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Students' Errors and Misconceptions in Solving Fundamental Mathematics Problem

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Abstract

The purpose of this research was to analyze students' errors and misconceptions in solving Fundamental Mathematics problems. The research method used in this study was descriptive research with a qualitative approach. The subjects of this study consisted of 23 students who took the Fundamental Mathematics course at the Computer Education Study Program. The instrument used in this research was the Fundamental Mathematics Test. The research procedure consisted of three main stages, namely: (1) preparatory stage: learning activities were carried out in 7 meetings and the development of Fundamental Mathematics questions; (2) implementation: research subjects completed the Fundamental Mathematics Test as an effort to collect data; and (3) data analysis from students' answers to Fundamental Mathematics questions to describe student mistakes in solving Fundamental Mathematics problems. The results showed that many errors and misconceptions that occurred in each question were caused by errors in understanding and translating arithmetic symbols in solving Fundamental Mathematics problems, errors in drawing conclusions, and errors in making graphs and images. In addition, misconceptions occur when solving problems involving arithmetic symbols. Furthermore, the recommendation from this study is to develop a Fundamental Mathematics didactic design that is able to minimize student errors.

Keywords: Error, Fundamental Mathematics, Misconception, Solving Problem

Abstrak

Tujuan penelitian ini adalah untuk menganalisis kesalahan dan miskonsepsi mahasiswa dalam penyelesaian masalah *Fundamental Mathematics*. Metode penelitian yang digunakan dalam penelitian ini adalah penelitian deskriptif dengan pendekatan kualitatif. Subjek penelitian ini terdiri dari 23 mahasiswa yang mengikuti mata kuliah *Fundamental Mathematics pada Department of Computer Education*. Instrumen yang digunakan pada penelitian ini adalah tes *Fundamental Mathematics*. Prosedur penelitian ini terdiri dari tiga tahapan utama yaitu: (1) tahap persiapan: dilakukan kegiatan pembelajaran sebanyak 7 kali pertemuan dan pengembangan soal *Fundamental Mathematics*; (2) implementasi: subjek penelitian menyelesaikan tes *Fundamental Mathematics* sebagai upaya pengumpulan data; dan (3) analisis data dari jawaban mahasiswa terhadap soal *Fundamental Mathematics* untuk mendeskripsikan kesalahan mahasiswa dalam penyelesaian masalah *Fundamental Mathematics*. Hasil penelitian menunjukkan bahwa kesalahan dan miskonsepsi yang terjadi pada setiap soal banyak disebabkan oleh kesalahan dalam pemahaman dan penerjemahan simbol aritmatika dalam penyelesaian masalah *Fundamental Mathematics*, kesalahan dalam penarikan kesimpulan, serta kesalahan dalam membuat grafik dan gambar. Selain itu, miskonsepsi terjadi saat menyelesaikan masalah dengan melibatkan simbol aritmatik. Selanjutnya, rekomendasi dari penelitian ini adalah mengembangkan desain didaktis *Fundamental Mathematics* yang mampu meminimalisir kesalahan mahasiswa.

Kata kunci: Kesalahan, Matematika Dasar, Miskonsepsi, Penyelesaian Masalah

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INTRODUCTION

The Indonesian education system is the fourth largest in the world. The cultural, ethnic, and geographical diversity of Indonesia, which is an archipelagic country, is a significant challenge for the world of Indonesian education (Kemendikbud, 2019). Mathematics is a science that can improve thinking skills and contribute to solving daily problems and the world of work, as well as the development of science and technology (Sari & Darhim, 2020; Sari & Mahendra, 2017). An understanding of mathematics prepares students to be able to survive in ever-changing and competitive conditions in the future.

