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Analysis of Students' Learning Obstacles in The Differential Equations Course Reviewed from Their Problem-Solving Ability

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ABSTRACT

Objective: This study examines the obstacles students may encounter when learning to solve differential equations with mathematical problem-solving. **Method:** A qualitative study with observation and interviews was conducted on the 5th-semester students of the Mathematics Education Study Program, Khairun University, Ternate, who took the Differential Equations course to explore students' mathematical problem-solving abilities. Samples were selected by purposive sampling by selecting two students each from the low, medium, and high problem-solving ability categories. **Results:** Based on the results of this study, the obstacles that students faced in studying differential equations were ontogeny obstacles, didactic constraints, and epistemological constraints. Several efforts can be made to help students overcome these barriers, such as improving students' collaborative skills, providing constructive feedback, strengthening students' learning motivation through contextual learning, and reflecting on students' learning processes. **Novelty:** The result of this research contributes to helping lecturers design learning that makes it easy to learn differential equation courses.

INTRODUCTION

Before beginning a lesson, teachers should note any obstacles students may encounter in their learning. This is because students' low learning achievement is most likely attributed to internal factors, such as their cognitive abilities, attitudes toward learning, affective behavior, and physical behavior, compared to other factors. According to Geary (2012), students with low mathematics achievement are typically those experiencing obstacles in their learning. Compared to other factors, psychological factors such as low intelligence, interest, learning motivation, and learning concentration cause students to experience 35% greater obstacles. Furthermore, Fauziah & Habibah (2017) examined obstacles in learning mathematics and found that the causes of these obstacles are students' interest (26.26%), motivation (30%), concentration (46.67%), study habits (30%), and intelligence (20%). Meanwhile, the self-confidence factor that may contribute to students' difficulties in learning mathematics has only been discussed in a prior study by Akbari and Sahibzada (2020).

Barriers experienced by students in their learning are better known as learning obstacles. Brousseau (2002) revealed that learning obstacles are caused by three factors, namely: 1) Ontogenic barriers (student's mental readiness to learn); 2) Didactical barriers (teacher's strategies or materials); and 3) Epistemological barriers (knowledge of students who have limited application contexts). Ontogenic barriers occur because The learning process is not by student readiness. To overcome these barriers, training is needed to make students more mentally prepared to solve problems gradually (Prabowo et al., 2022). Ontogenic barriers can be divided into psychological, instrumental, and conceptual obstacles. Instrumental ontogenic obstacles are students' unpreparedness related to technical matters of a learning process. This can be revealed through student responses and mistakes in the learning process. Meanwhile, conceptual ontogenic obstacles are students' unpreparedness related to previous learning experiences, including their lack of conceptual understanding of prerequisite materials (Hendriyanto et al., 2024).

The second category of learning obstacles, namely didactical barriers, occurs due to errors in the learning process and in teachers' selection and delivery of certain teaching materials (Supriadi, 2019). This can happen due to teachers' lack of competence or readiness to prepare for the lessons. For example, materials are repeated or skipped inefficiently, making meeting the predetermined learning objectives difficult. Lastly, epistemological barriers occur due to students' incomplete knowledge of specific contexts. If students are given a different context, their knowledge becomes unusable (Prabowo et al., 2022). Development of one's scientific knowledge faces numerous epistemological barriers, where conceptual schemas in learners experience cognitive constraints.

Students' problem-solving ability is considered one of the key components in solving mathematical problems, especially those with a high level of difficulty. Several final semester courses in college require good problem-solving skills in solving course-related problems. In the Mathematics Education Department, these important courses include Differential Equations as the basis for studying applied mathematics. Programming this course requires adequate mathematical problem-solving skills since differential equations are widely used in solving daily life problems (Crandall, 2022). Students must also have sufficient knowledge, particularly in converting actual situations into mathematics and vice versa. Students taking differential equation courses reported that they could not effectively apply the concept of the derivative of a function, an essential element of differential equations. Therefore, students must have a precise schematic construction of function derivatives to understand the concept of differential equations. This supports the findings of prior studies that students are generally unable to link mathematical materials, likely due to their extremely limited knowledge (Ansori, 2020).

