Infinity Journal of Mathematics Education
Volume 15, No. 2, 2026
p-ISSN 2089-6867
e–ISSN 2460-9285
https://doi.org/10.22460/infinity.v15i2.p463-482

Developing a TPACK-based e-module for first order differential equations to enhance the pedagogical competence of pre-service mathematics teachers

Ika Meika[1*], Nenden Suciyati Sartika[1], Asep Sujana[1], Hasbi Assidik[1], Ika Safitri Windiarti[2], Rully Mujiastuti[3], Hendra[4]
[1]Department of Mathematics Education, Universitas Mathla'ul Anwar, Banten, Indonesia
[2]Department of Information Technology, Universiti Muhammadiyah Malaysia, Malaysia
[3]Department of Information Technology, Universitas Muhammadiyah Jakarta, Jakarta, Indonesia
[4]Department of Information Technology, Universitas Muhammadiyah Jakarta, Jakarta, Indonesia
[*]Correspondence: ikameikamulhat@gmail.com

Received: Nov 18, 2025 | **Revised**: Mar 18, 2026 | **Accepted**: Mar 20, 2026 | **Published Online**: Apr 19, 2026

Abstract

Efforts to strengthen the professional competence of future mathematics teachers call for the development of instructional materials that effectively integrate technology. This study aims to develop an e-module based on Technological Pedagogical and Content Knowledge (TPACK) for differential equations that are valid and effective in improving the pedagogical competence of pre-service mathematics teachers. This study employed Design-Based Research (DBR) using the Plomp development model, comprising three phases: the preliminary phase, the prototyping phase, and the assessment phase. The study subjects were students of the Mathematics Education study program from two universities in Banten, namely Universitas Mathla'ul Anwar and Universitas La Tansa Mashiro. The research instruments included misconception tests, validation sheets, observations, interviews, and e-module effectiveness questionnaires. The results showed that students still experienced misconceptions in the conceptual, procedural, and computational aspects of solving differential equations. The developed TPACK-based e-module achieved an average validation percentage of 83.3% across the material, language, and media aspects, indicating high validity. The field trial showed an increase in student understanding, with an average N-Gain of 0.4–0.5 (moderate) and an effectiveness rate of 88.61%. These results indicate that implementing the TPACK-based e-module not only improves students' conceptual and procedural understanding but also effectively reduces misconceptions and strengthens pre-service mathematics teachers' pedagogical competence in integrating technology, pedagogy, and content synergistically.

Keywords:
E-module, First-order differential equations, Pedagogical competence, TPACK

How to Cite:
Meika, I., Sartika, N. S., Sujana, A., Assidik, H., Windiarti, I. S., Mujiastuti, R., & Hendra, H. (2026). Developing a TPACK-based e-module for first order differential equations to enhance the pedagogical competence of pre-service mathematics teachers. *Infinity Journal*, *15*(2), 463-482. https://doi.org/10.22460/infinity.v15i2.p463-482

1. INTRODUCTION

Differential Equations (DE) is an important subject in mathematics that has wide applications in various fields of science, such as physics, engineering, chemistry, biology, economics, and education (Bibi et al., 2019; Fralish et al., 2021; Makamure & Jojo, 2022). In higher education, first-order DE plays an important role in developing essential skills such as communication, critical thinking, quantitative reasoning, and knowledge integration (Vajravelu, 2018). A deep understanding of first-order DE serves as the basis for mastering advanced mathematical concepts and applying them in various scientific disciplines (Ogueda-Oliva & Seshaiyer, 2024). Therefore, effective instruction in first-order DE is essential to build a strong knowledge foundation for pre-service mathematics teachers (Vajravelu, 2018).

However, various studies show that pre-service mathematics teachers often experience difficulties in understanding the basic concepts of first-order DE (Aisha et al., 2018; Farlina et al., 2018; Johnson et al., 2022). These difficulties are often caused by misconceptions that develop early in the learning process (Msomi & Bansilal, 2022), lack of innovation in teaching methods (Vajravelu, 2018), and the limited availability of teaching materials that align with teacher education curricula and support technology-based learning (Guo, 2024). These challenges not only affect students conseptual understanding but also hinder the development of pedagogical competence required for effective teaching.

These findings are supported by Meika and Sujana (2026), who reported that misconceptions among pre-service mathematics teachers are dominated by procedural errors (72.63%), followed by computational errors (67.37%) and conceptual errors (54.74%). These results indicate that students understanding remains fragmented and not yet fully integrated, higglighting the need for instructional interventions that adress multiple dimensions of learning.

Students' learning difficulties in understanding the basic concepts of first-order DE are an important consideration for lecturers in designing teaching materials that meet their needs (Musyrifah et al., 2022; Puspita et al., 2023). One solution is the use of e-modules, namely digital learning modules that can be accessed flexibly and interactively, allowing students to learn independently and gradually understand the material (Alyusfitri et al., 2024; Istunıngsıh et al., 2018; Putri & Dwikoranto, 2022; Supriyadi et al., 2024). E-modules in first-order DE learning can help students grasp complex concepts through visual illustrations, animations, simulations, and interactive exercises that strengthen conceptual understanding. However, without a strong pedagogical and technological foundation, e-modules may function mrely as digital versions of textbooks rather than as transformative learning tools. In addition, previous research emphasizes the need for instructional strategies that balance conceptual understanding, procedural mastery, and computational accuracy in differential equations learning (Meika & Sujana, 2026).

Furthermore, textbooks designed for science and engineering students are often too advancedand less suitable for pre-service mathematics teachers (Guo, 2024). Therefore, first-order DE instruction for pre-service mathematics teachers requires additional pedagogical considerations to ensure that the material is more accessible and meaningful (Guo, 2021). This condition highlights the urgent need for instructional materials that are not only technologically integrated but also pedagogically tailored ti the characteristics and needs of pre-service mathematics teachers.

