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E-didactics design of differential calculus based on TPACK to overcome learning obstacles for mathematics pre-service teachers

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Abstract

Many mathematics pre-service teachers face obstacles in understanding basic differential calculus concepts, which could affect their teaching abilities. A deep understanding of learning obstacles and developing relevant learning strategies is necessary to address this issue. This research aims to identify learning obstacles experienced by mathematics pre-service teachers in differential calculus and evaluate the effectiveness of an e-didactics design based on TPACK in overcoming those obstacles. The research method is Design-Based Research (DBR) with the Plomp development model, which includes the stages of analysis, design, evaluation, and revision. The subjects involve 39 mathematics pre-service teachers from Mathla'ul Anwar University and La Tanza Mashiro University, Banten, Indonesia. Research instruments include pretest, post-test, validation, and effectiveness questionnaires with data analysis covering walkthrough, documents, triangulation, instruments, and qualitative analysis. The finding identifies three types of learning obstacles: ontogenic, epistemological, and didactical. The improvement in learning outcomes demonstrates the effectiveness of the e-didactics design: 52% in real number systems and functions, 74% in limits, 88% in derivatives, and 65% in the application of derivatives. The effectiveness survey recorded a score of 83%, indicating that the e-didactics design of differential calculus based on TPACK effectively addresses learning obstacles.

Keywords:
E-didactics design, Learning obstacles, Mathematics pre-service teacher, TPACK

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1. INTRODUCTION

Calculus is one of the most important subjects in higher education mathematics, an introductory course for science, technology, mathematics, and mathematics education programs (Turner & Álvarez, 2021), focusing on understanding changes and predicting the future (Adamczewski et al., 2021; Turner & Álvarez, 2021). This course requires a high-level mathematical thinking and reasoning (Kuzu, 2021) and serves as a crucial foundation in the development of structured logic, analytical reasoning, and critical thinking (Alam, 2020; Mudaly & Mpofu, 2019). Concepts such as limits, derivatives, and integrals encourage investigation, reasoning, and deep mathematical thinking (Ergene, 2019; Kuzu, 2021). Differential calculus also trains self-regulated learning, which enhances learning independence and thinking skills, supporting optimal performance in teaching mathematics (Ortube et al., 2024). For mathematics pre-service teachers, a clear and meaningful understanding of mathematical concepts is crucial to avoid teaching mistakes that can lead to misconceptions among students (Bingölbali et al., 2016; Erol & Saygı, 2024).

Nevertheless, research has revealed that the knowledge of mathematics pre-service teachers about differential calculus often tends to be procedural without a deep conceptual understanding (Toh et al., 2022). This will affect the mathematical learning experiences of pre-service teachers in the classroom, as well as their ability to address the learning difficulties of their students. Research shows that the concept of derivatives is often considered epistemologically difficult (Erol & Saygı, 2024), with learning obstacles influenced by both internal and external factors. According to Nurhayati et al. (2023), learning obstacles can be in the form of ontogenic obstacle, which are the mental readiness and cognitive maturity of students in receiving knowledge; didactic obstacle, which refer to the sequence of material in textbooks or the way the material is presented by the lecturer; and epistemological obstacle, which are the limitations in students' understanding of concepts. Therefore, teachers need to design appropriate didactic designs to address various learning obstacles faced by students (Musyrifah et al., 2022; Puspita et al., 2023).

In the digital era, millennial students demand that lecturers use effective technology as a pedagogical tool in teaching materials (Alqurashi et al., 2017). Digital didactics or e-didactics becomes relevant in the design of modern learning through the use of communication and information technologies (ICT) that support virtual classrooms, social networks, and other digital learning systems (Kameneva, 2020). This approach transforms the role of teacher from subject deliverers to learning designers who encourage students to actively engage in learning (Nicolau et al., 2020). However, the principles of didactic and pedagogical design for e-learning still require more attention (Theelen & van Breukelen, 2022). This transformation creates a new communication conditions between teacher and their students, as well as opens opportunities to design, create, and evaluate digital-based teaching materials (Kameneva, 2020). The integration of Technological Pedagogical Content Knowledge (TPACK) into teaching becomes an important strategy for lecturers in preparing learning in the digital era (Nuangchalerm, 2020).

TPACK is a teaching concept suitable for 21st century learning as a solution for learning activities in educational institutions (Hariati et al., 2022; Yantun et al., 2021). TPACK identifies types of knowledge to achieve better learning outcomes in the context of modern technology (Taopan et al., 2020). As a body of knowledge, the TPACK framework combines seven domains of knowledge as follows: Technology Knowledge (TK), Pedagogical Knowledge (PK), Content Knowledge (CK), Pedagogical Content Knowledge (PCK), Technological Content Knowledge (TCK), Technological Pedagogical Knowledge (TPK), and Technological Pedagogical Content Knowledge (TPACK) (Setyowati & Rachmajanti, 2023). It is expected that this will create a learning atmosphere that is easy, effective, responsive, and meets the needs of students, such as providing images, animations, simulations, video explanations of materials by teacher, and using software that supports learning such as GeoGebra, Heyzine Flipbook, and Canva. This aligns with research (Supianti et al., 2022) that animated teaching materials are more developed, use communicative language, and utilize the latest technology.