Problem-solving is an essential skill in facing real-world situations, inseparable from mathematical concepts and processes. Before solving a differential equation problem, students must be able to analyze and read the question carefully, as each type of problem has its unique solution (Ishak et al., 2022; Chacón-Castro et al., 2023). Misunderstanding or misinterpreting the problem from the beginning will have fatal consequences for the subsequent steps. This closely relates to students' mathematical literacy skills (Peters, 2020).

Analyzing mathematical problem-solving ability is crucial to understanding students' learning obstacles. Mathematical problem-solving ability is defined as one's capacity to formulate, use, and interpret mathematics in various contexts (Manfreda & Hodnik, 2021). This includes mathematical reasoning and mathematical concepts, factual procedures, and tools to describe, explain, and predict phenomena (OECD, 2019; Sitopu et al., 2024; Zahid, 2020). This ability helps people recognize mathematics's role in the world and make reasoned judgments and decisions as constructive, engaged, and reflective citizens (Suh et al., 2021). Meanwhile, mathematical literacy refers to literacy practices and strategies that enable students to develop mathematical understanding and communicate mathematical reasoning (Chacón-Castro et al., 2023).

According to Julie et al. (2023), mathematical literacy is one of the components needed to develop 21st-century skills. Nevertheless, mathematical literacy is still foreign to some people despite its importance for global society in the 21st century. Furthermore, as one of the key issues and current trends in mathematics education research, mathematical literacy remains a significant challenge in this field. This is because individuals must prepare for their roles as subjects who have learned independently to solve real-world problems requiring specific skills and competencies acquired through school and life experiences. The fundamental process by which students shift from real-world contexts to mathematical contexts, which is required to solve problems, is known as mathematization (Ludwig & Jablonski, 2021). This process allows students to interpret and evaluate problems and reflect on solutions that they believe are appropriate (Cottrell, 2023).

The basic concepts of problem-solving are closely related to mathematical problems. In this regard, problem-solving can refer to 1) the ability to understand and formulate mathematical problems, 2) the ability to explain and predict mathematical phenomena or problems, and 3) the ability to use mathematics in solving problems. According to Wijaya et al. (2023), the indicators of problem-solving achievement are: 1) formulation of problems or understanding of concepts; 2) utilization of reasoning to solve problems; 3) connection of mathematical abilities with various contexts; 4) problem-solving; 5) communication into mathematical language; and 6) interpretation of mathematical abilities in various real-world daily situations.

Based on the description above, conducting a study on students' obstacles in solving mathematical problems is crucial. Therefore, this study is expected to thoroughly explain students' learning obstacles (Herman et al., 2022; Luthfiatunnisa & Hardi, 2024). The results of this study can be used as a reference in the learning and application of differential equations and for other learning materials in general. This study is closely related to the first author's initial research on student learning difficulties (Ishak et al., 2021).

This research's contributions would provide significant insight into the pedagogical strategies for teaching differential equations, inform curriculum development, and suggest targeted interventions to help students overcome learning obstacles. Focusing on problem-solving abilities could also help instructors identify the areas where students typically struggle and tailor instruction to address those specific difficulties. Furthermore, it could lead to a deeper understanding of cultivating a positive problem-solving mindset in students, ultimately improving their overall learning experience in advanced mathematics courses.

RESEARCH METHOD

This study used a qualitative research method to explore existing learning obstacles in solving mathematical problems. The population of this study is 5^{th}-semester students of the Mathematics Education Study Program, Khairun University, Ternate, who took the Differential Equations course. Samples were selected by purposive sampling, which involved selecting two students representing each low, moderate, and high mathematical literacy category. Data were collected through triangulation (observation, in-depth interviews, and documentation). Observations were made to identify students' learning obstacles in solving differential equation problems (Tririnika et al., 2024).

