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Students' Problem-Solving Behavior in Differential Calculus Based on Mathematical Prior Knowledge

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Abstract

Background/purpose. This study aims to analyze students' ability to solve differential calculus problems in relation to their prior mathematical knowledge (PMK).

Materials/methods. A qualitative research design method was employed. Participants in this study were 103 third-semester students at the university enrolled in the Differential Calculus course. They were divided into three groups, i.e., high, medium, and low, based on their PMK scores. They were given the same real-life problems to solve using differential calculus. In-depth interviews were conducted to identify and clarify things written and not written on the answer sheets. Data were analyzed using the Miles and Huberman model, while the process stages were analyzed according to the Bransford and Stein stages.

Results. The results showed that the real number course was the most mastered, indicated by the highest average PRK test score. The majority of students, namely 50.49%, were at the medium PMK level. Only the best group at the high PMK level could achieve correct final results and follow the Bradford and Stein stages. The group that excelled most at solving differential calculus problems was those with high limit course scores, not those with high real number course scores. It was also found that converting real-life problems into mathematical models was the most difficult stage.

Conclusion. Students who included problem scenario images during this phase performed better than those who did not. The most challenging problem was transforming a real-life problem into a mathematical model. Therefore, it is recommended to add a phase of transforming a real-life problem into a mathematical problem after the problem identification phase in Bransford and Stein's stages.

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1. Introduction

The development of science and technology has created increasing challenges for students, both academically and in everyday life. To face increasingly complex challenges, students need to develop their problem-solving skills. This ability allows students to understand and then use it to solve various mathematical problems through the correct steps (Gavaz et al., 2021; Marchis, 2013; Phonapichat et al., 2014). Problem-solving involves students' ability to adapt various skills to carry out problem-solving stages by drawing on previously learned knowledge and skills to find the best response to new problems (Bakar et al., 2021; Schoenfeld, 1982). Therefore, teaching about problem-solving skills should emphasize students' abilities to develop problem-solving methods and recognize the need to review previous solutions. This urgency has rendered mathematical problem-solving a significant component of the mathematics curriculum adopted in numerous countries (Aydın Güç & Daltaban, 2021; Peng et al., 2020; NCTM, 2000).

Differential calculus is a branch of mathematics that plays an important role in developing modern technologies related to everyday life (Ishak et al., 2022) and is considered high-level (Megawati & Sutarto, 2021). Therefore, a strong foundation in mathematics is essential. Many learning strategies and techniques have been developed to achieve effective learning (Aisha et al., 2017). This is done to make learning differential calculus easier for students. Up until now, the main emphasis of teaching differential calculus has been on using analytical techniques to solve abstract mathematical problems. However, in addition to the growing complexity of integrating quantitative and qualitative methods, the focus on analytical techniques also affects partial learning outcomes (Ponce & Maldonado, 2015). Even worldwide educational standards emphasize that memorizing analytical techniques is insufficient for future comprehensive education (Lee, 2017; Hays & Reinders, 2020). Therefore, today's students must be able to develop competencies that go beyond the minimum requirements for solving differential calculus problems. They are required to apply problem-solving skills in real-life, specific contexts.

Several studies (Nurhayanti et al., 2020; Güner & Erbay, 2021; Santosa et al., 2022; Hiltrimartin et al., 2024) revealed that most students could not apply problem-solving steps correctly in solving mathematics problems. Disparities in prior mathematical knowledge (PMK) are thought to cause variations in how information is processed, which may influence different outcomes. However, previous studies on students' problem-solving skills related to PMK have usually been conducted independently (Lee & Chen, 2009; Mulbar et al., 2017; Nur & Palobo, 2018).

To conduct effective teaching, good knowledge of students' behavior with different PMKs in solving differential calculus problems related to real-life problems is needed. This study aims to analyze the process of solving differential calculus problems by students with different PMK. The problem-solving process is analyzed using the steps outlined by Bransford and Stein (1993). The results of this study are essential for educators to modify their lesson plans and curriculum design, particularly when it comes to calculus differential, because contextual learning tactics can greatly improve student comprehension and engagement. Teachers can design more engaging and successful learning experiences by knowing how students learn calculus best through real-life problems.

The foregoing context indicates the need for further study to address this problem. This study should address the following questions:

RQ1: How does the disparity of PMK affect the process of solving differential calculus problems by students in college?

RQ2: How is the problem-solving process carried out by students at various levels of PMK?

