

Analysis of Students' Difficulties in Using Mathematical Models to Solve Story Problems on Derivatives Material

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ABSTRACT

Mathematics plays an important role in helping students solve problems in everyday life. Real-world problems can be expressed in the form of mathematical word problems. To solve these problems, students need to follow several stages, starting with problem translation, where they select key information and transform it into a mathematical model. A model is a representation of an object, thing, or idea in a form different from the original entity. Mathematical modeling, on the other hand, is a way to simplify complex systems by using mathematical equations. This study aims to determine the level of students' understanding in solving derivative problems using mathematical modeling. This is a quantitative study with a descriptive approach. The population of the study consisted of all students in class XI MIPA-2, totaling 35 students. The sample for the study was students solving word problems on derivative topics. The results showed that 13 answers were correct and aligned with Polya's steps (7%), while 162 answers did not align with Polya's steps (93%) out of a total of 175 responses (100%). These findings are expected to provide insights for educators and curriculum developers in designing more effective and interactive learning strategies. The results indicate that students still face difficulties in understanding problems and forming mathematical models. This study is limited to a specific sample group and focuses solely on the topic of derivatives, not including other mathematical topics that might offer additional insights into students' ability to model real world problems.

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1. INTRODUCTION

Mathematics plays an important role in helping students solve problems in everyday life. (Permatasari et al., 2018). Matematika hadir sebagai alat yang mempermudah kehidupan manusia (Nanang, 2012). Therefore, mathematics is taught at every level of schooling to train students in identifying and solving problems, as well as applying mathematics to address various issues (Puspitasari, 2012). According to Afriansyah et al. (2020) learning mathematics is not just about performing calculations but also about training students to develop logical, analytical, systematic, critical, and creative thinking skills.

Real-world problems can be translated into mathematical word problems. Mathematical word problems are questions presented in narrative form, where mathematical operation symbols are not directly displayed. These problems invite readers to understand the situation and apply mathematical thinking within the given context. To solve word problems, students need to follow several stages. The process begins with problem translation, where they select key information and convert it into a mathematical model. Next, in the problem integration stage, students combine the model to plan a solution. During the solution planning stage, they outline a plan by detailing the steps to be taken. Finally, in the problem-solving stage, students execute the plan based on the steps they have previously outlined. (Zulkarnaen, 2020).

To solve contextual mathematical problems, mathematical modeling is required to transform real-world issues into abstract models. Romizwoski (1981), stated that learning outcomes manifest as knowledge and skills. Knowledge is classified into four categories: 1) facts, 2) concepts, 3) procedures, and 4) principles. Facts are related to knowledge about tangible objects, while concepts involve understanding groups of objects or their definitions. Procedures refer to the steps required to achieve specific goals, and principles explain relationships between two or more concepts, including causal or correlational connections. Skills, on the other hand, are divided into four types: 1) cognitive skills, 2) performing, 3) responding, and 4) interacting. Cognitive skills involve the ability to think critically in various situations, such as applying mathematical modeling to solve problems.

The research by Wulandari et al. (2014) showed that students' ability to solve word problems is still low, as seen in several aspects, such as a lack of understanding of the problem presented in the question and difficulty in transforming the story into a mathematical model. In line with this, the research by Farida (2015) concluded that students often make mistakes in converting the given information into mathematical expressions because they do not understand the meaning of the question. Furthermore, they also experience difficulties in determining the correct formula to solve the problem, often due to forgetting the formulas they need to use. Many students merely memorize formulas taught by the teacher, making them prone to forgetting them later.

Based on the research by Muntaha et al., (2020) these difficulties occur because students have not fully understood the process of mathematical modeling. They still struggle to interpret verbal sentences, especially in determining the relationship between two variables of the same type. Furthermore, students are unable to provide logical reasoning for the symbols they choose in the equations or mathematical models they create. Additionally, research by Bahir & Mampouw (2020) found that students' errors in mathematical modeling include failing to identify variables, not making model assumptions, and incorrectly formulating and solving equations. Internal factors include a lack of practice, understanding of modeling, and reliance on their own reasoning, while external factors involve difficult problems and a lack of learning resources.

According to Zulkarnaen (2020) students' weaknesses in solving word problems are believed to stem from their lack of ability in mathematical modeling. This modeling requires the selection and application of appropriate mathematical concepts or procedures to transform real-world problems into mathematical forms or to construct mathematical models.