Meanwhile, interviews were conducted to investigate students' applied steps in solving differential equation problems. This pertains to the following concerns: 1) the step of the solution where students experienced difficulties; 2) efforts made to overcome learning obstacles; 3) obstacles faced by students; and 4) feelings experienced in solving differential equation problems. Lastly, documentation was used to observe students' abilities in solving differential equation problems. Data collected through triangulation is processed descriptively by reducing data.

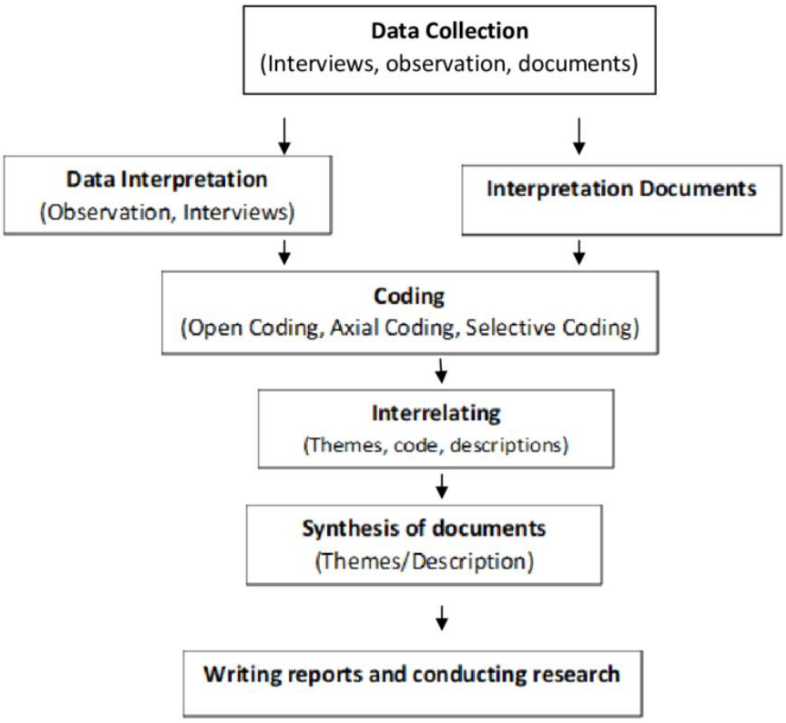

Figure 1. Flowchart

Furthermore, the qualitative method processed and analyzed data (Ravindran, 2019). Data were discussed and presented to obtain the results. Finally, conclusions were drawn, and suggestions were offered based on the analysis results.

RESULTS AND DISCUSSION

Result

To determine students' mathematical problem-solving abilities, their test results were analyzed by referring to four indicators, namely: 1) problem identification, 2) problem formulation, 3) strategy implementation, and 4) solution verification (Säfström et al., 2024). Data were classified according to the conditions and characteristics as proposed by Chan and Kwan (2016). In this study, however, several students did not answer the questions and/or merely rewrote the questions. Therefore, students were grouped into four categories, i.e., those with high mathematic problem-solving ability (K1), those with moderate mathematic problem-solving ability (K2), those with low mathematic problem-solving ability (K3), and those with no ability to solve mathematical problems (K0).

Table 1. Indicators of problem-solving ability on differential equations material.

Number question	Problem-solving ability indicators	K1 (High)	K2 (Moderate)	K3 (low)	K0 (no Ability)
1	1. Problem identification	10	2	6	7

Number question	Problem-solving ability indicators	K1 (High)	K2 (Moderate)	K3 (low)	K0 (no Ability)
	2. Problem formulation	5	3	5	10
	3. Strategy implementation	5	5	3	12
	4. Solution verification	2	4	5	14
2.	1. Problem identification	13	2	3	7
	2. Problem formulation	13	3	3	6
	3. Strategy implementation	5	10	7	8
	4. Solution verification	2	4	7	12

As seen in Table 1, students have very low problem-solving ability in learning differential equations; they still lack conceptual understanding and the ability to translate real-world problems into mathematical models effectively.