Based on the identified problems and characteristics of e-didactics, there is a need for technology-based learning resources in the form of e-didactics design based on TPACK to address learning obstacles in differential calculus. Previous research has shown that didactic designs have been widely developed for mathematics subject at school (Komala et al., 2021; Meika et al., 2022; Meika, Mauladaniyati, et al., 2023; Meika et al., 2019), as well as designs aimed at overcoming learning obstacles (Fitria & Suminah, 2020; Sartika et al., 2024). In differential calculus, most research projects focus on specific sub-materials, such as the concept of function asymptotes (Mudaly & Mpofu, 2019), limits (Jameson et al., 2023; Oktaviyanthi et al., 2024), derivatives (Chen, 2023), and instantaneous rates of change (Fonseca & Henriques, 2023). This research is different because it focuses on differential calculus as a whole, covering interrelated concepts.

Additionally, research on the use of technology during the pandemic show the effectiveness of video conference applications (Kaniadewi, 2022; Nehe, 2021; Safitri & Tyas, 2022) and platforms like Google Classroom (Diana et al., 2021; Oktaria & Rahmayadevi, 2021). Research on online learning experiences has also been conducted at the school level (Inawati & Setyowati, 2020; Suhaimah & Setyowati, 2021) and at the university level (Bao, 2020; Setyowati et al., 2021). However, research on e-didactics design based on TPACK at the university level is still limited. The integration of technology in this design allows for a more dynamic, visual, and relevant learning experience. The TPACK framework, which combines technology, pedagogy, and content of differential calculus, supports the development of adaptive and innovative teaching approaches, thereby enhancing the effectiveness of learning for mathematics pre-service teachers.

2. METHOD

The research method used is Design-Based Research (DBR) with a development model referring to the Plomp model. Plomp, in the Journal of Learning Design, explains that DBR is a systematic design process for education and instruction that includes activities of analysis, design, evaluation, and revision to achieve satisfactory results (Meika, Aprilianti, et al., 2023). The development procedure according to Plomp consists of three phases: (1) preliminary phase; (2) prototyping phase; and (3) assessment phase (Nurhasanah et al., 2022). The preliminary stage began with an analysis of learning obstacles, followed by self-evaluation which served as the basis for the preparation of prototype 1. After prototype 1 was complete, the prototyping stage continued with expert review and one-to-one, resulting in prototype 2. Prototype 2 was then tested through a small group and field test, so that the final result becomes prototype 3. This process is presented in Figure 1.

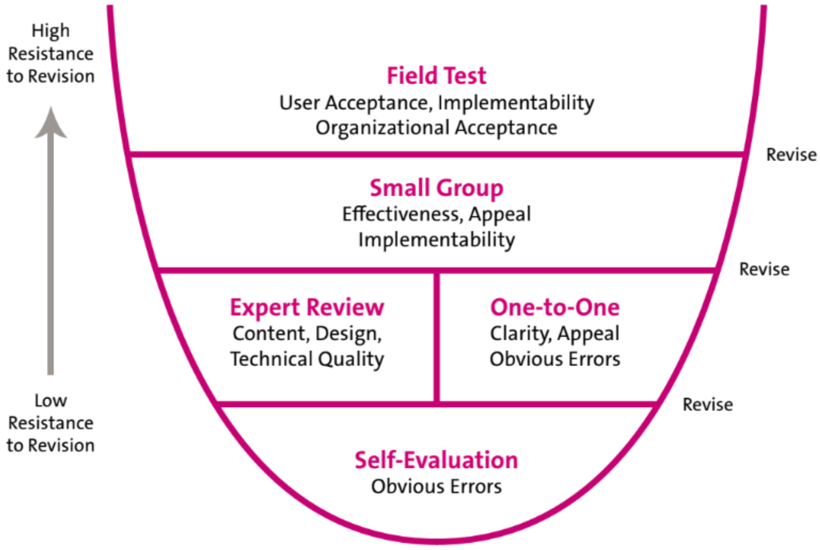


Figure 1. Formative evaluation from Tessmer (Plomp, 2013)

2.1. Preliminary Phase

The self-evaluation phase was conducted by analyzing the results of the learning obstacle test from 39 mathematics education students at Mathla'ul Anwar University and La Tansa Mashiro University, along with in-depth interviews with 12 selected students. The test was used to identify learning obstacles, while the interviews aimed to explore the expected solutions related to the teaching materials. This analysis served as an important foundation for designing an e-didactics design based on TPACK (prototype 1) that is relevant and effective in addressing learning obstacles in differential calculus.