As future educators, pre-service mathematics teachers are not only required to understand the basic concepts of first-order DE but are also expected to possess strong pedagogical competence to teach mathematical concepts using effective and innovative methods (Toh et al., 2022). Pedagogical competence is a crucial aspect in ensuring the quality of education (Mariscal et al., 2023; Toshtemirovich, 2019). This competence includes the knowledge, skills, and abilities needed to perform teaching tasks (Mariscal et al., 2023; Vathanophas & Thai-ngam, 2007). Furthermore, pedagogical competence also reflects a teacher's capacity to utilize technology to support a more effective learning process (Falloon, 2020; Harisman et al., 2020, 2021; Hidayat & Aripin, 2023; Mobo & Rahmat, 2021).

Nevertheless, many pre-service teachers still find it difficult to implement innovative and interactive learning when teaching complex topics such as first-order differential equations (López-Reyes, 2022). The Technological Pedagogical and Content Knowledge (TPACK) framework offers a comprehensive approach to addressing these challenges by integrating content knowledge, pedagogical knowledge, and technological knowledge (Falloon, 2020; Santos & Castro, 2021; Taopan et al., 2020). Previous studies have shown the value of TPACK-based design in teacher education and the effectiveness of digital modules in improving learning outcomes, but these studies have generally focused on broader classroom applications or on mathematical topics other than first-order differential equations (Alyusfitri et al., 2024; Meika et al., 2025; Santos & Castro, 2021; Yarman et al., 2025). At the same time, studies on differential equations have documented persistent misconceptions and the need for additional instructional support for pre-service mathematics teachers (Guo, 2024; Makamure & Jojo, 2022; Msomi & Bansilal, 2022). Therefore, a clear gap remains in the development and iterative evaluation of a topic-specific TPACK-based e-module for first-order differential equations that is explicitly grounded in students’ misconception profiles.

Based on this research gap, the study aimed to develop a TPACK-based e-module for first-order differential equations and to evaluate its validity, practicality, and effectiveness for pre-service mathematics teachers. Specifically, this study addressed the following questions: (1) what misconceptions do pre-service mathematics teachers experience in learning first-order differential equations? (2) how valid and practical is the developed TPACK-based e-module? and (3) how effective is the e-module in improving learning outcomes and reducing students' misconceptions?

2. METHOD

This study employed Design-Based Research (DBR) using the Plomp development model because the study aimed to produce and iteratively refine a learning product through implementation, evaluation, and revision (Asmara et al., 2024; Meika et al., 2023; Nindiasari et al., 2024; Nurhasanah et al., 2022). The Plomp model consisted of three phases: the preliminary phase, the prototyping phase, and the assessment phase. In this study, the cycle began with identifying students' misconceptions in first-order differential equations, continued with designing and revising the TPACK-based e-module through formative evaluation, and ended with limited implementation to examine its practicality and effectiveness. The overall procedure is presented in Figure 1.

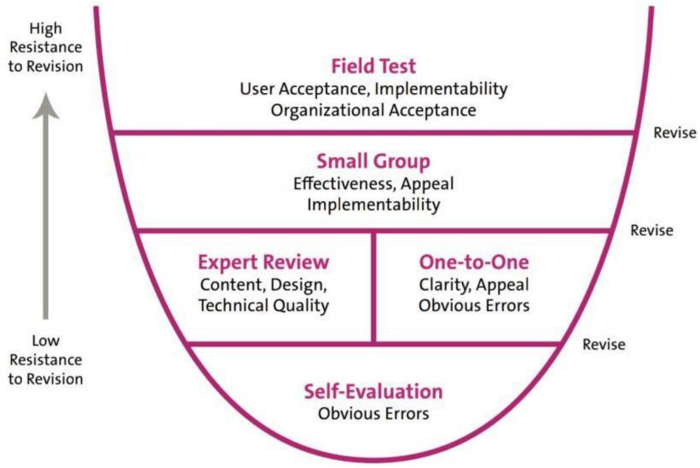


Figure 1. Tessmer's layers of formative evaluation

2.1. Preliminary Phase

In the preliminary phase, 19 mathematics education students from Universitas Mathla'ul Anwar and Universitas La Tansa Mashiro participated in a misconception test. The participants were selected purposively because they had learned or were currently taking introductory differential equations and were willing to participate. To obtain deeper explanations of the written responses, 12 students were then interviewed based on the variation of error types found in the test results so that conceptual, procedural, and operational difficulties could all be represented. The test was used to locate students' conceptual, procedural, and operational difficulties, whereas the interviews were used to explore the sources of these difficulties and students' expectations regarding learning support. The findings from this phase became the basis for developing Prototype 1 of the TPACK-based e-module.

2.2. Prototyping Phase

The expert review and one-to-one phases were conducted by evaluating Prototype 1 through the involvement of participants with distinct roles. The expert review involved three validators, namely a linguist, a subject matter expert, and a media/IT expert, who examined linguistic aspects, content appropriateness, and media quality to ensure that the developed e-module met academic standards. In addition, five eighth-semester students from the Mathematics Education study program at Universitas Mathla'ul Anwar were involved in the one-to-one phase as representative users who had completed most of the relevant coursework. Their role was not to act as experts but to provide feedback on the clarity of the display, readability of the content, and ease of navigation and access to the e-module. Based on the results of expert validation and student feedback, several revisions were made, including simplifying the language, adding visual elements, improving media feature compatibility, and reorganizing the navigation structure to enhance usability. The findings from these phases served as the basis for revising Prototype 1 into Prototype 2.

2.3. Assessment Phase

In the assessment phase, Prototype 2 was implemented with 12 mathematics education students at Universitas Mathla'ul Anwar who were taking the differential equations course. These 12 students were different from the five students involved in the one-to-one evaluation. The field test involved the same 12 students and was conducted across eight meetings covering three chapters of first-order differential equations. The intervention was implemented by the course lecturer during regular classroom learning, with the e-module serving as the main material for guided activities and independent study. The same 12 students completed a chapter pre-test before learning and a chapter post-test after learning, resulting in three sets of pre-test and post-test scores. In addition, students completed a practicality and effectiveness questionnaire after the implementation. The results of the small-group trial and field test were used to refine Prototype 2 into Prototype 3.