Question no. 1 was taken from a simple ordinary differential equation. Students' answers to this question demonstrate their very low ability to identify and formulate problems, apply strategies, and verify solutions. The following is one of the students' answers to question no. 1.

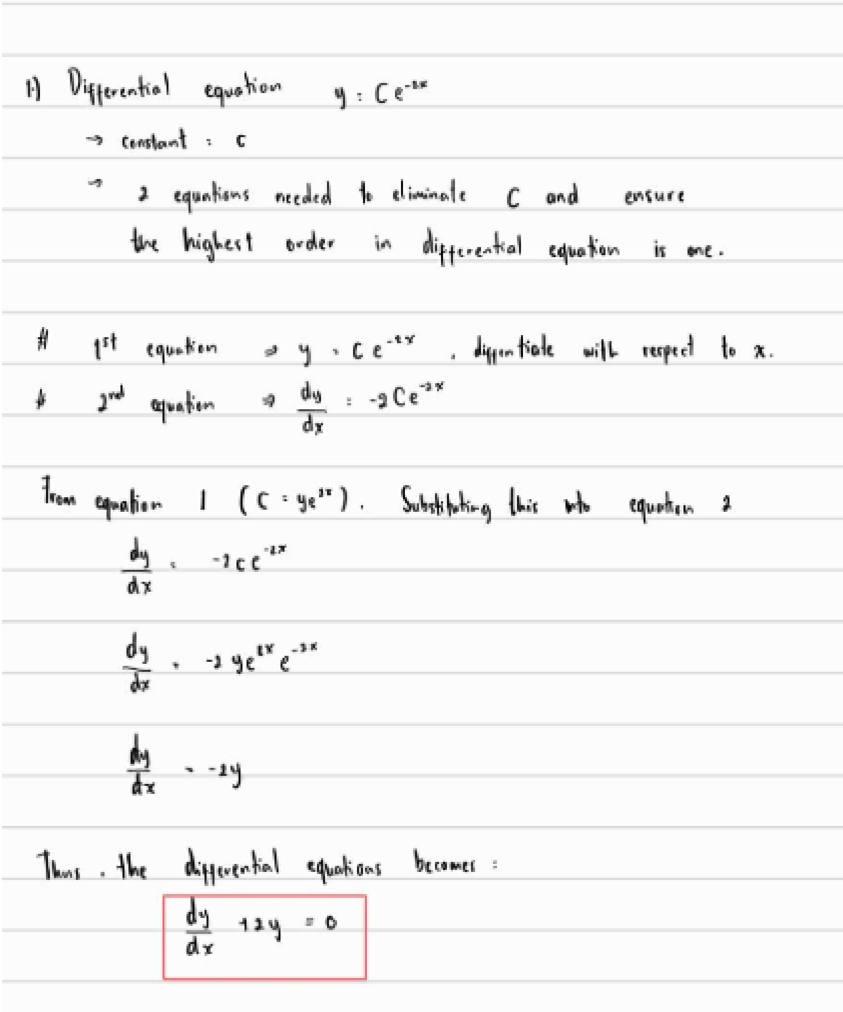

Figure 2. Example of students' answers to question no. 1.

Question No. 2 concerns applying differential equations in real-world situations. It was used to further test students' mathematical problem-solving abilities. Figure 2 displays one of the students' answers to question no. 2.