In the context of mathematics learning, the topic of derivatives is closely related to mathematical modeling. Mathematical modeling ability refers to students' capability to transform real-world problems into mathematical forms, such as diagrams, graphs, or systematic procedures. It also involves constructing clear explanations or descriptions to solve mathematical problems. Mathematical modeling serves as a bridge between simpler, unstructured mathematical understanding and more formal, structured mathematical concepts. Derivatives, as one of the key

topics in mathematics, are deeply interconnected with mathematical modeling in various contexts, such as optimization, speed and rate of change analysis, growth and decay, and more.

According to Devita & Wibawa (2020) optimization is the process of maximizing or minimizing the use of limited resources, which is closely related to optimization efforts. Additionally, Adi et al. (2015) define optimization as the process of finding a solution within a feasible area that has the minimum or maximum value of a function. In mathematical modeling, optimization involving derivatives is used to find the maximum or minimum values of a function. For example, in optimization problems such as determining the optimal price to maximize profit or minimize cost, derivatives are used to calculate the extrema points of the objective function.

The analysis of rate and change in derivatives describes the rate of change of one variable with respect to another. In mathematical modeling involving velocity, acceleration, or changes in dynamic systems, derivatives help represent and analyze how a system evolves over time. In growth and decay, derivatives are applied in models for population growth, radioactive decay, or other processes involving exponential changes. They are used to determine rates of change and predict the future behavior of a system. According to Pangesti & Mampouw (2019) growth and decay is one of the mathematical topics closely linked to contextual problems that arise in everyday life.

From the explanation above, it is evident that mathematical modeling ability plays a crucial role. Therefore, the author is interested in exploring students' understanding of their mathematical modeling ability in the context of derivatives. The objectives of this study are as follows:

- a) To understand the characteristics (definitions and indicators) of mathematical modeling ability.
- b) To determine the level of students' understanding in solving derivative problems using mathematical modeling.

2. METHOD

The type of research used is qualitative research with a descriptive approach. The qualitative descriptive approach is a research method aimed at describing and explaining a phenomenon or event in depth. In this case, the study focuses on understanding and describing the level of students' comprehension in solving word problems on the topic of derivatives.

This approach allows researchers to gain deeper insights into students' experiences and understanding of derivatives in mathematics learning. The data collection techniques used, namely word problem tests and interviews, align with the qualitative approach as they provide opportunities for further exploration of students' thoughts and conceptual understanding.

This study was conducted during the second semester of the 2023/2024 academic year, with the population consisting of students from Class XI at MAN 1 Karawang, specifically Class XI MIPA-2. A number of students' responses were selected as samples, considering the variations in their level of understanding when solving word problems on the topic of derivatives. The population for this research comprised all 35 students in Class XI MIPA-2, while the sample focused on students solving word problems related to derivatives.

The data for this study were collected from Class XI MIPA-2 students at MAN 1 Karawang. The data collection methods included test results and interviews. The test used for data collection consisted of five validated word problems on the topic of derivatives, reviewed by subject matter experts. The data analysis technique employed in this study was descriptive analysis, aimed at describing the situation observed in the field.

3. RESULT AND DISCUSSION

3.1. Model and Mathematical Modeling

Students have actually been learning about mathematical models since elementary school, for example, when they translate word problems into mathematical formulas. In everyday life, they often unknowingly engage in mathematical modeling. Various types of symbols are used by people in daily activities (Andriani, 2019). According to Zarlis (2008) a model is a representation of an object, thing, or idea in a form different from its original entity. This model contains information about a system that is designed to study the system. A model can also be a replica of a real object,

system, or event, which only includes information deemed essential for analysis. Furthermore, Zarlis (2008) states that a mathematical model of a problem is the formulation of the problem in the form of a mathematical equation or function. Meanwhile, mathematical modeling is a series of steps taken to obtain and use mathematical equations or functions to solve a problem.

According to Parlaungan (2008) there are at least four important components in a mathematical model. These four components are as follows:

1. Dependent variables
2. Independent variables
3. Constants or parameters
4. Relationships between variables

Mathematical modeling is an effort to mathematically represent and explain physical systems or processes in the real world using mathematical statements. The goal is to gain a more accurate understanding of these systems or processes. The result of this mathematical representation is referred to as a "mathematical model." The process of constructing, analyzing, and using mathematical models is considered one of the applications of mathematics in everyday life. (Widowati & Sutimin, 2007).