2.2. Prototyping Phase

In the expert review and one-to-one phase, prototype 1 was evaluated by three expert validators (language, content, and media/IT experts) and three fourth-semester students from the mathematics education program at Mathla'ul Anwar University. The validators assessed the language aspects, content material, and media technicalities to ensure that the design meets academic standards and user needs. Students provided feedback regarding clarity, readability, and ease of navigation. Based on this input, revisions were made, including simplifying the language, adding material visualizations, enhancing media feature compatibility, and refining the navigation structure to make it more intuitive. The results of the expert review and one-to-one sessions serve as the basis for analyzing and revising prototype 1 into prototype 2.

2.3. Assessment Phase

In this phase, prototype 2 was tested on a small group consisting of 12 mathematics education students from Mathla'ul Anwar University who have completed the differential calculus course. This test aimed to evaluate the practicality of the design. After the trial, students were asked to provide comments and feedback on prototype 2. A field test was conducted simultaneously with the small group, including pre-tests and post-tests to assess the improvement in understanding of the material after using the e-didactics design based on TPACK (prototype 2). The goal of this trial and field test is to evaluate whether the design is effective in enhancing understanding of the materials in differential calculus and addressing the learning obstacles faced by students. The results of the small group and field test served as the basis for finalizing the e-didactics design of differential calculus based on TPACK (prototype 3) to make it more effective and relevant.

2.4. Data Collection and Analysis

This research employed data collection techniques such as walkthroughs, documents, observations, and tests. In the expert review and one-to-one phase, the validity of the design was assessed in terms of content, language, and media (IT). Walkthrough data was obtained through comments and suggestions from validators and students, which provided input for improving the e-didactics design based on TPACK. The documents used include pre-test and post-test results, validator assessments, observation notes, and walkthrough sheets, which were analyzed to evaluate clarity, readability, and design effectiveness. Triangulation is performed by comparing the results from walkthroughs, documents, and observations to ensure data consistency and enhance the validity of the findings. Instruments in the form of student answer sheets were used to assess the effectiveness of the design in the small group and field test. All data were analyzed qualitatively to identify findings at each stage of the research, allowing for iterative design improvements based on feedback and evaluation results.

3. RESULTS AND DISCUSSION

3.1. Results

3.1.1. Preliminary Phase

The data for this research was obtained from the results of the Learning Obstacle (LO) test in differential calculus, which was completed by 39 students from two private universities in Banten, namely Mathla'ul Anwar University and La Tanza Mashiro University. This test consisted of five essay questions covering the material of real number systems, limits of algebraic functions, derivatives of algebraic and trigonometric functions, as well as the application of derivatives. The results of the LO test indicate that students experienced difficulties (learning obstacles) in solving the problems. The general data from the LO test results is presented in Table 1.

Table 1. Learning Obstacle (LO) test result on differential calculus

Case Number	Learning Obstacle		
	Ontogenic	Didactic	Epistemologic
1	79%	95%	54%
2	56%	67%	56%
3	85%	90%	79%
4	92%	87%	87%
5	90%	90%	87%
Average	**81%**	**86%**	**73%**

The analysis results show that mathematics pre-service teacher students face three main types of learning obstacles in the differential calculus course, namely ontogenic obstacles at 81%, didactic obstacles at 86%, and epistemological obstacles at 73%. Ontogenic obstacles reflect constraints arising from the cognitive development of students, such as a lack of mental readiness or prerequisite mathematical knowledge. Didactic obstacles are the highest, indicating a lack of alignment between teaching methods and learning resources. Based on interviews conducted with students from Mathla'ul Anwar University regarding the learning resources used, namely the Purcell book, students feel less supported in their learning. The book requires students to have a strong foundational knowledge of mathematics.

Meanwhile, epistemological obstacles indicate that students struggle to understand the basic concepts of calculus, possibly due to misunderstandings or the presentation of material that is less contextual. From the interview, students expressed difficulty in understanding the material through the book, which tends to be abstract and does not provide in-depth guidance. To address these obstacles, it is necessary to implement interactive learning strategies, select more appropriate reference books, and provide supporting modules. An interview with students from La Tansa Mashiro University between the Researcher (R) and Respondent 1 (R1) is presented below:

R : Can the learning resources used help you in learning differential calculus?

R1 : Quite helpful, ma'am, but sometimes what we learn from books and YouTube is usually different from what is taught by the lecturer. For example, the method to solve the problems is different.

R : What is needed from learning resources that can help you in learning differential calculus?

R1 : Ideally, I would like a book that explains each practical problem in detail and include video explanations within the book, like those with a barcode so that it makes learning easier for us. Because if i'm just reading the book, it is quite hard to understand, so I don't grasp it well.

Based on the results of the learning obstacle test analysis and interviews, an e-didactic design based on TPACK differential calculus was developed (prototype 1). This e-didactics design was organized into four chapters of material, namely: Chapter I (real number systems and functions), Chapter II (limits), Chapter III (derivatives), and Chapter IV (applications of derivatives). Each chapter was designed comprehensively, including concept maps, learning objectives, material, example problems accompanied by video explanations, written practice problems, online reasoning practice problems, and online reflections to support interactive and effective learning.