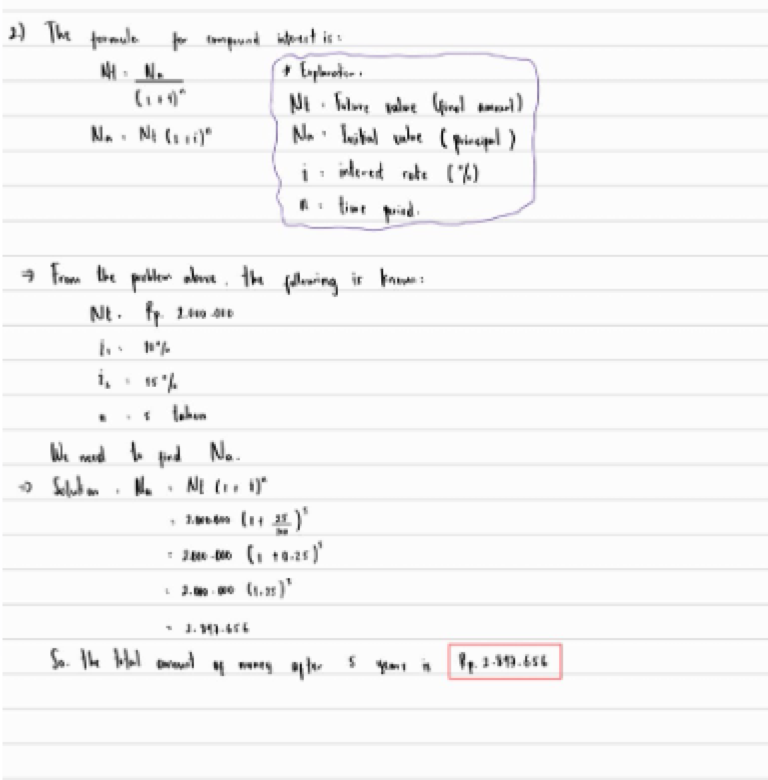

Figure 3. Example of students' answers to question no. 2.

One student from each category of students' problem-solving ability was selected for an interview and further analysis based on the indicators. Students with high, moderate, and low levels of problem-solving ability are represented by M1, M2, and M3, respectively.

Problem Identification Indicators

High problem-solving ability. M1 understands what is known and what is asked in question no. 1. It can explain the mathematical idea in a simple mathematical model, finish the entire steps, carry out the problem-solving procedure correctly, and use the calculus theorem to obtain a solution. For question no. 2, M1 can apply a mathematical model using assumptions from the given information, present the solution process thoroughly, and correctly carry out the problem-solving procedure. Additionally, M1 is also able to use the calculus theorem to obtain a solution and reach a conclusion. In the interview, M1 can verbally explain her answers.

Moderate problem-solving ability. M2 understands what is known and what is asked in question no. 1. It can explain the mathematical idea in a simple mathematical model, finish the entire steps, and correctly carry out the problem-solving procedure. However, she has not been able to use the calculus theorem to obtain a solution. For question no. 2, M2 has been unable to explain daily situations in a mathematical model, as seen in his examples. M2 also makes inaccurate calculations and cannot present the solution process. M2 explains the mathematical idea as a mathematical model and uses basic calculus formulas to obtain a solution and reach a conclusion. When interviewed, M2 can verbally explain the answers.

Low problem-solving ability. M3 understands what is known and what is asked in question no. 1, though not entirely correct, presents the solution process inattentively and describes the information directly using examples. However, M2 is unable to present the solution process. In question no. 2, M3 explains daily situations in mathematical form, but it is incorrect. In the interview, M3 struggles to put words together to explain the results of her work. M3 admitted that he could not solve the problem because he did not know the mathematical model to be used and forgot the basic calculus formula.

Problem Formulation Indicators

High problem-solving ability. For both questions, M1 can present information about the problems in mathematical equations to clarify the given question and explain the mathematical information needed.

Moderate problem-solving ability. In question no. 1, M2 can write the correct equation based on the question and determine the mathematical information needed. However, M2 fails to proceed to the next step of describing the problem in the question. In question no. 2, M2 cannot present a real-life problem in the form of a mathematical model and fails to solve the problem.

Low problem-solving ability. In question no. 1, M3 presents the information contained in the question in the form of a mathematical equation, but it is incorrect, so she cannot proceed to the next step. As for question no. 2, M3 fails to represent real problems in the form of mathematical models and cannot solve the problem. In the interview, M3 can mention the information contained in the question, although not entirely. M3 admitted that he was confused when she had to present the information mentioned in the form of equations or mathematical models.