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2. Literature Review

2.1. Problem-Solving Skills in Mathematics

Experts define mathematical problem-solving abilities as a set of mental operations used to recognize, evaluate, and resolve mathematical problems (Hartviksen & Haavold, 2025; Santos-Trigo, 2024). Students need this skill because it fosters creativity, pattern recognition, and logical thinking-all critical for success in mathematics (Nufus et al., 2024). Students gain the ability to connect abstract ideas to real-world practice by applying their mathematical knowledge to solve real-world problems (Rukmana et al., 2024; Uyen et al., 2021). Additionally, as students often need to try several methods before arriving at a solution, problem-solving can help them become more resilient and persistent. Students can tackle more complex issues because they have excellent problem-solving skills, which provide a foundation for profound mathematical understanding (Sigus et al., 2025; Rusmin et al., 2024). Therefore, the cognitive processes of recognizing, evaluating, and resolving mathematical problems are part of problem-solving skills in mathematics. These processes help students apply their mathematical knowledge to real-world situations and gain a thorough understanding of difficult concepts. They also encourage logical thinking, creativity, and resilience. Developing these abilities is a top concern for educators, as they affect students' critical thinking and overall learning style, in addition to their academic achievement.

Scientists and education specialists have developed several levels to evaluate mathematical problem-solving skills. Five primary signs of issue solving were established by Bransford and Stein (1993): (I) recognizing the problem, (D) framing and articulating the problem, (E) investigating potential options, (A) putting the strategy into practice, and (L) reviewing and assessing. Teachers can evaluate students' skills at every stage of the problem-solving process using these indicators, each representing a different stage (Özpınar & Arslan, 2023; Gunawan et al., 2020). Collie and Martin (2016) go on to discuss qualities like resourcefulness and approach flexibility, emphasizing that competent problem solvers may modify their plans of action in the face of unforeseen difficulties. Shekh-Abed (2024) highlights cognitive and metacognitive indicators, noting that for students to succeed in challenging problem-solving activities, they must monitor and control their thought processes.

2.2. The Relationship Between Prior Mathematical Knowledge and Basic Learning Skills

To get good grades in mathematics at university, one of the most crucial requirements is having a prior understanding of the subject from secondary school. Various authors have conducted studies to examine the relationship between university-level foundational learning skills and prior mathematical knowledge. Prior knowledge helps new learning by laying a foundation of comprehension, enabling connections to new information, and enhancing memory retention (Ye et al., 2020; Brod et al., 2023). According to Lambić and Lipkovski (2012) and Turmuzi and Lu'luilmaknun (2023), a strong preference for mathematics has a significantly bigger impact on the process of learning the subject. King and Cattlin (2015) found a significant negative impact on student completion rates when a large number of students enrolled in degrees, and Kahveci (2023) found that teacher attitudes toward student academic achievement have both positive and negative effects, depending on their attitudes. Thus, prior knowledge, preferences for mathematics, credentials, workload, greater levels of mathematical understanding, and instructor dispositions are all positively correlated with mathematics learning. While Kandeel (2021) found no correlation between teachers' mathematical proficiency and mathematics continuity, Hill et al. (2025) reported that teachers' knowledge influenced students' achievement.

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Students' movement toward self-efficacy in teaching is influenced by learning experiences and by teachers who use metacognitive skills to support their students (Huang et al., 2022; Halmo et al., 2024). Helleve et al. (2021) reported that case-based materials help students better understand theoretical topics, and Rezat (2024) demonstrated that the use of mathematics curriculum materials is becoming increasingly common for structuring mathematics instruction. According to Sachdeva and Eggen (2021), student thinking affects how well kids learn mathematics, while increasing teacher expertise affects students' mathematical understanding (Eminita et al., 2024), and peer evaluation helps math teachers advance (Patchan et al., 2022).

2.3. The Role of Prior Mathematical Knowledge as a Prerequisite for Learning

One of the most important questions is what students need to successfully navigate the challenges of studying mathematics in college. Prior empirical investigations have focused on emotional, psychological, and cognitive requirements (Hailikari et al., 2008; Martínez et al., 2019). A variety of individual factors, including metacognition and topic knowledge, are described in the framework of complex mathematical practices, such as proof and problem-solving, which affect students' capacity to engage in these activities (De Corte et al., 2011; Preiss et al., 2018). In line with the theoretical arguments discussed in the previous section, empirical findings also show that prior knowledge is a critical component of successful learning in the early phases of mathematics education (Chinnappan et al., 2012). From a cognitive-constructivist standpoint, every learning process, including the selection of learning strategies, depends on closely related prior information in order to construct new knowledge (Trigwell et al., 2013). There is little correlation between the acquisition of mathematical information at university and specific prior knowledge gained in school. In the field of differential calculus, however, the ideas taught in school and at university are identical and adhere to cognitive-constructivist learning theory. It is necessary to incorporate new information into preexisting knowledge. This integration will be successful if the new information and the existing knowledge are consistent.