3.1.2. Prototyping Phase

The e-didactics design that has been prepared was validated by three expert validators and three students. The assessment results from the expert validators on the TPACK-based differential calculus e-didactics design are summarized in Table 2.

Table 2. Validation test on prototype-1

No.	Validator Commentary	Validation Result				Average
		Chapter I	Chapter II	Chapter III	Chapter IV	
1	Subject	95%	96.25%	97%	98.75%	96.75%
2	Language	88%	92%	92%	96%	92%
3	Media	96%	96%	96%	96%	96%
	Average	**92%**	**94%**	**94%**	**95%**	**94.92%**

Next, a suggestion from student are presented on Table 3.

Table 3. Student's suggestion on prototype-1

No.	Aspect	Suggestion
1	Example question video	It is better to add discussion video regarding example question, because it is quite hard for us to understand.
2	Discussion Video	Adds an explanatory video regarding composition function material, because we are yet to understand it.

The results of the expert validation in Table 2 show that each chapter of the material in the e-didactics design has an average validity level above 90%, thus the design falls into the very valid criteria. Subsequently, prototype 1 was revised based on feedback from expert validators and students to improve its quality into prototype 2. An example of the improvements made to the design about video and content revision present in Figure 2, and Youtube video revision present in Figure 3.

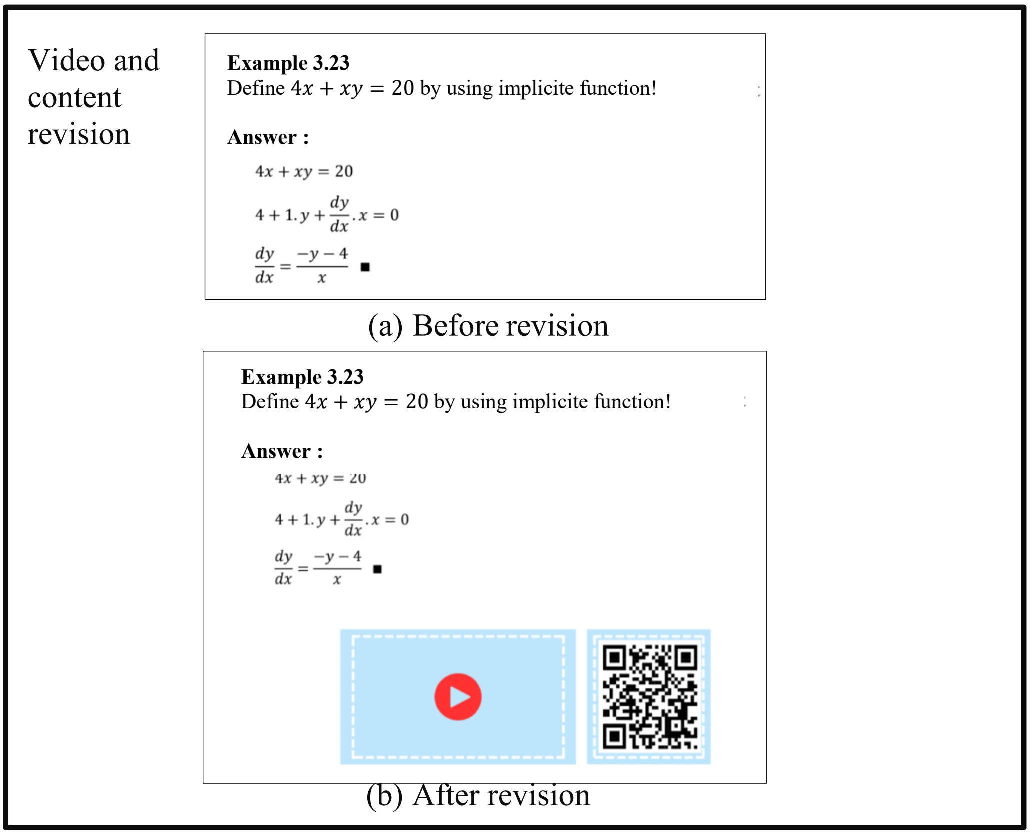


