. S7 work results

Based on the interview results, it was found that S7 often felt confused when working on story problems because of the difficulty of changing sentences into calculation forms. If the situation requires two or three arithmetic operations simultaneously, S7 is also confused about determining the work order. In addition, S7 forgets the material that has been taught previously.

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b. S8 is female

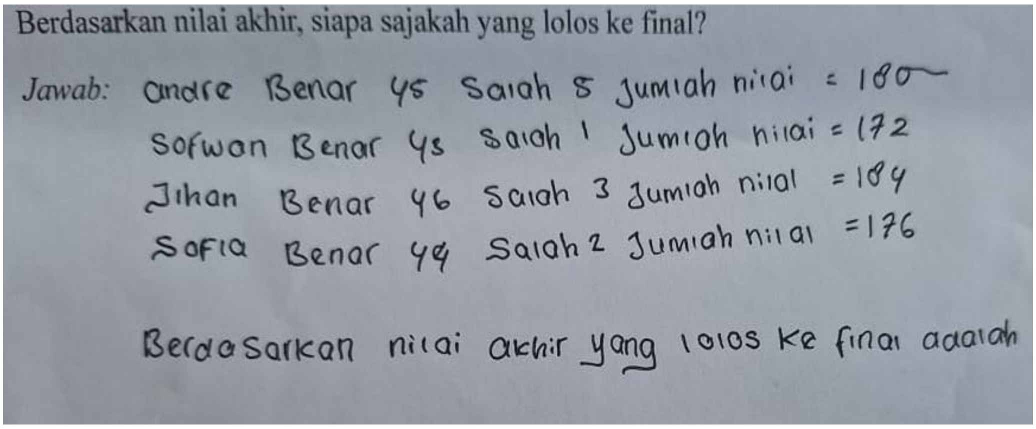

Figure 8. S8 work results

Based on Figure 8, it can be seen that S8 did not apply the arithmetic operation correctly and only wrote the answer, which was wrong. The interview results showed that S8 did not understand the concept of arithmetic operations as a whole, such as addition, subtraction, multiplication, and division. As a result, S8 had difficulty or did not use the proper steps to solve the problem.

Students often face challenges in solving mathematical story problems. One of the causes is the mathematisation process, namely the ability of students to model real situations into mathematical representations (Jupri & Drijvers, 2016). This factor often causes students to misinterpret the available information and fail to choose the appropriate arithmetic operation (Kusumadewi & Retnawati, 2020). So that students do not know the correct order of work when faced with problems involving more than one arithmetic operation. In addition, students experience additional difficulties due to a lack of contextual knowledge and errors in replacing values or developing relevant solution strategies (Martin *et al*., 2019).

To overcome students' difficulties in solving mathematical story problems, teachers must provide routine exercises focusing on understanding and changing problem sentences into mathematical forms. In addition, it is essential to re-teach the basic concepts of arithmetic operations gradually and contextually so that students can understand them more easily. Students must also be progressively accustomed to solving problems, especially problems requiring more than one arithmetic operation, so they are not confused when determining the work order. Providing scaffolding is very helpful when students experience confusion in their thinking process. In addition, teachers should link new material with previously taught material so that students' understanding is stronger and they are not easily forgotten. Contextual approaches and interesting learning media can also be alternatives to increase student interest and knowledge.