According to Ndi (2022) mathematical modeling is a method of simplifying complex systems through mathematical equations. This approach allows us to convert difficult-to-understand problems into mathematical forms that can be studied and used to explain intricate situations. By doing so, mathematical modeling enables us to analyze, forecast, and find solutions to the challenges we encounter.

Another definition of mathematical modeling is the process of depicting real-world problems using mathematical language in order to find solutions. In this process, complex issues or real-world situations are simplified into a mathematical format (Hartono & Karnasih, 2017). According to Parlaungan (2008) mathematical modeling is defined as the application of mathematical concepts and techniques to address real-world problems or complex situations that originate from the real world.

Real world problems are initially translated into mathematical statements (mathematical models) by understanding the issues at hand, such as identifying important information and determining what needs to be solved. Once the mathematical model is formed according to mathematical principles, the next step is to solve the model to find a solution. The solution to the mathematical model is then interpreted to provide an answer that can be used to resolve the problem.

Following Polya's steps (1973) we can understand how to solve word problems in the following way:

1. Understand the problem, which involves the following:
 - 1) Carefully reading and analyzing the problem.
 - 2) Restating the problem in your own words.
 - 3) Identifying the known information.
 - 4) Determining the question or the goal that needs to be answered.

In this step, students are asked to determine the information that is already provided and the question that needs to be answered in the word problem. If students encounter difficulties, the teacher will ask them to restate the problem in their own words. The next step is for the students to clearly confirm what is known and what needs to be found from the problem.

2. Formulating a plan to solve the problem

After understanding the meaning of the problem, the next step is for students to plan how to solve it by considering various strategies, such as:

- 1) Using diagrams, tables, images, or other data provided in the problem.

- 2) Identifying the relationship between the information provided in the problem and what needs to be answered.
- 3) Determining the steps or mathematical formulas that can be used.
- 4) Considering alternative methods or strategies that can be applied.

3. Implementing the solution plan

At this stage, students are expected to choose the appropriate strategy or technique to solve the mathematical model they have created.

4. Checking the solution

After finding the answer, students are asked to verify its correctness by applying the answer back to the original problem to ensure the result is accurate.

From the explanation, mathematical modeling involves transforming real-world problems into mathematical representations and using mathematical steps to solve those problems. Based on the mathematical modeling process and the problem-solving methods outlined by Polya (1973), the indicators of mathematical modeling ability can be summarized as follows.

1. Identifying the problem

- 1) Understanding the information presented in the problem.
- 2) Understanding the mathematical concepts relevant to the problem.
- 3) Identifying key words or important information in the problem to assist in the solving process.

2. Creating the mathematical model

- 1) Being able to transform the known elements into variables.
- 2) Being able to formulate a mathematical model that aligns with the information from the problem.
- 3) Being able to simplify the mathematical model.

By following the steps outlined by Polya, students can develop their mathematical modeling skills, starting from identifying the problem to formulating and simplifying the appropriate model. This process is expected to help them face and solve real-life problems in their daily lives.

3.2. Level of Student Understanding

This section will describe the results of the research regarding the level of understanding of students in solving mathematical modeling problems in the topic of derivatives. The research data will be explained through excerpts from the answers of the subjects, which have been coded, referring to the code of excerpts from the test and interview transcripts. The code for the excerpts of the subject's answers consists of four to five digits starting with "S1", "S2", or "S3", representing subjects with high (S1), medium (S2), or low (S3) ability levels. The third or fourth digit indicates the absence number, for example, "1" represents the first absence number, and so on. The fourth or fifth digit, which is an alphabetic letter, indicates the question number: "a" represents question 1, "b" represents question 2, "c" represents question 3, "d" represents question 4, and "e" represents question 5. For example, the code "S21a" indicates the answer of a subject with medium ability, absence number 1, and question number 1. The code for interview excerpts is marked with "P".

In this study, the researcher analyzes the test results of students on the topic of derivatives to understand the application of mathematical modeling. The researcher selected samples based on students' answers who solved word problems by following Polya's steps, rather than randomly, to ensure that the data obtained is more relevant and representative. The test results provide an overview of how well students can use mathematical models in understanding and solving derivative problems. Below is a description of the test results, demonstrating how students apply the concept of derivatives and problem-solving steps in practice.

In this study, the researcher analyzes the test results of students on the topic of derivatives to understand the application of mathematical modeling based on the students' test responses. The sample selected was not random but based on the students' answers in solving word problems by

following Polya's steps, ensuring that the data described is relevant and representative of the problem being researched. Below are the questions and descriptions of the mathematical modeling on the topic of derivatives based on the students' test results.