Figure 2. Revision of prototype 1 based on validator

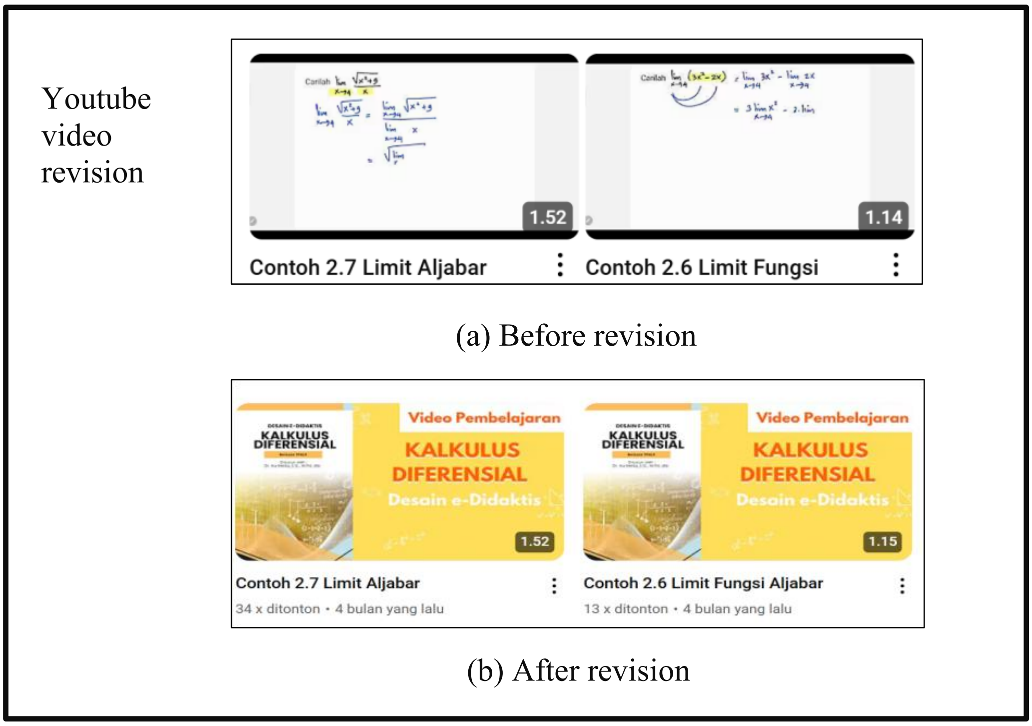


Figure 3. Revision of prototype 2 based on student suggestion

Figure 2 and Figure 3 present the changes in the e-didactics design of differential calculus based on TPACK, which were made based on input and feedback from expert validators in content, language, media (IT) and students. The revised e-didactics design was then tested on mathematics pre-service teacher to evaluate its impact on overcoming learning obstacles in the differential calculus course and to assess the effectiveness of the e-didactics design.

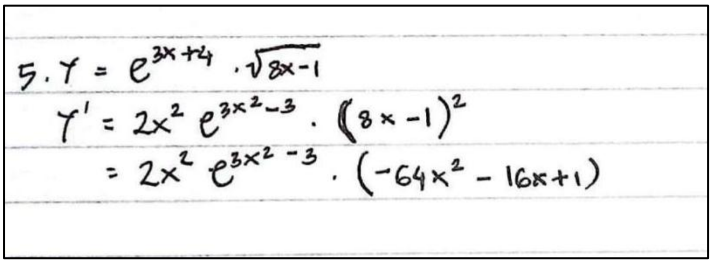
3.1.3. Assessment Phase

In a small group trial, prototype 2 was tested on 12 students. This trial lasted for eight meetings. The students provided feedback on the design, answered questions, and explored their thinking processes in understanding the material. Before studying prototype 2, the students took a pre-test, and afterwards, they were given a post-test. The trial of prototype 2 was conducted per chapter of the material, which consisted of four chapters, so each student received four pre-test scores and four post-test scores. The data were analyzed using normalized N-Gain to calculate the improvement in student learning outcomes. The N-Gain results from the prototype 2 trial are presented in Table 4.

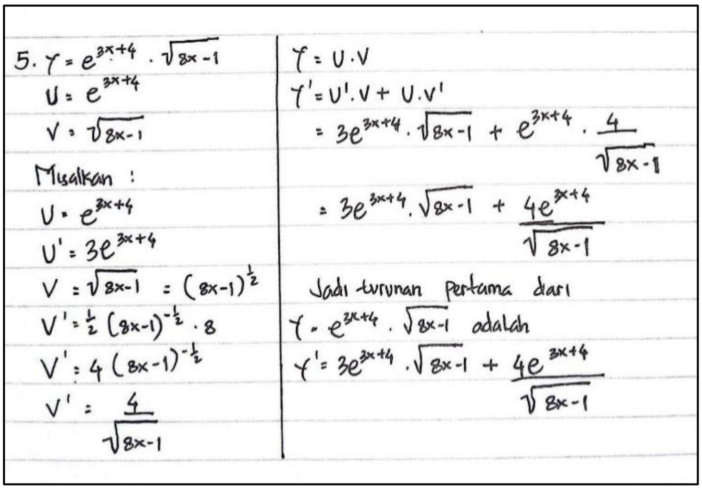
Table 4. N-Gain data on field test of prototype-2