Fundamental Mathematics is a compulsory subject in the Computer Education Study Program. Fundamental Mathematics is a course that forms the basis for mastering students' mathematical and algorithmic ability to support core computer science courses, so that mastery of Fundamental Mathematics material will support advanced courses related to mathematics and programming. Based on previous research, mastery of mathematical ability has a strong relationship with the programming ability of students in the Computer Education Study Program (Sari, Sukmawati, et al., 2018). This is also in line with several other studies that state the cognitive benefits and outcomes of learning programming that are closely related to mathematics (Feurzeig, Papert, & Lawler, 2011; Subramaniam, Maat, & Mahmud, 2022; Sung, Ahn, & Black, 2017; Sung & Black, 2020).

Seeing the importance of mastering the ability of Fundamental Mathematics in students is in contrast to the low average student learning outcomes in mathematics courses. This is in line with the statement that around 71% of Indonesian students have difficulty dealing with situations that require problem-solving skills using mathematics (Kemendikbud, 2019). These difficulties can be identified by looking at the mistakes and misconceptions made by students.

Student errors in solving math problems are divided into three categories: errors in understanding concepts, errors in problem-solving skills, and errors in problem solving (Romadiastri, 2016). Student errors in solving mathematical problems in general can be in the form of procedural errors and conceptual errors. Errors that are often experienced in solving mathematical problems are related to relative numbers and especially to the rule of signs (Gagatsis & Kyriakides, 2000). Repetitive mistakes made by students occur because there are beliefs that they hold, such as that they cannot learn from mistakes and that mathematics consists of unrelated rules and procedures (Sarwadi & Shahrill, 2014). It was also mentioned that the factors that caused students to experience errors in solving problems were that they did not master the concepts in the previous material, which were prerequisite materials, abstract mathematical representations, and a lack of practice in working on questions (Gagatsis & Kyriakides, 2000; Romadiastri, 2016; Sari, et al., 2018; Sarwadi & Shahrill, 2014). Therefore, if individuals cannot adapt new ideas to existing knowledge and accommodate them, then this can form gaps in their cognitive structure, which results in errors in their learning outcomes.

Misconceptions are misunderstandings and misinterpretations based on the meaning of wrong concepts that hinder students' reasoning (Ojose, 2015). In line with this, misconceptions are defined as consistent conceptual errors in solving different problems (Parwati & Suharta, 2020). Errors and misconceptions occur due to a failure to build relationships between knowledge. Misconceptions are the interpretation of concepts in inaccurate statements, the wrong use of concepts, the wrong classification of examples, and the incorrect hierarchical relationship of concepts (Kang, Scharmann, Kang, & Noh, 2010). Misconceptions occur when students are wrong in generalizing an idea, thus disturbing students in interpreting new understandings that they are actively constructing (Mohyuddin & Khalil, 2016). Of course, learning depends heavily on the cognitive level of students and the complexity of the concepts to be learned. It is impossible to expect that every student will learn the concept for the same results with the correct algorithm, so some students may come out and experience misconceptions in the process of learning the concept (Ay, 2017; Lee & Ginsburg, 2009). Misconceptions that occur in students can also be caused by misconceptions made by teachers, namely errors in the application of a rule or inaccurate generalizations (Dzulfikar & Vitantri, 2017; Rosyidah, Maulyda, & Oktaviyanti, 2020), or even by textbooks as a source of student learning (Kajander & Lovric, 2009). Thus, misconceptions are solving problems that are considered correct by students, even though there are misconceptions about the generalization of ideas, so that they occur repeatedly and consistently.

The study by Sari, Darhim, et al. (2018) looked at how students who learned using REACT strategies compared to those using traditional methods performed in solving math problems related to representation ability. They focused on understanding the mistakes and misunderstandings made by the students. This study discusses geometric material, namely the polyhedron. In contrast to this research, which examines student errors and misconceptions in solving Fundamental Mathematics problems, namely the material on the real number system, equations and inequalities, and sets, in research that discusses the potential for mathematical errors to identify student errors in fractional material (Bray, 2016), in another study, mathematical misconceptions were presented, namely on operations with fractions (arithmetic) and addition of exponents (algebra) (Cockburn & Littler, 2008; Mohyuddin & Khalil, 2016; Ojose, 2015). In addition to differences related to the material being analyzed, an analysis of misconceptions was conducted among students at the elementary level based on gender (Mohyuddin & Khalil, 2016). In contrast to this, this study analyzes errors and misconceptions among students in higher education. Research on set material has also been carried out before, and this study also discussed errors in determining the Cartesian product of two sets (Janan et al., 2022).