New concepts or ideas can be added to existing knowledge as long as they don't conflict with it. Numerous studies attest to the fact that past mathematical knowledge has a major impact on academic accomplishment at both the school (Ahmad & Zakariyya, 2024; Emefa et al., 2020) and university levels (Hailikari et al., 2008; Greefrath et al., 2017). We use Hailikari's (2008) study as an example of a study in the field of forecasting academic achievement at a university. They verified that prior knowledge, especially procedural knowledge, predicts success in mathematics courses as evidenced by final grades using a sample of 202 students from two mathematics courses, the majority of whom were majoring in mathematics. To put it briefly, there is a wealth of data indicating that mathematical proficiency is a significant predictor of learning achievement, both in school and at university. Beyond the straightforward maxim "the more knowledge, the better," it is unclear exactly which knowledge is important for reassembling preexisting knowledge and incorporating new information during the transition to university mathematics.

3. Methodology

3.1. Research Design

This study used a qualitative approach to evaluate students' behavior in solving differential calculus problems based on their PMK. The first stage involved evaluating and grouping participants' PMK. Grouping was based on PMK test scores for courses that are prerequisites for differential calculus. The second stage involved evaluating the differential calculus problem-solving process for each PMK group. The process evaluation was conducted using the steps outlined by Bransford and Stein (1993). In-depth interviews with participants were also conducted during this process evaluation. The third stage involved evaluating the educational intervention in a workshop.

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Interviews were conducted with participants to assess the effects of the instructional techniques used to improve problem-solving skills at a qualitative level.

3.2. Participants

Participants were 103 3rd-semester students in the Mathematics Education Department of Universitas Muhammadiyah Semarang enrolled in differential Calculus courses. They were divided into three groups based on their PMK level, i.e., high (H), medium (M), and low (L).

3.3. Data Collection

3.3.1. PMK Data Collection

The PMK data were taken through a mathematics problem-solving test consisting of mathematics questions, which are prerequisite courses for taking differential calculus courses, which include real numbers (RN), functions and graphs (FG), equations and inequalities (EI), and limits (Lim). Three groups were created based on PMK test results: those with high (H), medium (M), and low (L) scores. The grouping was carried out by referring to the categories of previous researchers' formulas (Nurhayanti et al., 2020; Wardono et al., 2024), i.e., $X \geq (\bar{\bar{X}} + SD)$, $(\bar{\bar{X}} - SD) < X < (\bar{\bar{X}} + SD)$, and $X \leq (\bar{\bar{X}} - SD)$ for the high, medium, and low groups, respectively. Parameters X, $\bar{\bar{X}}$, and SD are the test score, the average scores, and the standard deviation of participants' scores, respectively.

3.3.2. Data Collection for Differential Calculus Problem-Solving Behavior

All participants were asked to answer the same questions about real-life problems, and their answers were used as data on differential calculus problem-solving abilities. The questions were as follows:

> *Mr. Amat has a rectangular plot of land that will be planted with vegetables. He wants to build a fence topped with 100 m of barbed wire. What size of land can be fenced, so that the largest area is obtained?*

The test results are then grouped based on scores that include the group with the highest score from the high (HH), medium (HM), and low (HL) of PMK; the group based on the lowest score from the high (LH), medium (LM), and low (LL) of MPK. Each group is made up of five participants. In-depth interviews were used to identify and clarify considerations that are sometimes not written down when completing differential calculus problem-solving tests.

3.3.3. Data Collection for Evaluation of Educational Intervention

Data for the evaluation of the educational intervention were collected throughout the intervention process workshop. Each workshop session was observed in detail using video recordings. These recordings served as a useful tool for identifying participant-researcher interactions, researcher behavior, student responsibilities in the lecture, and how well students approached problem-solving using Branford and Stein's stages. Lastly, student behaviors, researcher roles, and researcher-student interactions were identified through the utilization of the instructional process as a teaching tool. This workshop was attended by three students at each PMK level (HH, HM, HL, LH, LM, and LL) who were chosen randomly. During the workshop, they were interviewed to investigate the person's perspectives, lessons learned, and difficulties encountered during the learning process. They must answer the following questions.

- *Before participating in this study, did you use Bransford and Stein's stages in solving differential calculus problems?*
- *Briefly explain the stages in Bransford and Stein for effective problem solving.*
- *What mistakes have you made before working with Bransford and Stein's stage?*

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- *How is your academic performance in the course on differential calculus?*

3.4. Data Analysis

The Miles and Huberman analytical approach (Miles & Huberman, 1994), consisting of data reduction, data presentation, and conclusion, was used for analyzing the data. Data reduction was done by summarizing and coding the results of observations and interviews with students. Summarizing data was conducted by focusing on the essence of students' answers, while coding was carried out to obtain important data regarding the presentation of existing data. Meanwhile, the results of the differential calculus problem-solving test were analyzed using the Bransford and Stein steps, which consist of the IDEAL problem-solving steps: identify the problem, define the goal, explore possible strategies, act on the strategy, and look back and learn. Educational intervention evaluation data were collected from workshops and student responses to questions during the events. The purpose of analyzing educational interventions is to understand how students respond to teaching techniques intended to improve their problem-solving skills.