2.4. Data Collection and Analysis

Data were collected through tests, interviews, validation sheets, observation notes, documentation, and questionnaires. The instruments included a misconception test, a caption-based pre-test, and a post-test on first-order differential equations. The pre-test and post-test for each chapter were designed as parallel forms, measuring the same indicators using different items. The content validity and clarity of the instruments were evaluated through expert judgment. The reliability of the test instruments was assessed using Cronbach's alpha to ensure internal consistency. The equivalence of the pre-test and post-test was established by aligning their test blueprints and confirming their consistency through expert validation.

The validation sheets used in this study were developed by the researchers based on established criteria for instructional material evaluation, covering aspects of content, language, and media/IT, and were reviewed by experts prior to use. The validation sheets used during the expert review phase encompassed material, language, and media/IT aspects, while the questionnaire administered during the assessment phase addressed ease of use, attractiveness, learning time efficiency, TPACK integration, and implementation. Quantitative data were analyzed descriptively using percentages and normalized gain (N-gain). Meanwhile, qualitative data from interviews, observations, and validator feedback were analyzed using an interactive model of qualitative data analysis involving data reduction, coding, data display, and conclusion drawing. Triangulation across multiple data sources tests, interviews, observations, and documentation was employed to enhance the credibility of the findings.

3. RESULTS AND DISCUSSION

3.1. Results

3.1.1. Preliminary Phase

Data in this study were obtained from the results of a differential equation misconception test involving 19 students from two private universities in Banten, namely Universitas Mathla'ul Anwar and Universitas La Tansa Mashiro. The intrument consicted of five close-ended dignodtic itmes and five essay items covering introductory concepts in differentiak equations, order and degrre, identification of independent and dependent variables, direct integration, separation of varibles, and exact versus inexact differential equations. The close-ended items were interpreted together with students' written work and follow-up interviews, so misconceptions were not identified from selected answers alone.

Data on misconceptions were obtained from the test results and were then analyzed based on three categories of error causes: conceptual errors, procedural errors, and computational/operational errors. The results of the analysis of the percentage of student misconceptions are presented in Table 1.

Table 1. Percentage of error types in the differential equation misconception test

Type of Error	Question Number					Average
	1	2	3	4	5	
Conceptual Error	5.26	31.58	73.68	84.21	78.95	54.74
Procedural Error	-	78.94	100	100	84.21	72.63
Operational Error	-	84.21	78.95	89.47	84.21	67.37

Table 1 shows that students experience significant difficulties in understanding basic concepts and in applying procedures for solving differential equations. Conceptual errors increase as the complexity of the problems increases, while procedural errors are highly dominant, reaching 100% in certain items. Furthermore, operational errors are consistently high, indicating weak technical calculation skills. In addition to the misconception test results, interview data with students from Universitas Mathla'ul Anwar also revealed that the learning resources used do not provide optimal support for the learning process. The reference books used do not provide step-by-step guidance for solving problems, causing students to experience confusion in following procedural steps.

3.1.2. Prototyping Phase

The designed differential equations e-module that needed validation was prepared based on a preliminary study on misconceptions among pre-service mathematics teachers in understanding differential equation (Meika & Sujana, 2026). The results of the validators' assessment of the TPACK-based e-module for differential equations are presented in Table 2.

Table 2. Validation results on the design of the TPACK-based e-module

No	Expert Validator	Average	Percentage
1	Material	0.83	83.3
2	Language	0.86	86.7
3	Media	0.80	80.0
	Average	0.83	83.3

Table 2 shows that the TPACK-based e-module design is valid, with an average score of 83.3%, indicating it is suitable for use with minor revisions. Next, suggestions from students are presented in Table 3.

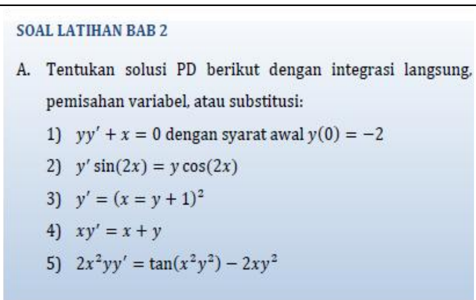
Table 3. Student suggestions on the design of the TPACK-based e-module

No	Part	Suggestion
1	Sample question video	Add a discussion video to Example 2.6 (Determine the solution of the differential equation: $2xy' - x^2 - 2y = 0$!); because we think it is difficult.
2	Discussion video	Add a video explaining how to construct the graph of the implicit function $x^2 + y^2 = 1$(a circle centered at (0,0) with radius 1), which is the solution of the differential equation $y\,y' = -x$, along with its direction field so that users can understand how to create it.

Table 2 shows that the validation result of the e-module design is categorized as very valid (83.3%), meaning it can be used directly in implementation with only minor revisions. Furthermore, Prototype 1 was revised based on input from validators and students to improve the quality of the e-module and develop Prototype 2. Examples of improvements made to the design particularly in the language revisions are presented in Figure 2, while revisions to Example Question 1.3 are presented in Figure 3. The addition of a video explaining how to create curves and directional fields, accessible via YouTube, is presented in Figure 4.

The following Figure 2 show the process of improving the language used in the differential equation problem instructions. These improvements were made to increase clarity for students in understanding the required steps for solving the problems.

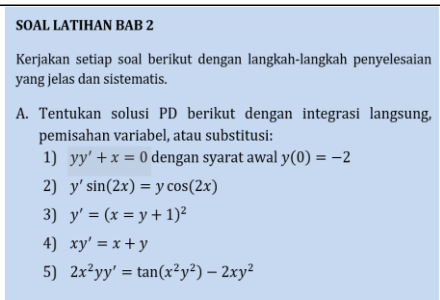
Improvement of the Language in Problem Instructions


SOAL LATIHAN BAB 2

A. Tentukan solusi PD berikut dengan integrasi langsung, pemisahan variabel, atau substitusi:

1) $yy' + x = 0$ dengan syarat awal $y(0) = -2$
2) $y' \sin(2x) = y\cos(2x)$
3) $y' = (x = y + 1)^2$
4) $xy' = x + y$
5) $2x^2yy' = \tan(x^2y^2) - 2xy^2$

(a) Before Improvement


SOAL LATIHAN BAB 2

Kerjakan setiap soal berikut dengan langkah-langkah penyelesaian yang jelas dan sistematis.