Student errors can be used to produce a diagnosis to improve students' cognitive structures, which must be addressed immediately so as not to have further impacts (Sari, et al., 2018) and look for patterns of possible causes of these errors and misconceptions (Sarwadi & Shahrill, 2014). In addition, analyzing mathematical errors publicly can introduce conceptual understanding (Bray, 2016; Kazemi & Stipek, 2009) and enable students to explore regular reasoning mechanisms, then help teachers identify and meet students' learning needs (Gagatsis & Kyriakides, 2000). The number of errors and misconceptions experienced by students can be a clue to their understanding, mathematical ability, and mastery of the learning material. These errors must be addressed immediately so as to minimize errors and prevent them from being repeated again. Therefore. The purpose of this research is to analyze students' errors and misconceptions in solving Fundamental Mathematics problems.

METHODS

The research method used in this study was descriptive research with a qualitative approach. The instrument used in this study was the Fundamental Mathematics Test, which consisted of 4 questions. The Fundamental Mathematics Test indicators include: (1) operating exponents based on their properties; (2) determining the discriminant and set of solutions of a quadratic equation; (3) completing and sketching a number line from Inequality; (4) analyzing problems regarding sets and drawing a Venn diagram. The Fundamental Mathematics Test instrument consists of three materials, including the real number system, equations and inequalities, and sets.

The research procedure consists of three main stages, namely preparation, implementation, and data analysis. In the preparatory stage, learning activities were carried out through seven meetings and the development of Fundamental Mathematics questions. Furthermore, the research subjects completed the Fundamental Mathematics Test in an effort to collect data. The last stage is data analysis from students' answers to Fundamental Mathematics questions to describe students' errors and misconceptions in solving Fundamental Mathematics problems.

The data were analyzed and described inductively. Data analysis techniques include the stages of data collection, data reduction, data presentation, and drawing conclusions. Triangulation of data sources to ensure data validity. The subjects of this study consisted of twenty-three Computer Education students. The subjects of this study have the same character, namely students taking Fundamental Mathematics courses. This research subject was chosen because it had entered the formal operational stage. At this stage, individuals are able to solve problems based on assumptions and thoughts that involve many formal logical rules (Bakirci et al., 2011). Furthermore, Table 1 below shows the error and misconception assessment rubric to analyze student errors and misconceptions in solving Fundamental Mathematics problems.

Table 1. The error and misconception assessment rubric

The Types of Errors	Response	Score
1. Incomplete Answer 2. Misused Data: the procedural steps are proven correct, but errors in drawing conclusions	There are no answers or wrong answers	0
3. Technical Error: a computational error, an error in manipulating elementary algebraic symbols, a careless error, or an error in using processes and skills usually mastered in a prerequisite course	Only partially correct answers	1
4. Distorted Definition: altered definition that is relevant to the solution of the problem	Answered almost all of the questions correctly	2
5. Misconceptions	Answered with logical arguments and draw logical conclusions completely, clearly, and correctly	3

The types of errors identified in this study include: (1) Incomplete Answer; (2) Misused Data: the procedural steps are proven correct, but errors in drawing conclusions; (3) Technical Error: a computational error, an error in manipulating elementary algebraic symbols, a careless error, or an error in using processes and skills usually mastered in a prerequisite course; (4) Distorted Definition: altered definition that is relevant to the solution of the problem; and (5) Misconceptions (Sari, et al., 2018; Schnepper & McCoy, 2013). Based on Tabel 1, each type of error can be analyzed based on 4 student responses: (1) there are no answers or wrong answers with a score of 0, (2) only partially correct answers with a score of 1, (3) answered almost all of the questions correctly with a score of 2, and (4) answered with logical arguments and draw logical conclusions completely, clearly, and correctly with a score of 3.