4. Results

4.1. Prior Mathematical Knowledge

The composition of participants based on PMK for H, M, and L levels is 19.42%, 50.49%, and 30.1%, respectively. The average value for the differential calculus prerequisite course, i.e., real number (RN), function and graph (FG), equations and inequalities (EI), and limits (Lim), for all participants and each PMK level, is depicted in Figures 1 and 2. The participants' abilities in real numbers are more dominant than in other subjects, and conversely, participants have the most difficulty in equations and inequalities (Figure 1(a)). The distribution of average grades for prerequisite courses across PMK levels is shown in Figure 2.

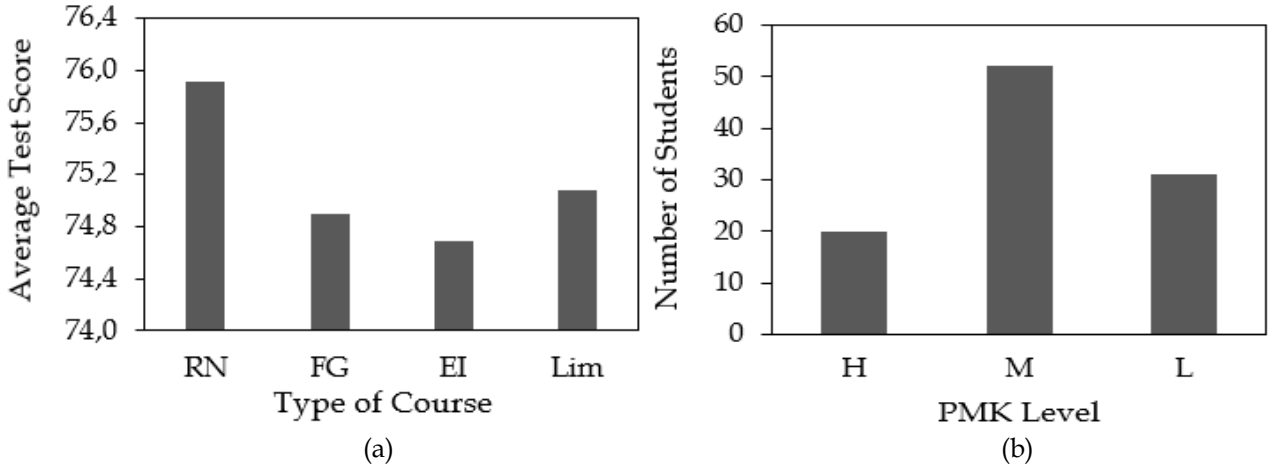

Figure 1. The PMK Participant Profile: (a) Average Test Scores for Real Number (RN), Function and Graph (FG), Equations and Inequalities (EI), and Limits (Lim); (b) Distribution of the Number of Students at Each PMK Level

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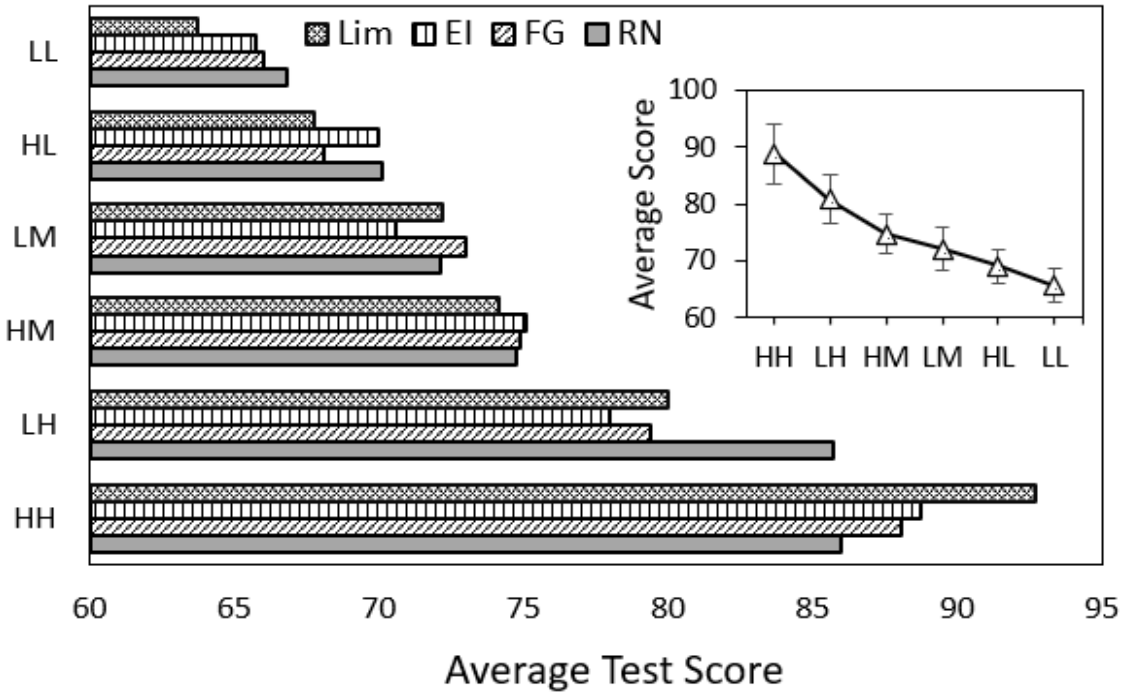