Strategy Implementation Indicators

High problem-solving ability. M1 provides the correct statement with logical reasons and uses mathematical equations to support the given statement. In the interview, M1 explains that describing the problem before giving a statement can help her understand the problem contained in the question. This shows that M1 can relate the questions given and the definitions she understands to analyze the situation and come to a reasonable conclusion.

Moderate problem-solving ability. M2 can provide statements and answers from the assumptions given for both questions, but the reasons stated are not entirely correct. Unlike students with a high literacy level, M2 answers the questions, provides reasons, and draws the questions. From the interview, it is known that M2 only presents the questions in mathematical models because she does not understand what the questions mean.

Low problem-solving ability. M3 does not explain the answers. During the interview, she was confused and remained silent when asked to explain her answer.

Solution Verification Indicators

High problem-solving ability. M1 can explain what is known and what is asked in the question. In the interview, M1 can identify the elements known and the elements asked as the problem-solving procedures to obtain the results. However, M1 made a mistake in writing the result.

Moderate problem-solving ability. In question no. 1, M2 can find the length of calculating simple differential equations. However, in question no. 2, M2 cannot do the calculation because she incorrectly represents the problem in the mathematical model of differential equations. In the interview, M2 was able to identify the elements known and asked in the question but did not write them on the answer sheet. M2 stated that she was still confused about the next steps to take to find the distance between cars when they stopped.

Low problem-solving ability. M3 defines the problem as a differential equation, but it is not entirely accurate. When interviewed, M3 could partially mention the information known and asked in the question. However, she could not explain the solution that she wrote on the answer sheet and was confused when asked to explain the steps to be used in solving the problem.

To explore this further, a student in the low ability category (M3) was interviewed about question no. 1.

Q: What do you think about question no. 1?
M3: Actually, that question is easy, Ma'am, mainly number 1 because it has been studied in Calculus.
Q: Then, why did you answer it incorrectly?
M3: At first, I had difficulty understanding the questions and started to forget some of the calculus material, Ma'am.
Q: You can reopen your notes or reference books if you forget.
M3: In North Maluku, Ma'am, it is not easy to find reference books that are relevant to this topic.
Q: There are many online materials about calculus and differential equations.
M3: The internet is less effective here; sometimes, when we need [to look for] learning materials, there is no internet connection.
Q: What do you need to help you study for good results?
M3: We need relevant books or modules, Ma'am.
T: *(smile)* Thank you for your time.
M3: You are welcome, Ma'am.

Furthermore, a student who did not answer question no. 2 (M) was interviewed.

Q: Is this your answer sheet? *(showing the answer sheet with section no. 2 left blank)*
M: Yes, Ma'am.
Q: Why didn't you answer a question?
M: I am having trouble understanding it, Ma'am. I do not know how to do it.
Q: If I gave a model like this in the question:
$N = Ce^{kt}$
With the information in question no. 2, can you solve it?
M: If there is a mathematical model like this, Ma'am, I know the solution.
N = 2,000,000 with t(0) = 0, t(1) = 2, and t(3) = 3
Q: That is right.

Based on the analysis results mentioned above, students' learning obstacles in studying differential equations can be classified into three categories, namely ontogenic barriers, didactic barriers, and epistemological barriers. Table 2 presents a detailed explanation of these learning obstacles.

Table 2. Students' learning obstacles were reviewed from the perspective of their mathematical problem-solving ability.