RESULTS AND DISCUSSION

After the implementation of seven meetings of learning activities, followed by the Fundamental Mathematics Test, errors and misconceptions experienced by students in solving Fundamental Mathematics problems were analyzed based on the indicators studied. The indicator for question number 1 is operating exponents based on their properties. Problem number 1 covers students' ability to operate exponents and simplify them into positive powers. The mistake in working on this problem was that students were not able to apply the properties of exponential operations correctly, and the final result of the negative exponential operation was not converted to a positive exponential form. The final result of question number 1a is $a^9b^{-10}c^{-4}$ has not been converted into a positive form. A conceptual error was found in simplifying the exponential into a positive form; that is, if the exponential is already in a positive form, then the exponential is multiplied by 1, and if it is a negative exponential, then the exponential will be multiplied by -1, so that the final result becomes $(a^9)^1(b^{-10})^{-1}(c^{-4})^{-1} = a^9b^{10}c^4$. The idea derived from the wrong processing step is to change a number with a negative power to a positive power without paying attention to the properties of the exponent, where it should be $a^{-n} = \frac{1}{a^n}$. It can be seen that students manipulate the concept by changing negative exponents to positive exponents to reflect the same value regardless of the rules. Next, the final result should be $\frac{a^9}{b^{10}c^4}$. In previous studies, this was included in the application of the rules (Nurkamilah & Afriansyah, 2021; Sari & Afriansyah, 2020).

Furthermore, misconceptions were found in the results of problem number 1b. This can be seen in Figure 1 below.

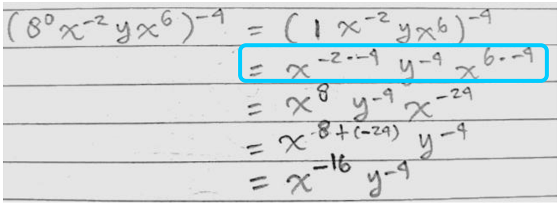

Figure 1. Misconceptions in solving problem number 1b

At a glance, the solution to the final step looks correct and has applied the exponential properties. However, if you look at the second step, which is marked with the blue box above, a misconception is found in the operation of positive numbers and negative numbers to translate the completion of exponential properties. In Figure 1, step 2, the multiplication operation shows that there is no separation between the dot symbols to represent multiplication with a negative sign in the integers. What is written is $x^{-2\cdot-4}y^{-4}x^{6\cdot-4}$. Instead, place the negative number in parentheses after the operation sign. This can be translated into $x^{(-2)\cdot(-4)}y^{-4}x^{6\cdot(-4)}$. This is because students do not correctly understand the rules and principles for solving positive and negative integer arithmetic operations (Cockburn & Littler, 2008; Mohyuddin & Khalil, 2016; Nurkamilah & Afriansyah, 2021; Rosyidah et al., 2020). In other words, students' understanding of the concept of integer operations is relatively weak. This also applies to question number 2.

The indicator for question number 2 is to determine the discriminant and set of solutions for a quadratic equation. Errors in solving this problem included students not being able to deduce the roots obtained from a quadratic equation into a set of solutions, errors in simplifying operations with mixed integers, and errors in writing formulas so that the processing process to obtain results also cannot be justified. An error in simplifying mixed integer operations occurs during discriminant operations $D = b^2 - 4ac = 3^2 - 4 \cdot 3 \cdot (-7)$, and then there was an error performing mixed operations, which became $9 - 4 \cdot (-21) = 5 \times (-21)$. Supposedly, in a mixed arithmetic operation, the first operation step to be performed is the multiplication or division operation, then the subtraction or addition operation. In addition, there are errors in the simplification of fraction operations. This can be seen in Figure 2 below.