A. Tentukan solusi PD berikut dengan integrasi langsung, pemisahan variabel, atau substitusi:

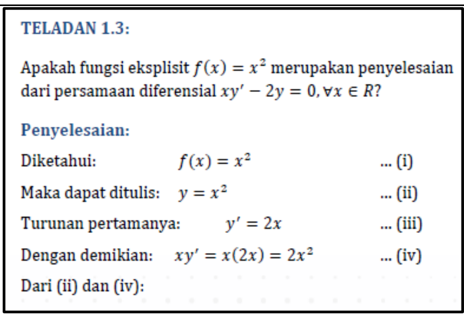
1) $yy' + x = 0$ dengan syarat awal $y(0) = -2$
2) $y' \sin(2x) = y\cos(2x)$
3) $y' = (x = y + 1)^2$
4) $xy' = x + y$
5) $2x^2yy' = \tan(x^2y^2) - 2xy^2$

(b) After Improvement

Figure 2. Prototype 1 improvements by the language expert validator

Figure 3 shows the process of improving the clarity in the Example Question 1.3 by adding contextual elements to the problem so that the questions become more meaningful and easier for students to understand.

Improvement of the problem clarity in Question Example 1.3


TELADAN 1.3:

Apakah fungsi eksplisit $f(x) = x^2$ merupakan penyelesaian dari persamaan diferensial $xy' - 2y = 0, \forall x \in R$?

Penyelesaian:

Diketahui: $f(x) = x^2$ ... (i)

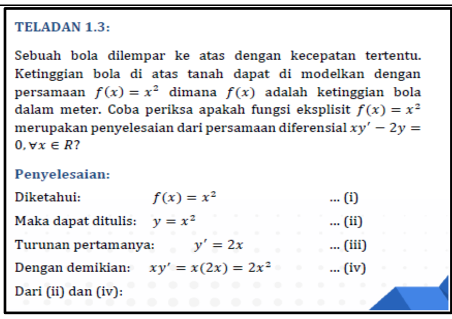
Maka dapat ditulis: $y = x^2$ ... (ii)

Turunan pertamanya: $y' = 2x$ ... (iii)

Dengan demikian: $xy' = x(2x) = 2x^2$ ... (iv)

Dari (ii) dan (iv):

(a) Before Improvement


TELADAN 1.3:

Sebuah bola dilempar ke atas dengan kecepatan tertentu. Ketinggian bola di atas tanah dapat di modelkan dengan persamaan $f(x) = x^2$ dimana $f(x)$ adalah ketinggian bola dalam meter. Coba periksa apakah fungsi eksplisit $f(x) = x^2$ merupakan penyelesaian dari persamaan diferensial $xy' - 2y = 0, \forall x \in R$?

Penyelesaian:

Diketahui: $f(x) = x^2$ ... (i)

Maka dapat ditulis: $y = x^2$ ... (ii)

Turunan pertamanya: $y' = 2x$ ... (iii)

Dengan demikian: $xy' = x(2x) = 2x^2$ ... (iv)

Dari (ii) dan (iv):

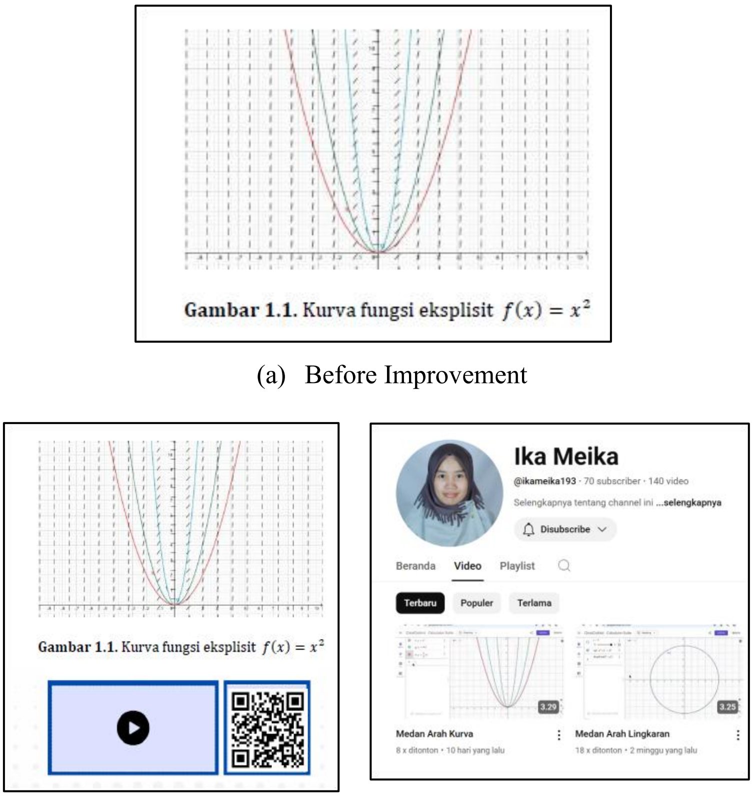
(b) After Improvement

Figure 3. Prototype 1 improvements by the material expert validator

Figure 4 ilustrates the addition of an optional video to support students in visualizing direction fields. The video explains how to create an explicit function curve and its directional field, for example: $f(x) = x^2$.

Figures 2, 3, and 4 show the improvements made to the e-module design based on suggestions from material, language, and media (IT) experts. The revised version was then piloted on pre-service mathematics teachers to examine its effectiveness in addressing misconceptions in the differential equations course.