Figure 2. The PMK Test Score. The HH, LH, HM, LM, HL, and LL are the Highest of the High, the Lowest of the High, the Highest of the Medium, the Lowest of the Medium, the Highest of the Low, and the Lowest of the Low, Respectively

4.2. Differential Calculus Problem-Solving Behavior

The results of the answers from the six selected subjects (representing the highest and lowest scores in each PMK level) were analyzed, and then in-depth interviews were conducted regarding the process of solving differential calculus problems. The stages of the work process, including in-depth interviews, are presented in Table 1. It can be seen that only students who are in the HH criteria solve differential calculus problems by going through all the Brainford and Stein stages (Bransford & Stein, 1993). The contrasting situation is that students with LL criteria can only carry out the problem identification stage.

Table 1. Differential Calculus Test and In-Depth Reviews. The I, D, E, A, and L are Identifying Problem, Define Goal, Explore Possible Strategies, Act on the Strategy, and Look Back and Learn, Respectively.

Criteria		Steps					Depth-interviews
		I	D	E	A	L	
High (H)	HH	√	√	√	√	√	HH has been able to use problem-solving strategies and conclude the answer correctly.
	LH	√	√	√	√	x	LH used the strategy correctly, but did not confirm the correctness of the answer or write a conclusion. Their final answer is correct.
Medium (M)	HM	√	√	√	x	x	HM could not use the strategy correctly, as indicated by the wrong solution steps. The correctness of the answers was not reviewed, so HM did not know if there were any incomplete answers.

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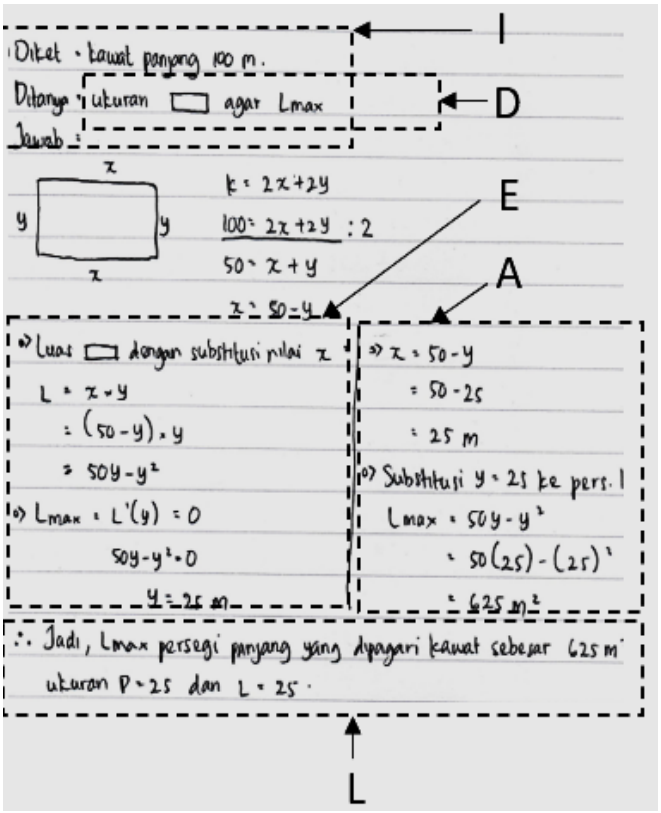
	LM	√	X	√	x	x	The description of the problem situation has not been added, but LM can extract some information to create a problem-solving strategy. The solving strategy is not implemented, so the final answer cannot be found.
Low (L)	HL	√	x	√	x	X	The concept of circumference is improperly understood and fails to apply problem-solving strategies.
	LL	√	x	x	x	x	LL is not yet able to do several crucial things, including identifying problems correctly, determining the final goal of solving the problem, and exploring information to create an appropriate solution strategy.