Subject	N-Gain			
	Chapter I	**Chapter II**	**Chapter III**	**Chapter IV**
M1	0.70	1.00	1.00	0.80
M2	0.62	0.33	0.76	0.51
M3	0.54	1.00	0.95	0.78
M4	0.54	0.33	0.97	0.55
M5	0.36	0.65	0.56	0.72
M6	0.38	0.87	0.78	0.61
M7	0.39	0.97	0.95	0.64
M8	0.43	1.00	0.77	0.66
M9	0.33	1.00	1.00	0.63
M10	0.59	0.80	0.98	0.71
M11	0.33	0.43	0.90	0.47
M12	1.00	0.50	0.97	0.73
Average	**0.52**	**0.74**	**0.88**	**0.65**
Category	Medium	High	High	Medium

Table 4 shows the results of field tests on the prototype 2 trial where the abilities of mathematics pre-service teacher have improved. The smallest increase occurred in Chapter I with 52%, which was caused by several obstacles in the trial process, such as psychological unpreparedness, as the students returned to classes in the odd semester after the even semester break of 2023/2024. In Chapter II, the increase reached 74% because the students began to adapt to the e-didactics design-based learning method and were more prepared to attend classes. Subsequently, in Chapter III, the students' abilities increased significantly by 88% with a high category, indicating the effectiveness of the e-didactics design in this material. However, in Chapter IV, which discusses the use of derivatives, the increase decreased to 65%. This decline was due to the higher complexity of the material and its applicative nature in everyday life, leading students to face greater challenges in understanding and applying it. The pre-test and post-test answers of one student on the material of Chapter III (derivatives of functions) are presented in Figure 4. The questions given regarding the derivative of exponential functions and algebraic functions were, "Find the first derivative of $y = e^{3x+4}.\sqrt{8x-1}$ ".



(a) Pre-test result



(b) Post-test result

Figure 4. Pre-test and post-test result of respondent 2

From Figure 4, the results of one student's answer (Respondent 2) show a significant difference between the pretest and post-test results. In the pretest, Respondent 2 attempted to solve the problem by converting the root form into a square form, but this step was incorrect, resulting in an incorrect solution. In contrast, in the post-test, Respondent 2 was able to solve the problem correctly, applying the derivative rules accurately with complete solution steps. Below are the results of the interview with Respondent 2:

R : How do you solve this pre-test question?

R2 : So, the way to solve it is to first find the first derivative, then break down what's inside the parentheses.

R : How did you get this answer, $2x^2$*and* $(8x-1)^2$*?*

R2 : I forgot the exponential derivative formula; that root form actually becomes power 2 instead of power $\frac{1}{2}$*, so I just operated on it without knowing the formula.*

R : Alright, after using e-didactics, how do you solve the problem?

R2 : Because the derivative formula for functions is f(x)' = u'.v + uv'. So first, identify u and v. Let's assume the exponential function is u and the root function is v, then find the first derivative of u and v. After that, substitute it into the formula and then operate it.

R : Is it still difficult to solve problems that consist of two different functions like this?

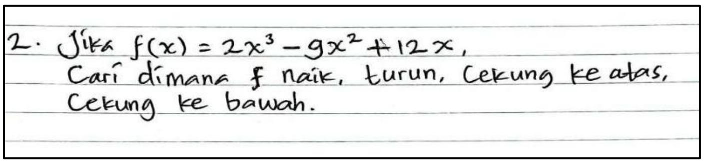
R2 : It seems the difficulties have decreased, ma'am, because we can first break down the functions, making the steps clearer.

R : After using e-didactic, does it provide a good understanding of the material?

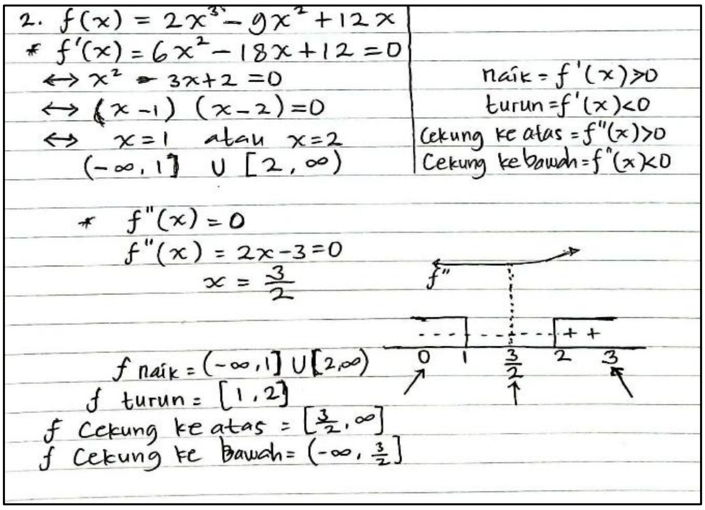
R2 : Yes, I feel more understanding; I replay the videos until I understand, and solving the problems has become easier to answer.