The population of a country is proportional to the current population. Currently, the population is 80 million people. Ten years ago, the population was 70 million people. Assuming this trend continues, determine the expression for the estimated population of the country at any time (t) (use (t = 0) for the current condition).

a. Answer from a high ability student (S110c)

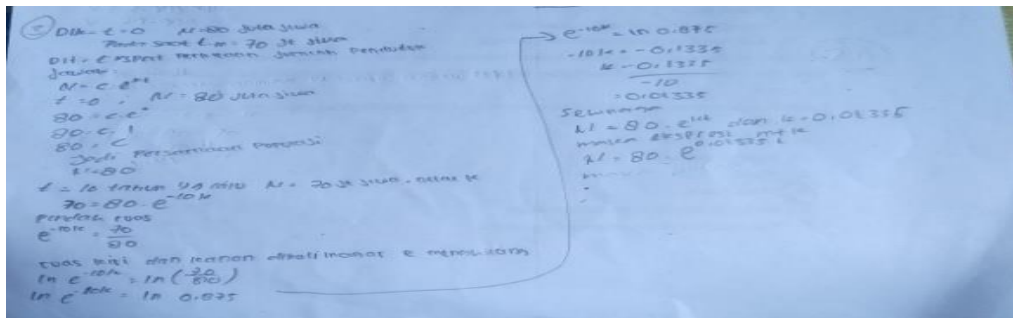


Image 1. High Ability Student's Answer Number 3 Mathematical Modeling.

The subject performs the steps of solving the word problem systematically, starting from understanding the problem, formulating the solution steps, carrying out the solution steps, and checking the answer. The subject also meets the indicators of ability in mathematical modeling, which include identifying the problem (understanding the information, understanding the relevant mathematical concepts in the problem, understanding key words or important information in the problem) and understanding the mathematical model (transforming known elements into variables, formulating the mathematical model, and simplifying the mathematical model).

b. Answer of the student with moderate ability (S218c)

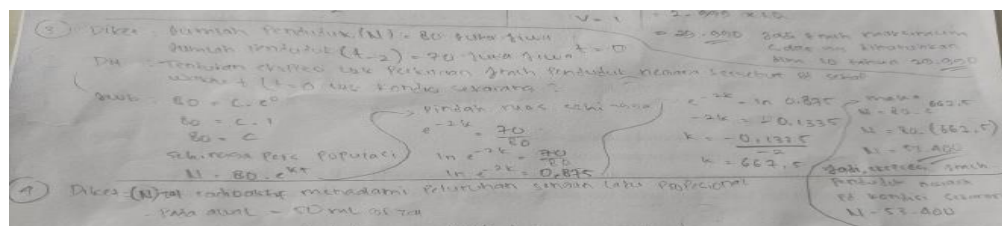


Image 2. Moderate Ability Student's Answer Number 3 Mathematical Modeling.

The subject performs the steps of solving the word problem systematically, starting from understanding the problem, formulating the solution steps, carrying out the solution steps, and checking the answer. However, the subject makes an error in carrying out the solution steps in the calculation of the population equation $N = 80 \cdot e^{kt}$. In the next step, the subject writes $e^{-2k} = \frac{70}{80}$ when it should have been $e^{-10k} = \frac{70}{80}$ leading to an incorrect result. The subject also meets the indicators of ability in mathematical modeling, which include identifying the problem (understanding the information, understanding the relevant mathematical concepts in the problem, understanding key words or important information in the problem) and understanding the mathematical model (transforming known elements into variables, formulating the mathematical model, and simplifying the mathematical model).

Based on the answer to question number three above, it appears that the subject has a limited understanding of what the problem in the question is. As a result, the subject made an error in the final answer. This is also supported by the results of the interview between the researcher and the subject.

- P : Do you know what is given and what is being asked??
 S213d : What is given is the population, and what is being asked is the mathematical expression.
 P : Based on this answer (the researcher points to one of the answers), which mathematical expression is it?
 S213d : This one
 P : Pay attention to the solution for number three, this part (the researcher points to the incorrect part). Is there anything wrong? Where is the mistake?
 S213d : Which part
 P : The part where $e^{-2k} = \frac{70}{80}$ it should be $e^{-10k} = \frac{70}{80}$
 S213d : Yes, i didn't understand it well. I remembered it like the one in the PDF. But when I was allowed to look at the PDF, I think I understood it.