The results of the students' answer sheets in the differential calculus test to solve real-life problems, as shown in Table 1, show that only students with the HH level of PMK can solve the questions with complete stages, each stage is done correctly, and the final answer is correct. Examples of student worksheets in solving differential calculus problems are presented in Figures 3 and 4. An example of the student's answer sheet for a student with the HH level is shown in Figure 3.

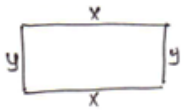


Translation:

Known: wire length 100 m

Asked: size ▭ so that L is maximum

Answered:



$$k = 2x + 2y$$
$$\frac{100 = 2x + 2y}{50 = x + y} : 2$$
$$x = 50 - y$$

➢ Área ▭ with substitution of x values:

$$L = x.y$$
$$= (50 - y)y$$
$$= 50y - y^2$$

➢ L max = L'(y) = 0

$$50 - 2y = 0$$
$$y = 25\ m$$

➢ $x = 50 - y$
$= 50 - 25$
$= 25\ m$

➢ Substitute y = 25 into the area equation

$$L\ max = 50y - y^2$$
$$= 50(25) - (25)^2$$
$$= 625\ m^2$$

So, the maximum area of a rectangle fenced with wire is $625\ m^2$ with a length = $25m$ and a width = $25m$

Figure 3. Student Answer Sheet with HH Level, with Complete IDEAL Stages

Students with the LL level are only able to identify problems. An example of a student's answer sheet in this category is shown in Figure 4, which indicates that an attempt has been made to write down the objectives, even though they do not match those targeted in the question. However, exploration and lookback were not carried out. As shown in Table 1 and Figure 4, student achievement in the differential calculus course is closely related to their mastery of limit material; students with high limit scores also achieve higher scores in differential calculus.

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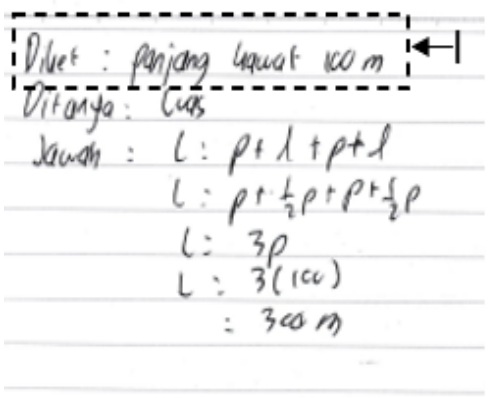

Translation:

Known: fire length 100m

Asked: area?

Answered: $L = p + l + p + l$

$$L = p + \frac{1}{2}l + p + \frac{1}{2}l$$

$$L = 3p$$

$$L = 3(100)$$

$$= 300m$$

Figure 4. Example of Student Work on the Student Answer Sheet with Low-Level PMK (LL)

Most of the participants were at the medium PMK level (50.49%). The average score for the RN course was the highest among the other prerequisite courses. However, for students with a high PMK level, the highest average score was in the limit course, contributed by 25.5% of the total students at that level. The contradictory phenomenon was shown in the EI and Lim courses, as shown in Figures 2 and 5. The limit course contributed the highest to PMK at the H level, and EI contributed the highest to PMK at the L level. This phenomenon shows that students with high limit course abilities dominate in contributing to the PMK level position. This initial condition indicates that students in PMK H have better basic concepts for learning differential calculus. Indeed, Limit is not calculus, but it is fundamental to understanding calculus-based mathematical concepts (Denbel, 2014; Sebsibe & Feza, 2020).

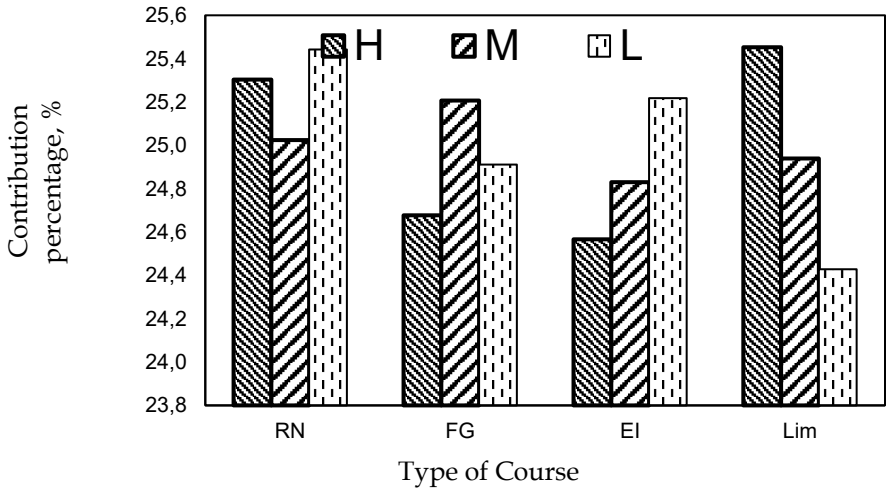

Figure 5. Contribution of Differential Calculus Prerequisite Courses at the PMK Level