Improvement by Adding a YouTube Video Explaining How to Create an Explicit Function Curve for $f(x) = x^2$ and Its Directional Field



(a) Before Improvement

(b) After Improvement

Figure 4. Adding a YouTube video on how to create curves and their direction fields

3.1.3. e-Module Design Assessment

Twelve pre-service mathematics teachers participated in the trial of the TPACKbased e-module for first-order differential equations. The implementation lasted for eight meetings and covered three chapters. At the beginning of each chapter, students completed a pre-test, then used the e-module in guided learning and independent review, and at the end of the chapter they completed a post-test. The codes R1–R12 in Table 4 refer to participant codes. Improvement in learning outcomes was analyzed using normalized gain (N-gain), as presented in Table 4.

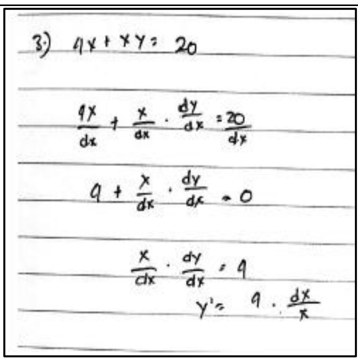
Table 4. N-gain data on the trial of the TPACK-based e-module for differential equations (first-order differential equations)

N-Gain	Subject												Average	Category
	R1	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**	**R10**	**R11**	**R12**		
Chapter 1	0.3	0.2	0.4	0.3	0.5	0.6	0.4	0.6	0.4	0.5	0.3	0.4	0.4	Moderate
Chapter 2	0.2	0.2	0.4	0.2	0.0	0.6	0.4	0.6	0.4	0.6	0.3	0.4	0.4	Moderate
Chapter 3	0.7	0.5	0.3	0.4	0.5	0.3	0.4	1.0	0.2	0.8	0.2	0.3	0.5	Moderate

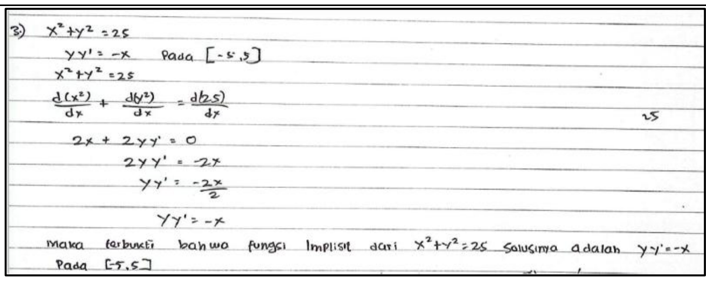
Table 4 shows that the results of the design trial of the TPACK-based e-module for differential equations indicate an increase in the abilities of the pre-service mathematics teachers in each chapter. The average N-Gain value for Chapter 1 was 40%, Chapter 2 was 40%, and Chapter 3 was 50%, all of which fall into the moderate category.

The improvement in Chapter 1 (40%) is still considered moderate because students are just beginning to adapt to the use of the TPACK-based e-module and adjusting to independent learning patterns. In Chapter 2 (40%), the improvement remains in the moderate category, indicating that students are becoming more accustomed to the structure and learning flow of the e-module. Meanwhile, Chapter 3 (50%) shows the highest improvement among the three chapters, reflecting students' increasingly better and deeper understanding of differential equations concepts. Overall, these results indicate that the implementation of the TPACK-based e-module for differential equations (first-order differential equations) provides an improvement in student learning outcomes within the moderate category, with a tendency to increase in each chapter. This indicates that the developed e-module is effective in helping students understand the material but still requires further development so that improvements in learning outcomes can reach the high category.

The pre-test and post-test answers from one of the students for the material in Chapter 1 (Definition of Differential Equations) are shown in Figure 5. The questions relate to the derivative of a differential equation, namely the pre-test question "Determine the derivative of $4x + xy = 20$" and the post-test question "Is the implicit function $x^2 + y^2 = 25$, a solution to the differential equation $yy' = -x$ on $[-5, 5]$?"



(a) Pre-test results



Translate:
It is therefore established that the implicit function defined by satisfies function $x^2 + y^2 = 25$ satisfies $yy' = -x$ on [-5, 5]

(b) Post-test results

Figure 5. Pre-test and post-test results of respondent 8

Based on the pre-test and post-test results, there was an increase in understanding of the concept of implicit differentiation. In the pre-test, students were unable to correctly apply the rules for product derivatives to solve the problem $4x + xy = 20$, often treating xyas a single variable rather than a product. As a result, they omitted one factor's derivative or did not apply the product rule at all. Additionally, students showed misconceptions in applying the chain rule to terms involving *y*, leading to incorrect derivative forms and inconsistent results. These errors indicate specific conceptual misunderstandings of both the product rule and the chain rule in implicit differentiation.

In contrast, in the post-test, students successfully differentiated the function $x^2 + y^2 = 25$ correctly to $yy' = -x$ and concluded that the function satisfied the given differential equation. This indicates that students understood the application of the chain rule and the relationship between implicit functions and differential equations. Thus, there was an increase in students' conceptual and procedural abilities in understanding and applying implicit differentiation after the learning. The following are the results of an interview with Respondent 8.

R : During the pre-test, you seemed unable to determine the derivative of the function 4x+xy=20. What made this question difficult for you?

R8 : I was a bit confused, Ma'am, because it did not look like its usual form. I did not know how to differentiate xy part, so I just differentiated it normally.

R : So, you had not applied the derivative rules yet?

R8 : Yes, Ma'am, I forgot that the derivative of xy uses the product rules. I simply differentiated each part without multiplying the derivatives of x and y.

R : After using the TPACK-based e-module for differential equations, how did you solve the questions on the post-test?

R8 ; After studying the e-module, I learned that the derivative of xy uses the product rules, so it becomes $x\frac{dy}{dx} + y$*. From there, I could differentiate it correctly and find the value of y'.*

R : What do you think about the e-module? Does it help in understanding the concept of implicit differentiation?