Based on the interview results, R2 experienced ontogenical obstacles in completing the pretest questions. R2 also faced epistemological obstacles, namely difficulties in understanding the basic concepts or formal rules related to function derivatives. These obstacles are related to R2's limited knowledge in connecting derivative formulas with their applications. This mistake is likely caused by a lack of prior learning experiences that emphasize the correct application of derivative rules. As a result, R2 only performed operations without understanding the underlying concepts. This condition also led to the emergence of didactical obstacles.

Furthermore, the results of the pre-test and post-test answers from respondent (R3) on the material in Chapter IV (the use of derivatives) are presented in Figure 5. The questions given regarding the use of derivatives in cases of increasing, decreasing, and concavity functions are: "If given *f*(x) $= 2x^3 - 9x^2 + 12x$, find where f is increasing, decreasing, concave up, and concave down."



(a) Pre-test result



(b) Post-test result

Figure 5. Pre-test and post-test result of respondent 3

As shown in Figure 5, the results of the pretest and posttest from R3 show a significant difference. In the pretest, R3 did not answer the given questions and only copied the questions without attempting to solve them. However, in the posttest, R3 was able to complete the questions thoroughly and accurately. The posttest results indicate that R3 understands the concept of using derivatives well, including determining increasing and decreasing functions, as well as concavity. Below are the results of the interview with R3:

R : *Can you explain how you worked on this pretest question?*

R3 : *In this pretest, when I read the question, I was confused about how to work on it. I didn't understand even though it had been taught in semesters 1 and 2, but I forgot again.*

R : *What difficulties did you experience in solving this question?*

R3 : *The difficulty for me was that I hadn't understood the concept or the methods, because during my time in vocational school, the learning was less detailed in mathematics, focusing more on the major subjects. Therefore, I struggled when encountering very complex mathematics questions in college.*

R : *Alright, after learning using e-didactics, can you explain the steps to solve the question?*

R3 : *This question determines the intervals where the function is increasing and decreasing. So, it is increasing when* $f'>0$*, and decreasing when* $f'<0$*. First, we find the derivative, then we find the value of x when* $f'=0$*. Next, we create a number line to determine the sign of* f'*. For concavity, we use the second derivative, so* f' *is differentiated again to become* f''*, if* $f''>0$ *it means concave up, and if* $f''<0$ *it means concave down.*

R : *What difficulties do you face in solving questions like this?*

R3 : *Understanding the concepts and steps often leads to difficulties and mistakes.*

R : *Has there been a change in your understanding of the material after learning with e-didactics?*

R3 : *Yes, because besides the learning being more interesting, e-didactics also greatly helps in understanding the material, allowing for independent study and reviewing the material to gain a better understanding.*

Based on the interview results, R3 experienced ontogenetic obstacle caused by the limitations of individual cognitive development due to previous learning experiences. R3 came from a vocational school background, which has a different focus in learning compared to high school. As a result, R3 lacked a strong foundation in basic mathematics, especially in concepts that frequently appear at the college level. The limitations of past learning experiences have caused R3 to struggle with understanding more complex material, such as differentiation and integration.

Additionally, R3 also faced epistemological obstacle, which are difficulties in understanding concepts or methods due to the nature of the material itself or the perspective on knowledge that makes R3 easily forgetful. R3's difficulty in solving derivative function questions reflects that the student only follows step-by-step procedures without understanding the conceptual meaning behind the process, such as the significance of the number line or sign tests. R3 also experienced didactical obstacle. These obstacle arise from teaching methods, learning materials, or learning designs that do not meet the needs of the students.

In addition to analyzing test results, the effectiveness of this design is also measured through a special questionnaire designed to assess the extent to which prototype 2 supports learning. The assessment results from the effectiveness questionnaire are provided in Table 5.

Table 5. Questionnaire review on prototype-2 effectivities

Statement	Result
Learning with the e-didactics design of differential calculus based on TPACK makes me more motivated to study differential calculus.	86.67%
Learning with the e-didactics design of differential calculus based on TPACK can help me understand the material of differential calculus.	88.33%
Learning with the e-didactics design of differential calculus based on TPACK can help me solve differential calculus problems.	78.33%
Learning using the e-didactics design of differential calculus based on TPACK can help me understand difficult concepts.	80%
The use of videos in the e-didactics design of differential calculus based on TPACK makes the material easy to understand.	93.33%
Using the e-didactics design of differential calculus based on TPACK accelerates my learning process.	75%
The e-didactics design of differential calculus based on TPACK helps me learn differential calculus anywhere and anytime.	81.67%
The integration of technology, pedagogy, and content in e-didactics design of differential calculus based on TPACK helps me overcome the learning difficulties I experience.	76.67%
The language used in the e-didactics design of differential calculus based on TPACK is easy to understand.	86.67%
The exercises in the e-didactics design of differential calculus based on TPACK can help in understanding the material.	83.33%
AVERAGE	**83%**

Based on Table 5, the results of the effectiveness assessment of prototype 2 indicate that this design is effective for use in learning. This is proved by the assessment percentage of 83% which falls into the effective category. Thus, this e-didactics design has successfully supported differential calculus learning optimally, especially in overcoming the learning obstacles faced by mathematics pre-service teacher.