4.3. Evaluation of Educational Intervention

In order to evaluate the educational interventions, all participants were interviewed for this study. The objective was to qualitatively assess the effects of the instructional techniques used to improve students' problem-solving skills. The primary objective of this analysis of educational interventions was to understand how students responded to instructional techniques designed to enhance their problem-solving abilities. Perceptions, experiences, and difficulties in the learning process were all questioned during the interviews. The most specific and often asked questions from these interviews are included here.

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Before participating in this study, did you use Bransford and Stein's stages in solving differential calculus problems?

The students generally stated that they had never known Branford and Stein's stages for solving mathematical problems. Only two students commented that they had discussed the stages of problem solving with each other, and then they knew that it was Branford and Stein's stages after confirming it with a teacher during their secondary education. They also stated that although they did not know the stages, they had used the problem-solving stages, which had many similarities to that stage.

Briefly explain the stages in Bransford and Stein for effective problem solving.

They emphasized the need to focus on reading the problem and comprehending the necessity of reviewing the data, or identifying the variables or unknowns in the situation. In this manner, they linked the facts to create a plan (how would they accomplish this?), computed strategies, carried out the plan, solved the problem, and confirmed that the solution was accurate. One student emphasized that before creating an equation to solve the problem, it was crucial to thoroughly understand the situation, determine the required variables, and set them up. The last step was to gather input on whether the results were accurate and whether the approach was successful. This process reminded one student of the stages of problem-solving in mathematics that her high school math teacher taught her. These stages were very similar to those of Branford and Stein.

What mistakes have you made before working with Bransford and Stein's stage?

According to each student, they were required to comprehend the issue, formulate a strategy, and go over the resolution. We found it challenging to accurately address the challenge when reading quickly and without a broad perspective. All students answered that changing real-life problems into mathematical models was the most difficult stage, because if this stage was wrong, the next stage would be wrong too. However, when they were unable to identify a solution, students opted for a different approach and began the process again with a different alternative. Although it takes a lot of time, this approach has a higher chance of producing superior outcomes. All things considered, every student was able to greatly improve their capacity to connect numerical data to variables and choose the appropriate mathematical model when addressing difficulties in daily life.

Its effectiveness as a tool for teachers to alter traditional procedures and inspire students to study has also been confirmed. Student HH3 stated, “Before using this method, I used to follow a step-by-step process for each exercise, like following a sequence instead of asking myself which variables are relevant and which are not. I used all the given variables, but I could not distinguish which ones were useless. So, this method helped me overcome this kind of doubt.”

How is your academic performance in the course on differential calculus?

Students generally expressed satisfaction regarding the method utilized to hone problem-solving abilities due to their academic achievement in the differential calculus course was better than it was in the previous term.

5. Discussion

The results of the PMK test show that the dominance of limit mastery over other prerequisite courses results in the highest calculus scores at the high level of PMK (HH), and the decrease in differential calculus scores also decreases the average limit score (Figure 2). This shows that the ability in the limits course is very dominant in influencing students' ability to solve differential calculus problems. The limit course contains the basic concepts of calculus. Based on a study conducted by Domondon et al. (2022), it was shown that students' weaknesses in learning differential calculus are

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the difficulty in understanding the concepts of differential calculus, so that misconceptions often occur in the problem-solving process.

Students who added problem situation images at the problem-solving stage showed that they could perform problem-solving steps well compared to students who did not add images. The addition of these stages helps students explore strategies (Szabo et al., 2020; Yu et al., 2015), and the actual problem context can be more easily understood through the application of differentials (Khotimah & Masduki, 2016). In addition, students can identify new variables to be used in building mathematical models. This will improve students' understanding of the concept and help them develop problem-solving skills (Corte, 1990; Rahman, 2019).

Many students have not used the look-back-and-learn strategy to interpret the results, even though this stage is essential to solving the problem. Students feel that the solution will be completed after implementing the planned strategy without evaluating the correctness of the answers obtained. Therefore, it is necessary to add a stage for interpreting the results. The addition of a result interpretation stage will help students understand the solution's context and how it is applied in real life (Zhong & Xu, 2019). Interpreting the results can also allow us to explain the solution obtained to others (Iffah & Masruroh, 2019). It can be used to make more appropriate decisions (Medová et al., 2019).