R8 : Yes, it is very helpful, Ma'am. The explanations in the e-module are clear, with sample questions, video explanations, and interactive exercises, so I can review them until I understand.

R : How do you feel after being able to complete the post-test questions correctly?

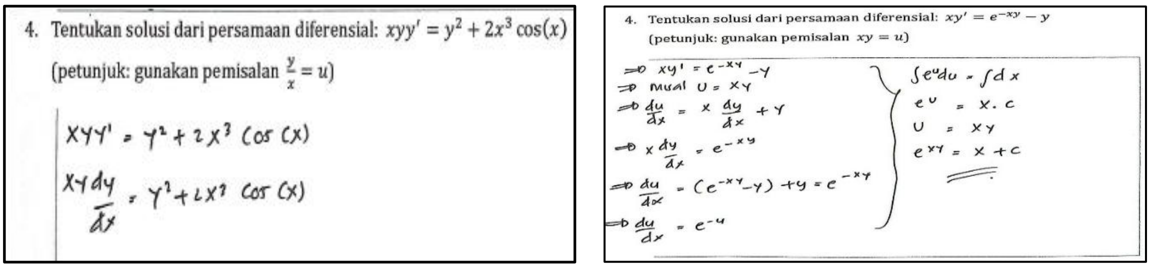
R8 : I feel more confident because now I understand the steps and can distinguish when to use regular differentiation and when to use implicit differentiation.

Based on the interview results, Respondent 8 in the pre-test had conceptual misconceptions, namely difficulty in understanding the basic concept of implicit differentiation and the application of product rules. After learning using the TPACK-based e-module, respondents showed an increase in conceptual and procedural understanding in deriving implicit functions and applying derivative rules correctly.

Next, the results of the pre-test and post-test answers from Respondent 11 on the material in Chapter 2 (First-Order Differential Equations) are presented in Figure 6. The questions given were related to determining the solution of a differential equation using several methods, including the substitution method (variable separation). The pre-test question was: Determine the solution of the differential equation: $xyy' = y^2 + 2x^3 \cos\cos(x)$ (hint: use the substitution $\frac{y}{x} = u$). The post-test question was: Determine the solution of the differential equation: $xy' = e^{-xy} - y$ (hint: use the substitution: $xy = u$).

Based on the pre-test and post-test results, there was an increase in students' understanding of solving differential equations using the substitution method. In the pre-test, students were unable to correctly apply the substitution $\frac{y}{x} = u$ to the problem $xyy' = y^2 +$

$2x^3cos\ (x)$. They only wrote some of the steps without continuing with the substitution and integration processes, indicating procedural and conceptual errors.



Translate:
4. Determine the solution of the differential equation:
$xyy' = y^2 + 2x^3cos(x)$
(Hint: use the substitution $\frac{y}{x} = u$)

Translate:
4. Determine the solution of the differential equation:
$xyy' = e^{-xy} - y$
(Hint: use the substitution $xy = u$)"

(a) Pre-test results (b) Post-test results

Figure 6. Pre-test and post-test results of respondent 11

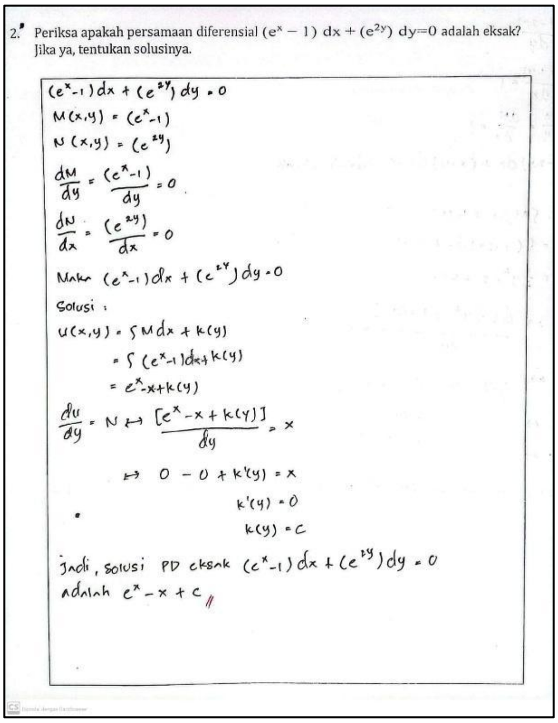
In contrast, in the post-test, students were able to solve the problem $xy' = e^{-xy} - y$ systematically by using the substitution xy = u, correctly performing differentiation, substitution, and integration, and obtaining the result $e^u = x + c$. This indicates that students had developed a good understanding of the substitution concept and the integration process. Thus, there was a significant increase in students' conceptual and procedural abilities after using the developed TPACK-based e-module for differential equations. The following are the results of an interview with Respondent 11.

R : During the pre-test, it seemed like you were not able to solve the problem correctly. What made this differential equation problem difficult for you?
R11 : I was confused, Ma'am, because the question asked for an analogy, but I didn't know where to start. I just wrote the initial form without knowing how to continue with the substitution process.
R : So, you did not understand how to use the substitution y/x=u?
R11 : Yes, I knew there should be a substitution, but I didn't know the differentiation formula or how to replace it into a new form.
R : After using the TPACK-based e-module for differential equations, how did you solve the post-test question?
R11 : After studying the e-module, I understood the steps. First, make the substitution xy = u, then differentiate, substitute into the equation, and continue with the integration process. From there, the results can be obtained more easily and systematically.
R : Do you feel that the e-module helps you understand the concepts of substitution and integration in differential equations?
R11 : Yes, it is very helpful, Ma'am. The e-module explains the substitution steps using similar examples, so I can follow the pattern as I work.
R : How do you understand the substitution method now?
R11 : Now I understand it better, Ma'am. I know when to perform the substitution, how to differentiate the substitution result, and how to solve the integral. So I am not just memorizing; I also understand the process.