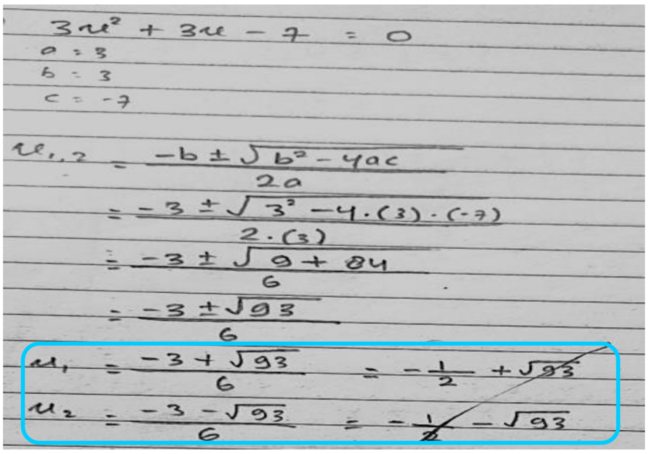

Figure 2. Error Solving Problem Number 2

Figure 2 illustrates errors frequently encountered by students when simplifying fractions. For example, $x_1 = \frac{-3+\sqrt{93}}{6}$, if translated, it equals $\frac{-3}{6} + \frac{\sqrt{93}}{6}$. The denominator is placed on both terms, not just on the first. The simplified result should be $-\frac{1}{2} + \frac{\sqrt{93}}{6}$.. As a result, in Figure 2, only the first term is simplified, regardless of the second term, which should also have a denominator or $\frac{\sqrt{93}}{6}$. This also applies to the simplification of the value x_2. This error is a fractional operation error (An & Wu, 2012; Bray, 2016; Mohyuddin & Khalil, 2016), in which students manipulate fractional simplifications without paying attention to the concept of rules (Ojose, 2015).

The indicator for question number 3 is completing and sketching the number line of inequality. In solving problem number 3, errors or inaccuracies were found by students in operating integers. Common mistakes in drawing a number line to determine the solution set of inequality include: (1) not writing the number line symbolized by the variable x or y; (2) there is no full integer marker for the inequality sign $\leq$ or $\geq$ and no integer marker for inequality sign $<$ or $>$; (3) errors in concluding the solution set due to errors in determining the direction of the arrow to the right or left, shaded areas, and positive or negative areas. In addition, misconceptions were found in the simplification of inequality, which is shown in Figure 3.

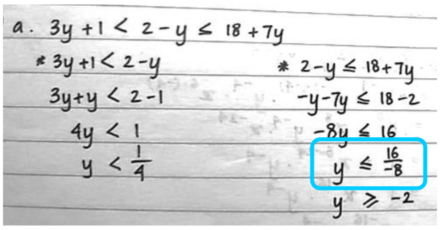

Figure 3. Misconceptions of solving problem number 3

Figure 3 illustrates the solution to the problem regarding inequality. Where should the rules be, if both sides are divided by a negative number, then the sign of the inequality changes. If before dividing a negative number in an inequality is marked with the symbol $\leq$, then in solving inequality divided by a negative number must change to $\geq$. Vice versa. In this case, both sides of inequality $-8y \leq 16$ are divided by -8. When divided by a negative number, the step in the blue box in Figure 3 is $y \geq \frac{16}{-8}$. With the same end result as above. Misconceptions about the rule of signs are errors that are often experienced in solving mathematical problems (Gagatsis & Kyriakides, 2000).