Solving differential calculus problems requires a constructivist process that requires prior knowledge as prerequisite material (Mahadewsing et al., 2024; Jatisunda et al., 2024; Voskoglou & Gr, 2010). This causes the problem-solving process to be imperfect, thereby giving PMK a very important influence on the success of student problem-solving (Kamarudin et al., 2020; Nurhayanti et al., 2020). Constructivist methods that build on prior knowledge are beneficial for addressing differential calculus problems. For this reason, a strong foundation in algebra and pre-calculus is necessary, since differential calculus builds on basic ideas such as limits and derivatives. To master these ideas and apply them to problem-solving, a constructivist approach is essential, in which students actively work to increase their understanding.

Based on in-depth interviews, it is clear that all students consider the most difficult part of solving everyday problems is transforming them into a mathematical model. This condition allows only students with high PMK and HM to correctly formulate the defined goals. The generic mathematical modeling process in this context encompasses (Leikin et al., 2025; Çetin et al., 2023; Omar et al., 2024) (i) problem identification, which involves clarifying the issue, enumerating and categorizing factors, establishing assumptions, and articulating a suitable problem statement; (ii) mathematical model formulation, which entails representing factors with mathematical symbols, positing relationships among these factors, and converting these assumptions into mathematical equations; (iii) model resolution, which requires employing analytical and numerical techniques to derive a solution; (iv) solution interpretation and validation against real-life scenarios. Therefore, lecturers need to incorporate real-life problem modeling techniques into their mathematical formulations (Spooner, 2020; Kandemir & Eryilmaz, 2025).

The results, as documented in the worksheet and in-depth interviews with students, showed that students had difficulty transforming real-life problems into mathematical ones. Based on these findings, it is necessary to add a stage, i.e., transforming real-life problems into mathematical problems, to solve differential calculus problems. This stage is carried out in the second step, replacing the defined goal stage. The second defining goal stage does not need to be done because it is included in the identify problems and explore possible strategies stage. And adding the results interpretation stage at the end of the process. The implementation of new problem-solving stages in the field is carried out to determine the advantages, disadvantages, and the effectiveness of the

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design. Based on the analysis of the results and the discussion in this section, the reconstruction of the problem-solving process comprises six stages.

6. Limitations and Recommendations

A limitation of this study is that differential calculus achievement was only analyzed based on students' PMK, even though the effectiveness of teaching strategies also significantly influences it. Although the Bransford and Stein framework for problem-solving is a useful tool, it needs deeper involvement with mathematical processes and more inventiveness. While there have been a number of curriculum modifications brought about by advancements in the incorporation of technology resources, problem-solving techniques have not undergone major updating. Student learning is hampered by this circumstance at both the philosophical and epistemic levels. Gaining proficiency in solving problems in math is essential for fostering learning according to a social and cultural standpoint, and prior studies have shown that teacher preparation programs are where its flaws start [Gonçalves & Núñez, 2021]. These shortcomings are seen in the instructional techniques of these professionals in the classroom as well as in the application of these abilities during the learning process of teachers and undergraduate students. Programs for teacher training that focus on improving their most visible areas of weakness could be put in place. Better learning outcomes could then be attained through teacher-student collaborative interventions.

Future studies might explore combining different approaches to measure results more precisely and in greater depth. Considering these approaches would enable more precise evaluation of the effects of instructional tactics, both on students' academic performance and on their problem-solving ability. Additionally, a more thorough examination of the tactics employed at every stage of the procedure is advised, taking into account potential alterations and additions that could substantially enhance outcomes. Enhancing students' learning experiences and improving their capacity to apply their skills in non-mathematical contexts can be achieved by implementing extra methods at various phases of the process. This method provides a more comprehensive understanding of students' learning and problem-solving skills while also being in line with the metacognitive difficulties they encounter.

7. Conclusion

The behavior of solving real-life problems using differential calculus has been carried out. Among the prerequisite courses for differential calculus, the limit course is the one that has the greatest influence in strengthening the mastery of solving differential calculus problems. When it came to the issue-solving procedures, pupils who included pictures of the problem scenario during the phase performed better than those who did not. Many students did not apply the technique of reflecting on the past and learning to comprehend the outcomes. Without assessing the precision of the responses, students believed that the solution would be finished once the intended approach was put into practice.

The problem that is considered the most difficult by students is transforming real-life problems into mathematical models. This greatly affects students' performance in solving calculus problems. Therefore, at the Bransford and Stein stage, it is highly recommended to add a stage of transforming real-life problems into mathematical problems, especially for contextual problems. Future work is needed to emphasize the effectiveness of the transformation stage in mathematical models for improving students' ability to solve differential calculus problems.

Declarations

Author Contributions. D. Sulistyaningsih: Literature review, conceptualization, methodology. S.B. Waluya: data analysis. Isnarto: review-editing and writing. Sugiman: original manuscript preparation. Every author has reviewed and given their approval to the article's final publication.

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