3.2. Discussion

This research aims to identify the learning obstacles experienced by mathematics pre-service teacher in the differential calculus course and to evaluate the effectiveness of e-didactics design based on TPACK in overcoming these obstacles. To achieve the research objectives, the study employs the Design-Based Research (DBR) development method from Plomp. In the preliminary stage, a self-evaluation was conducted through learning obstacle tests and interviews. The results of this self-evaluation serve as the basis for the initial e-didactics design based on TPACK, referred to as prototype 1. This step is crucial to ensure that the teaching materials designed meet the needs and obstacles faced by mathematics pre-service teacher (Haryonik & Bhakti, 2018; Kamal, 2020).

The results of the learning obstacle tests (see Table 1) and interviews reveal that the main obstacle that needs to be addressed is the didactical obstacle. Students' errors in answering questions indicate learning difficulties, not due to a lack of ability, but because of limited class time and inadequate learning facilities (Nasrum & Herlina, 2019). Differential calculus is known to be difficult (Shodikin et al., 2019) and requires teaching materials that support independent learning. Students feel that the available textbooks do not adequately support independent learning and require guidance from lecturers, which is not always fulfilled. Additionally, educational videos available on the internet are often confusing due to differences in the presentation of material. Students need valid, practical, easily accessible online learning resources, accompanied by explanations of the material and problem discussions that can be repeated to maximize understanding.

The e-didactics design was intended to help overcome the learning obstacles faced by mathematics pre-service teacher in the differential calculus course. This design provides digital-based teaching materials (e-didactics) that integrate learning content with technology according to the TPACK framework. This design uses the Heyzine Flipbooks application, which facilitates students in accessing materials through their devices, allowing them to learn independently anytime and anywhere. Furthermore, this e-didactics design is equipped with video explanations of problems presented directly by the teacher, enabling students to understand the material in depth and review it as needed. The features available in Heyzine Flipbooks provide a flexible and effective learning experience while supporting the development of relevant independent learning skills in the digital era (Kamza et al., 2023; Nasrum & Herlina, 2019).

The results of expert and student validation (see Table 2 and Table 3) indicate that the e-didactics design meets the criteria of being very valid in terms of content, language, and media. Several changes have been made to this design (see Figure 2 and Figure 3) based on feedback from expert validators and students. The e-didactic design includes four subtopics, accompanied by 70 videos explaining the material and problems. These educational videos are designed to help students construct knowledge independently and support the development of thinking skills (Crompton & Burke, 2018).

The results of field testing in a small group (see Table 4) show that the e-didactics design improves students' abilities in differential calculus material, with moderate improvements in criteria (Chapters I and IV) and high improvements (Chapters II and III), indicating a positive effect from the implementation of this e-didactic design. Interviews with students (R2 and R3) reinforce this effectiveness. R2 states, "yes, I feel more understanding, I repeat the videos until I understand, solving problems has also become easier to answer." This statement indicates that learning obstacles related to teaching methods and teaching materials have been addressed. This result aligns with the views of Sulistiawati et al. (2015); Sakinah et al. (2019) that didactic design is an effort to reduce learning obstacles. Meanwhile, R3 adds, "indeed, because besides the learning being more interesting, this e-didactics is also very helpful in understanding the material so I can learn independently and review the material to understand better." This shows that the e-didactic design not only enhances understanding but also creates a more engaging learning experience and supports independent learning.

The limitations of this design include trials being limited to one higher education institution, as well as dependence on adequate internet access and digital devices. Additionally, the features of the Heyzine Flipbook application are still limited to content and videos, without any interactive simulations. The effectiveness of using this design heavily relies on the motivation and discipline of students to learn independently, which requires special attention from lecturers as facilitators.

4. CONCLUSION

Research and development of e-didactics design of differential calculus based on TPACK to address learning obstacles in mathematics pre-service teacher has resulted in several key conclusions. First, this research successfully identified three types of learning obstacles experienced by students, namely ontogenic obstacles, epistemological obstacles, and didactical obstacles. Second, the e-didactics design proved effective in overcoming these obstacles. Field test results showed an improvement in students' abilities in the moderate category for the material on real number systems, functions, and the use of derivatives, as well as in the high category for the material on limits and derivatives. Questionnaire assessments also indicated that this design is effective in addressing learning obstacles.

The implications of this research highlight the importance of integrating technology in differential calculus learning to support independent and in-depth learning. e-didactics design based on TPACK can serve as an innovative model that can be applied to other courses and contribute to the development of relevant digital teaching materials in the digital era. Further research can also be conducted on larger student groups or across universities to test the effectiveness of this e-didactics design more generally. Additionally, the design can incorporate the development of other interactive features and training for teacher and students to optimize the use of e-didactics.

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Declarations

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