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Test-Taking Errors

a. S9 is male

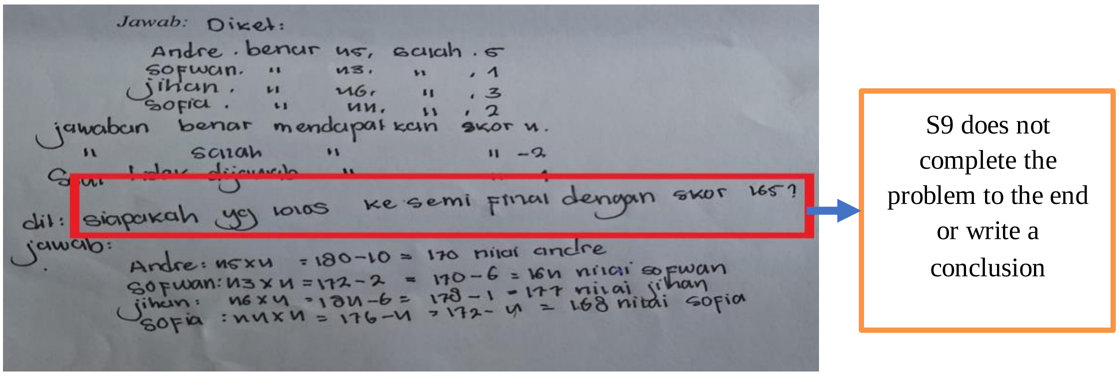

Figure 9. S9 work results

b. S10 is female

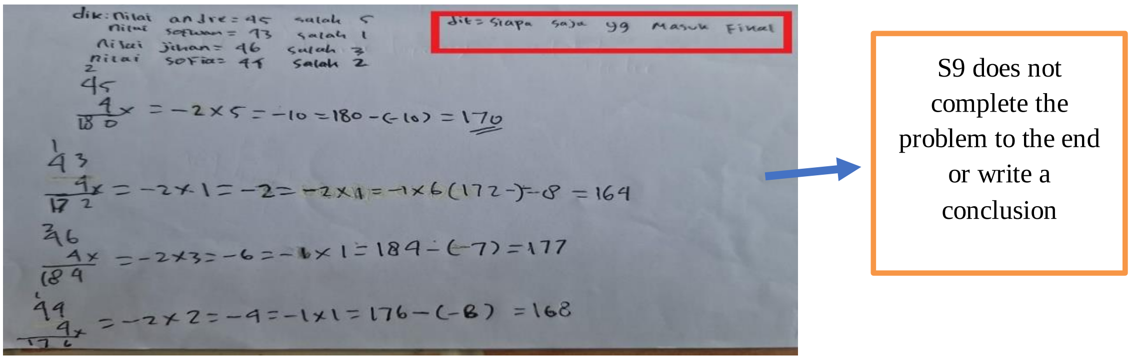

Figure 10. S10 work results

Based on the results of interviews with S9 and S10, it is known that S9 forgot to conclude at the end. Meanwhile, S10 thought it was enough to do it like on the answer sheet, because the desired values were already known. So S10 felt that there was no need to write a conclusion.

Due to high cognitive load, students often forget to conclude when solving mathematical story problems. This process requires students to understand the verbal context, translate information into a mathematical representation, perform calculations, and conclude the results. Each of these stages requires significant working memory capacity. When cognitive load exceeds students' working memory capacity, they tend to focus on calculations and ignore the final step, which is drawing clear and complete conclusions. This is in line with previous findings showing that solving mathematical problems requires the integration of various cognitive processes, and high mental load can hinder the completion of the task as a whole (Arsenault & Powell, 2022).

In addition, verbal skills play an essential role in solving mathematical story problems. Previous research found that verbal skills are the most consistent predictors of success in solving mathematical story problems (Strohmaier *et al.*, 2022). Students with good verbal skills can better understand the context of the situation and draw appropriate conclusions. In addition, math anxiety can also affect students' ability to conclude. Students who experience anxiety tend to rush to complete calculations and ignore the final step. Previous research has shown that math anxiety can interfere with working memory efficiency, especially in tasks that require simultaneous verbal and numerical understanding (Ashcraft & Kirk, 2001).

Then, from a pedagogical perspective, mathematics learning that emphasises procedural aspects too much can cause students to ignore the importance of concluding. Meanwhile, the National Council of Teachers of Mathematics emphasises that communication skills in mathematics, including stating

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results in the form of conclusions, are one of the essential standards in learning (National Council of Teachers of Mathematics, 2000). Teachers must apply explicit, consistent, and structured learning strategies to help students overcome the tendency to forget to conclude when working on math story problems. In addition, teachers also need to include the conclusion aspect as an assessment component in the evaluation rubric. Thus, students will be encouraged to write complete conclusions because they understand that it affects their grades. It is also essential for teachers to model how to conclude verbally when discussing answers in class.

Conclusion

Careless errors and conceptual errors dominate cognitive errors in completing integer arithmetic operations. Data show that female students make more errors in all categories than male students, so gender aspects become an important variable in planning mathematics learning. Misreading errors arise due to a lack of understanding of problem information, confusion, or excessive anxiety. Careless errors occur due to a lack of accuracy and a tendency to rush without rechecking. Meanwhile, conceptual errors are caused by a weak understanding of basic mathematical principles and the habit of memorizing procedures without understanding the meaning. Application errors occur when students have difficulty applying concepts to the context of story problems, especially in determining the order of operations. Nolting's theory has proven effective in identifying and classifying errors comprehensively. Therefore, teachers must design learning strategies that are varied in models and media and responsive to gender differences and students' initial abilities. Further research is recommended to develop interventions based on Nolting's theory that utilize a metacognitive approach and evaluate their long-term impact through longitudinal studies.

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