Based on the interview results, Respondent 11 experienced procedural and conceptual misconceptions during the pre-test, specifically not understanding how to apply the substitution method in solving differential equations and having difficulty proceeding to the integration phase. After learning with the TPACK-based e-module, Respondent 11 demonstrated improved conceptual understanding and more systematic steps in problem-solving. The student was able to connect the substitution, differentiation, and integration processes correctly, indicating reduced learning barriers and enhanced analytical thinking skills.

Next, the results of the pre-test and post-test answers from Respondent 7 on the material in Chapter 3 (Exact and Inexact Differential Equations) are presented in Figure 7. The questions were related to exact and inexact differential equations. The pre-test question was: Check whether the differential equation $(e^x - 1)dx + (e^{2y})\,dy = 0$ is exact? If yes, determine the solution. The post-test question was: Check whether the differential equation $2xy\,dx + (4y + x^2)dy = 0$ is exact? If yes, determine the solution.

Based on the pre-test and post-test results, there was an increase in students' understanding of solving exact differential equations. In the pre-test, students were able to determine *M(x,y)* and *N(x,y)*, and check exactness, but the steps were not systematic, and the final results were not precise.

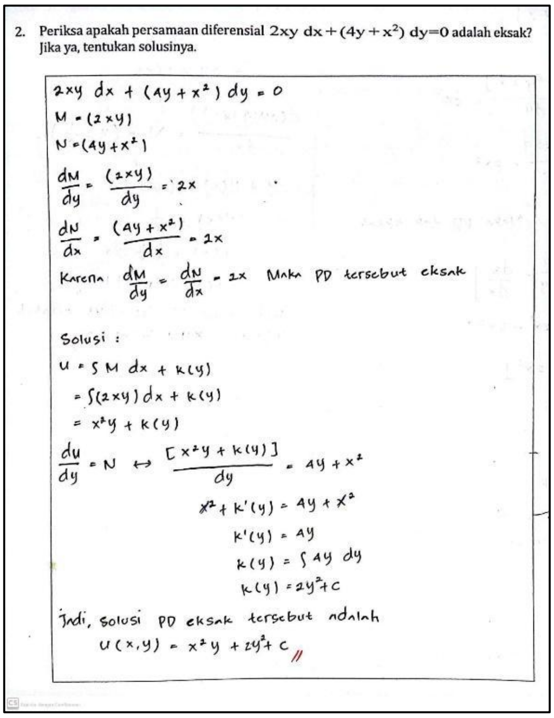


2. Periksa apakah persamaan diferensial $(e^x - 1)\,dx + (e^{2y})\,dy = 0$ adalah eksak? Jika ya, tentukan solusinya.

$(e^x-1)dx + (e^{2y})dy = 0$
$M(x,y) = (e^x-1)$
$N(x,y) = (e^{2y})$
$\frac{dM}{dy} = \frac{(e^x-1)}{dy} = 0$
$\frac{dN}{dx} = \frac{(e^{2y})}{dx} = 0$
Maka $(e^x-1)dx + (e^{2y})dy = 0$
Solusi :
$u(x,y) = \int M\,dx + k(y)$
$= \int (e^x-1)dx + k(y)$
$= e^x - x + k(y)$
$\frac{du}{dy} = N \leftrightarrow \frac{[e^x - x + k(y)]}{dy} = x$
$\leftrightarrow 0 - 0 + k'(y) = x$
$k'(y) = 0$
$k(y) = c$
Jadi, solusi PD eksak $(e^x-1)dx + (e^{2y})dy = 0$ adalah $e^x - x + c$ //

Translate:
Check whether the differential equation $(e^x - 1)dx + (e^y)dy = 0$ is exact. If not, find its solution.

(a) Pre-test results



2. Periksa apakah persamaan diferensial $2xy\,dx + (4y + x^2)\,dy = 0$ adalah eksak? Jika ya, tentukan solusinya.

$2xy\,dx + (4y + x^2)\,dy = 0$
$M = (2xy)$
$N = (4y + x^2)$
$\frac{dM}{dy} = \frac{(2xy)}{dy} = 2x$
$\frac{dN}{dx} = \frac{(4y + x^2)}{dx} = 2x$
Karena $\frac{dM}{dy} = \frac{dN}{dx} = 2x$ Maka PD tersebut eksak
Solusi :
$u = \int M\,dx + k(y)$
$= \int (2xy)\,dx + k(y)$
$= x^2y + k(y)$
$\frac{du}{dy} = N \leftrightarrow \frac{[x^2y + k(y)]}{dy} = 4y + x^2$
$x^2 + k'(y) = 4y + x^2$
$k'(y) = 4y$
$k(y) = \int 4y\,dy$
$k(y) = 2y^2 + c$
Jadi, solusi PD eksak tersebut adalah
$u(x,y) = x^2y + 2y^2 + c$ //

Translate:
Determine whether the differential equation $2xy\,dx + (4y + x^2)\,dy = 0$ is exact. If it is, find its solution.

(b) Post-test results

Figure 7. Pre-test and post-test results of respondent 7

In the post-test, students showed significant improvement by solving the problems sequentially, determining exactness, constructing the potential function $U(x, y)$, and obtaining the final result $U(x, y) = x^2y + 2y^2 + C$. This indicates that students had a better understanding of the concepts and procedures for solving exact differential equations after the learning. The following are the results of an interview with Respondent 7.

R : *During the pre-test, you seemed to have tried to determine M(x,y) and N(x,y) but the final result was not quite right. What made this problem difficult for you?*

R7 : *I'm still confused, Ma'am, about how to determine whether an equation is exact or not. I know I have to find the partial derivatives, but I often get confused between* $\frac{\partial M}{\partial y}$ *and* $\frac{\partial N}{\partial x}$. *So the steps are not systematic (in order).*

R : *So you know the first steps, but you're not sure how to check for exactness?*

R7 : *Yes, that's right, Ma'am. I understand the basic concept, but I get confused when I move on to the potential functions.*

R : *After using the TPACK-based e-module, how did you solve the same questions on the post-test?*

R7 ; *After learning with the e-module, I understood that I had to first check exactness by comparing* $\frac{\partial M}{\partial y}$ *and* $\frac{\partial N}{\partial x}$. *I If they are the same, the equation is exact, and I can continue to find the potential function U(x,y). I followed the steps in the module and obtained the result* $U(x, y) = x^2y + 2y^2 + C$.