Based on the excerpt from the interview, it can be concluded that the subject did not understand what the problem was. The subject also made an error, resulting in an incorrect answer.

c. Answer of the student with low ability (S322c)

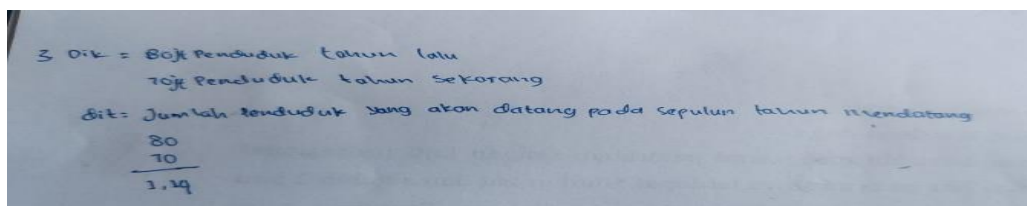


Image 3. Low Ability Student's Answer Number 3 Mathematical Modeling.

The subject performs the solution steps in an unsystematic manner, failing to formulate solution steps, carry out the solution, and check the answer. The subject does not meet the indicators of ability in mathematical modeling, which include identifying the problem (understanding the information, understanding the relevant mathematical concepts in the problem, and understanding key words or important information in the problem) and understanding the mathematical model (transforming known elements into variables, formulating the mathematical model, and simplifying the mathematical model). The subject is only able to understand what is given and what is being asked in the problem.

Based on the answer to question number one above, it appears that the subject does not fully understand the problem, starting from what is given and what the problem is, and also does not rewrite the answer to the question. This is also supported by the results of the interview between the researcher and the subject.

- P : Do you know the formulas for the derivatives of functions?
 S321a : I don't know
 P : Do you know what is given and what is being asked??
 S321a : I don't know, but I know the second one.
 P : What formula or steps did you use to solve this problem??
 S321a : I'm not sure.
 P : Is the calculation correct?

S321a : It seems all wrong, teacher.

Based on the excerpt from the interview, it can be concluded that the subject does not understand what the problem is, the subject also made errors in the calculations, resulting in an incorrect answer, and did not draw a conclusion from the question.

From the explanation above, it can be concluded that the students' understanding of mathematical modeling in word problems on the topic of derivatives, based on the solution of the word problem and the indicators of ability in mathematical modeling as explained by Polya, can be measured using research instruments. The percentage of understanding is calculated by applying the basic percentage formula to determine how well the students understand the concept. Below are the formula and the steps used:

$$\text{Percentage} = \left(\frac{n}{N}\right) \times 100\%$$

Explanation

n = number of correct answers according to Polya's steps

N = total number of answers

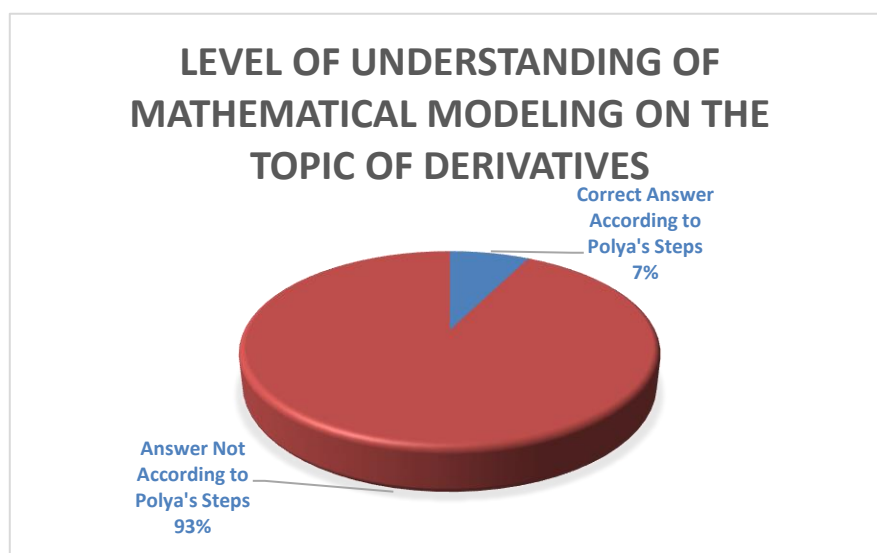


Image 4. Pie Chart of Students' Understanding Level of Mathematical Modeling on the Topic

From the pie chart above, it is known that 13 correct answers are in accordance with Polya's steps (7%), and 162 answers do not follow Polya's steps (93%) out of a total of 175 answers (100%). The percentage is the same as the combination of the high-ability group and the moderate-ability group, which consists of seven students out of a total of thirty-five students.