NO	Obstacle	Causative factor
1	Ontogenic barriers	Cognitive aspects 1. Difficulty in understanding mathematical symbols and remembering basic differential equation material: Some students find it difficult to understand mathematical symbols, such as the sigma symbol (∑), the integral symbol (∫), and the equation symbol (=). Consequently, more complex mathematical concepts may become challenging to comprehend. 2. Difficulty in understanding mathematical language: Some students struggle to understand the wordings in differential equation problems, making it challenging to communicate differential equation problems. 3. Difficulty with calculations: Some students have trouble with calculations, which can affect their ability to understand more complex mathematical concepts, such as algebra or calculus. 4. Difficulty visualizing mathematical concepts: Students struggle to understand and visualize differential equation problems. For example, the concept of multidimensional space or very complex functions may be difficult to understand visually. Psychological aspects 1. Feeling anxious or insecure when learning mathematics. 2. Lacking motivation to learn due to a failure to recognize the benefits of mathematics.
	Didactic barriers	1. Irrelevant teaching materials: Students may become reluctant to learn mathematics if the materials are unrelated to their daily lives or do not align with their interests and needs. The lack of connection to real-world contexts can make students feel less motivated and struggle to understand mathematical concepts. 2. Ineffective teaching methods: Students may encounter learning obstacles if the teacher uses inappropriate methods to teach specific math concepts. For example, some students may understand math better through a visual approach, while others may need a more abstract or concrete one. Students' comprehension of math concepts may be hampered by using methods that do not suit their learning styles. 3. Inappropriate language use: Mathematics is a unique

NO	Obstacle	Causative factor
		language that is often tricky for students to understand. Students will find it difficult to understand mathematical concepts if teachers do not use appropriate and easy-to-understand language.
	Epistemological barriers	1. Difficulty understanding abstract concepts: Some students may have difficulty understanding abstract mathematical concepts unrelated to their real-world experiences, such as algebra and number theory. 2. Shallow understanding: Students tend to rely on shallow understanding or procedural memorization without genuinely comprehending the reasonings of mathematical concepts. This hinders their ability to apply mathematical knowledge in different problem contexts. 3. Limited understanding of mathematical structure: Students struggle to recognize connections and patterns between mathematical concepts, which hinders their overall understanding. 4. Difficulty in converting mathematical representations: Students struggle to model real-life situations into mathematics and vice versa. 5. Difficulty in understanding math problems: Applications of differential equations involve proof or logical arguments to support a concept. Students have difficulty in thinking logically and understanding differential equation problems.

Discussion

This study provides a valuable examination of the challenges students face when learning differential equations, particularly within the context of a mathematics education program. It uses qualitative methods, such as observation and interviews, to explore the experiences of 5th-semester students from Khairun University in Ternate. By categorizing students based on their problem-solving abilities (low, medium, and high), the study aims to pinpoint the specific obstacles encountered in learning and applying differential equations and to suggest strategies to mitigate these challenges.

The study identifies three main types of obstacles that students face:

1. Ontogeny Obstacles refer to personal or developmental barriers, such as cognitive limitations or prior knowledge gaps. For example, students may not fully grasp prerequisite concepts from earlier mathematics courses, such as calculus or linear algebra, which are crucial for understanding differential equations.
2. Didactic Constraints: These are obstacles related to teaching methods and instructional approaches. For example, the study suggests that students may struggle with certain pedagogical practices, such as overemphasizing rote learning or an insufficient focus on conceptual understanding. This could hinder their ability to apply mathematical theory to solve real-world problems.
3. Epistemological Constraints: These involve limitations related to the nature of knowledge itself. Students may have difficulty understanding the abstract concepts

of differential equations, especially regarding their deep theoretical foundations or their application in various problem-solving contexts.

The study offers several potential solutions to help overcome these barriers:

1. Improving Collaborative Skills: Encouraging peer collaboration can allow students to discuss and work through complex problems together, fostering a deeper understanding of the material.
2. Providing Constructive Feedback: Timely and specific feedback can help students recognize their errors, clarify misunderstandings, and guide them toward more effective problem-solving strategies.
2. Contextual Learning: By linking the content of differential equations to real-world applications, students may find the material more engaging and easier to grasp. This approach can help contextualize abstract concepts, making them more relevant and tangible.
3. Reflecting on the Learning Process: Encouraging students to reflect on their problem-solving methods can help them develop metacognitive skills. This allows them to identify what strategies work best and adjust their approach accordingly.