The indicator for question number 4 is to analyze the problem regarding Set and draw a Venn diagram. Common mistakes in solving problem number 4 are errors in representing arithmetic symbols into integers, errors in representing arithmetic symbols in sets into Venn diagrams, errors in determining the result area in translating operations on two sets, and errors in determining the placement of elements in the specified set. Furthermore, there are quite interesting errors to be discussed in the operation of the two sets $E \times D$, shown in Figure 4 below.

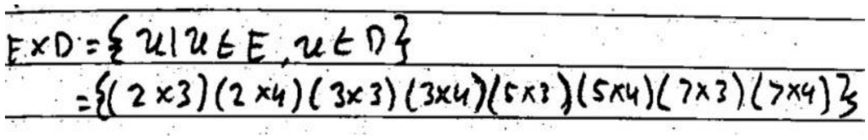

Figure 4. Error solving problem number 4

Operations on sets for Cartesian Products are ordered pairs. In Figure 4, the error starts with defining the Cartesian Product. It is known that the set $E = \{2, 3, 5, 7\}$ and $D = \{3, 4\}$. Figure 4 illustrate that there is an error in interpreting the sequential pair (e, d) into $(e \times d)$ such as translating the problem in a clear way. So that the answer looks like in Figure 4. If seen from the order of the elements of the set in the Cartesian Product solution, it has been sorted correctly, but conceptually, it is wrong. It should be, $E \times D = \{(e, d) | e \epsilon E \ dan \ d \epsilon D\}$. This is a misunderstanding of the concepts and rules that apply (Janan et al., 2022).

Furthermore, the recommendation from the conclusion of the errors and misconceptions that have been analyzed is that it is necessary to analyze the reasons why students make these mistakes, design approaches, and take actions for improvement (An & Wu, 2012). The provision of scaffolding by lecturers in the form of explaining, reviewing, and restructuring, and developing conceptual thinking encourages students to correct these mistakes (Anghileri, 2006; Hartati, 2016; Purwasih & Rahmadhani, 2022). Lecturers are expected to carry out lecture activities that are meaningful for students so that it is not easy for them to forget the material concepts that have been explained (Ningsi et al., 2022). Mathematical reasoning didactic design can minimize problems and obstacles to student learning (Oktaviani et al., 2022). This is done to explore students' thoughts and understand the difficulties and challenges of learning for them. Thus, what needs to be done next is to develop a Fundamental Mathematics didactic design that is able to minimize student errors.

CONCLUSION

The conclusions obtained from the analysis of errors and misconceptions obtained from this study are very interesting to discuss. The mistake in working on problem number 1 with indicators operating exponents based on their properties was that students were not able to apply the properties of exponential operations correctly, and the final result of operations with negative powers was not changed to positive powers. The errors experienced by students in problem number 2 with indicators determining the discriminant and set of solutions of a quadratic equation are students not being able to deduce the roots obtained from a quadratic equation into a set of solutions, errors in simplifying mixed integer operations, and errors in writing formulas so that the process of processing to the acquisition of results also can't be justified. Common student mistakes in drawing number lines to determine the solution set of inequality include not writing a number line, which is symbolized by the variable x or y, there are no full circle markers for inequality signs $\leq$ or $\geq$ and no empty integer markers for inequality marks $<$ or $>$, an error in concluding the settlement set due to an error in determining the direction of the arrow to the right or left; the shaded area; and the positive or negative area. Common mistakes in solving problem number 4 analyzing problems regarding sets and drawing Venn diagrams are errors in representing arithmetic symbols into integers, errors in representing arithmetic symbols in sets into Venn diagrams, errors in determining the result area in translating operations of two sets, and errors in determining the placement of elements in the specified set.

Furthermore, a misconception was found in the operation of positive numbers and negative numbers to translate the completion of exponential properties. In addition, there is a misconception about solving inequality. If before dividing a negative number in an inequality is marked with the symbol $\leq$, then in solving an inequality divided by a negative number must change to $\geq$. Vice versa. Thus, in this study, misconceptions occur when solving problems involving arithmetic symbols.

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