3.3. Discussion

As previously explained, most students struggle to create mathematical models from word problems related to derivatives. According to Pratikno (2019), students with low mathematical abilities tend to have difficulty modeling problems, indicating that their skills in this area are relatively weak. Common mistakes students make in mathematical modeling include the inability to identify variables within a problem, resulting in a lack of variable explanations to construct a model. According to Saparwadi (2022), three common mistakes students make in understanding mathematics are being inattentive while reading problems, struggling with solution steps, and failing to create assumptions from the given information, which hinders problem-solving.

According to Meiria Rahmasari & Waluya (2024) students face difficulties in understanding problems, as evidenced by their failure to include known and required information. In the planning stage, they do not outline steps or necessary formulas. During problem-solving, errors occur in applying formulas, or they directly provide answers without calculations. In the evaluation stage, students do not draw conclusions from their work.

Additionally, students often fail to make accurate assumptions about the model to be formulated into equations and make errors in formulating and solving these equations. Internally, factors contributing to these mistakes include a lack of practice with word problems, limited understanding of mathematical modeling and its importance in problem-solving, and a tendency to rely on intuition or personal reasoning when tackling problems. Externally, the difficulty of the problems and insufficient support in terms of resources, such as books or other learning materials, also contribute to these errors (Bahir & Mampouw, 2020).

According to Hilda & Karimah (2023) errors in mathematical modeling are influenced by three main factors: cognitive skills, accuracy, and time management. Cognitive factors arise when students struggle to understand the problem's meaning. Accuracy issues stem from students' lack of attention to correctly recording questions and failure to review their answers. Meanwhile, time-related factors involve students rushing through problems due to ineffective time management. Additionally, research by Khusna & Ulfah (2021) reveals that students' mathematical modeling abilities vary and do not always correlate directly with their overall mathematical proficiency, whether high, medium, or low. Interestingly, students with high abilities do not consistently perform better in modeling than those with medium or low abilities.

To address these issues Fiyah & Shodikin (2021) suggest that teachers and prospective teachers should focus more on observing how students solve problems and ensure the availability of resources and facilities that support the learning process. Meanwhile, students are encouraged to practice solving problems more diligently and enhance their understanding of mathematical problem-solving.

Several efforts are needed to enhance students' understanding of mathematical modeling. One approach is designing contextual learning that connects mathematical concepts to students' real-life experiences. For instance, using the concept of buying and selling can help students see the practical application of mathematics in everyday life (Mandasari et al., 2023). A study by Saputri & Zulkardi (2020) linked mathematical modeling to online ride hailing services, a familiar context for students. This approach aims to engage and challenge students, making the learning process more appealing. The findings show that guiding students through the stages of mathematical modeling positively impacts their modeling skills.

From the explanation above, it is crucial for teachers and prospective teachers to address students' difficulties in mathematical modeling, particularly in translating real-world problems into mathematical forms. This can be achieved through more contextual approaches, such as designing lessons that connect mathematics with current real-life situations, providing effective solutions. Additionally, the role of teachers in identifying and addressing the factors contributing to errors—be it cognitive, accuracy, or time management—should be emphasized. This approach can explore more effective strategies to enhance students' mathematical modeling abilities, turning challenges into opportunities for learning.

4. CONCLUSION

Based on the explanation above, it can be concluded that students still face difficulties in mathematical modeling for derivative word problems based on Polya's steps and indicators. From 175 responses (100%), only 13 answers (7%) were correct and followed Polya's steps, while 162 answers (93%) did not. This highlights the challenge students face in translating real-world problems into mathematical forms, particularly in understanding the problem and creating a mathematical model. The ability to model real-world problems into mathematical forms is crucial for students, as it helps enhance their understanding and design effective solutions to everyday problems. These findings should serve as valuable input for educators and curriculum developers to design more effective and interactive learning strategies. Recognizing that students struggle to understand problems and form mathematical models, it is important to note the study's limitations. The research

focused on a specific sample group and only addressed derivatives, leaving other mathematical topics unexplored, which could provide additional insights into students' abilities in mathematical modeling.

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