The novelty of this research lies in its focus on understanding the cognitive and pedagogical challenges faced by students learning differential equations. The study offers a comprehensive framework that can guide educators in addressing these challenges by categorizing obstacles into ontogeny, didactic, and epistemological categories. Additionally, the proposed strategies for overcoming these barriers—such as fostering collaboration, providing constructive feedback, and contextualizing learning—offer practical solutions to enhance mathematics education's teaching and learning experience.

This study highlights the importance of adopting a multifaceted approach to teaching differential equations:

a. Recognizes the complexity of students' barriers and addresses them at various levels (individual, instructional, and epistemological). Recognizing the individual differences in students' cognitive abilities and prior knowledge can help instructors tailor their teaching methods to suit diverse learning needs (Alshahrani & Khasawneh, 2024; Bernacki et al., 2021; Chen & Wang, 2021; Grecu, 2023; Zohuri, 2024). For instance, students who struggle with ontogeny obstacles might benefit from extra tutoring sessions or remedial courses to solidify their foundational knowledge before tackling more advanced topics.
b. Active Learning Strategies: The emphasis on collaborative learning suggests that instructors should consider incorporating group projects, peer teaching, and problem-solving workshops into their lessons. These approaches can help students learn from each other and collectively build a deeper understanding of differential equations. The suggestion to use real-world applications of differential equations—such as in physics, engineering, or economics—aligns with current trends in mathematics education that seek to bridge the gap between abstract mathematical concepts and practical problem-solving. By seeing how differential equations apply to real-world phenomena, students may feel more motivated and connected to the subject matter.

Further Research Directions offers valuable insights; there are several avenues for further research:

1. Longitudinal Studies: Conducting longitudinal studies could provide more data on how students' problem-solving abilities evolve and how their responses to obstacles change as they progress through their coursework.
2. Impact of Teaching Interventions: Future studies could assess the effectiveness of specific teaching strategies—such as collaborative learning or contextualization—in overcoming the identified obstacles. Experimental studies or controlled trials could provide more robust evidence of the impact of these interventions on student learning outcomes.
2. Broader Contexts: Expanding the research to include students from different universities or regions could provide a broader perspective on the challenges and solutions in teaching differential equations.

His study comprehensively examines the obstacles students face when learning differential equations and offers practical strategies to overcome them. By addressing ontogeny, didactic, and epistemological barriers, instructors can better support students in their mathematical problem-solving journeys (Fenici & Mosca, 2023; Jatisunda et al., 2024; Lagarto, 2024; Woods & Copur-Gencturk, 2024; Yunianta et al., 2023). The insights from this research can help inform the design of more effective, student-centered teaching practices in mathematics education, ultimately making differential equations more accessible and engaging for all learners.

CONCLUSION

Fundamental finding: Our results reveal that in solving differential equation problems, we must pay attention to the obstacles experienced by students in differential equation courses. The obstacles students face in learning differential equations are ontogeny, didactic, and epistemological. Several efforts can be made to help students overcome these obstacles, such as improving students' collaborative skills, providing constructive feedback, strengthening students' learning motivation through contextual learning, and reflecting on the student's learning process. **Implication**: Addressing these obstacles requires a multifaceted approach, including improved teaching methods that emphasize active learning and problem-solving strategies, better assessments that challenge students to think critically, and additional resources to support individual learning. **Limitation**: Limitation analysis of students' learning obstacles in a Differential Equations course from a problem-solving perspective reveals that both cognitive and pedagogical factors play key roles in students' ability to succeed. The course structure, assessment methods, resources, and individual student characteristics must all be considered when addressing the barriers students face. A holistic approach to teaching, including diverse instructional methods, active learning, and personalized support, can mitigate these limitations and enhance problem-solving abilities in students. **Future Research**: Future research on students' learning obstacles in differential equations, particularly from the perspective of problem-solving ability, should adopt a multifaceted approach that considers cognitive, pedagogical, emotional, and cultural factors. Educators can identify more effective teaching practices, assessment strategies, and support mechanisms by exploring how students think, learn, and approach problem-solving. Research focusing on real-world applications, interdisciplinary teaching, and personalized learning interventions will help create a more holistic and accessible learning environment for all students.

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