R : *Did the e-module help you understand the concepts and steps of solving exact differential equations?*

R7 : *Yes, Ma'am, it's very helpful. The explanations in the module are coherent, and there are sample questions and exercises, so I can learn while comparing them with my own work.*

R : *How do you understand the process of solving exact differential equations now?*

R7 : *Now I understand better, Ma'am. I know the sequence of steps—from determining M and N, checking exactness, to constructing the potential function. So, during the post-test, I could work with more confidence.*

Based on the interview results, Respondent 7 experienced procedural and conceptual misconceptions during the pre-test, specifically not yet understanding the systematic steps to determine exactness and construct potential functions in exact differential equations. After learning with the TPACK-based e-module for differential equations, Respondent 7 demonstrated improved conceptual understanding and procedural ability in solving problems coherently and correctly. This indicates that students had a better understanding of the relationship between exactness and potential functions after the learning process.

The design of the TPACK-based e-module for differential equations that has been implemented in learning has proven effective in addressing misconceptions. In addition to analyzing test results, the effectiveness of this design was also measured using a special questionnaire designed to assess the extent to which Prototype 2 supports the learning process. The results of the effectiveness questionnaire are presented in Table 5.

Table 5. Results of the effectiveness assessment of the TPACK-based e-module

No	Aspect	Assessment Results
1	Aspect of Ease of Use	86.25%
2	Aspect of Attractiveness	82.78%
3	Aspect of Learning Time Efficiency	90.00%
4.	Aspect of TPACK Integration	90.00%
5	Aspect of Implementation	94.00%
	Average	88.61%

Table 5 shows that the results of the assessment of the effectiveness of the TPACK-based e-module for differential equations indicate that over all the e-module is in the very effective category, with an average score of 88.61%. When viewed from each aspect, the aspect of implementation obtained the highest score of 94%, indicating that the e-module is very easy to apply in learning activities. The aspect of TPACK integration and the aspect of learning time efficiency both obtained a score of 90%, indicating that the e-module is able to integrate elements of technology, pedagogy, and content well and help students learn efficiently.

Furthermore, the aspect of ease of use scored 86.25%, indicating that the e-module's display and navigation were quite easy for users to understand. The aspect of attractiveness scored 82.78%, which, although the lowest among the aspects, still falls into the very good category. Overall, these results indicate that the TPACK-based e-module for differential equations is effective for use in learning and is able to provide an engaging, accessible, and efficient learning experience for pre-service mathematics teachers.

3.2. Discussion

The development process of the TPACK-based e-module for differential equations in this study follows the phases of the Plomp development model, which include the preliminary phase, the prototyping phase, and the assessment phase, as stated by Nurhasanah et al. (2022). The results of the study indicate that through the Design-Based Research (DBR) approach, the developed e-module is not only valid and effective, but also able to address the misconceptions of pre-service mathematics teachers.

In the preliminary phase, a self-evaluation was conducted by identifying misconceptions experienced by pre-service mathematics teachers in the differential equations course and by evaluating the effectiveness of the initial design of the TPACK-based e-module for differential equations. Students were found to experience difficulties in the conceptual, procedural, and computational aspects of solving differential equations. These findings align with research conducted by Haryonik and Bhakti (2018) and Kamal (2020), which emphasize that the development of teaching materials needs to begin with mapping problems and learning needs so that the resulting solutions are relevant to students' conditions. The results of this phase became the basis for developing the initial prototype of the TPACK-based e-module for differential equations (prototype 1).

The prototyping phase resulted in a TPACK-based e-module for differential equations that integrates elements of technology, pedagogy, and mathematical content. Validation by experts (see Table 2) showed a very valid level (83.3%), meaning that the e-module met the eligibility criteria for content, language, and media. This supports the opinion of Muthohir (2019) that the validity of teaching materials is an important indicator for determining the feasibility of implementing a learning product before it is used widely.

In the assessment phase, which included one-to-one evaluation, small-group trial, and field testing, the results showed that the use of the e-module could improve students' ability to understand the concept of differential equations. The average N-Gain value of 0.4–0.5 (moderate category) indicated an increase in students' conceptual understanding and procedural skills. The increase in understanding in the procedural aspect reflects the role of the pedagogical knowledge component integrated into the e-module through interactive exercises, while the increase in conceptual understanding represents the contribution of content knowledge contextualized through learning videos and applicable examples. The highest increase occurred in Chapter III (exact differential equations), with a score of 50%, which indicates the effectiveness of integrating learning videos and contextual examples in strengthening students' understanding. This finding is supported by the results of a study by Meika et al. (2025), which showed that the use of a TPACK-based approach can improve learning outcomes and overcome conceptual misconceptions.

As a concrete example, the results of the small group trial and field test (see Table 5) show that in Chapter I, students who initially experienced conceptual errors in applying the chain rule to implicit differentiation were able to correctly derive functions and understand the relationship between implicit functions and differential equations after using the TPACK-based e-module for differential equations. Meanwhile, in Chapter II, students showed significant improvement in solving problems using the substitution method after utilizing the discussion videos and interactive exercises available in the e-module. This is reinforced by the results of an interview with Respondent 8, who stated, "Yes, it is very helpful, Ma'am. The explanations in the e-module are clear, with sample questions, video explanations, and interactive exercises, so I can review them until I understand." This statement confirms that the integration of technological and pedagogical aspects in the e-module supports an iterative and reflective learning process, helping students correct misconceptions at both the conceptual and procedural levels.

The field test results showed that the e-module was highly effective in supporting the learning process, with an average effectiveness score of 88.61%. The aspect of implementation received the highest score of 94%, indicating ease of implementation in learning. The aspect of TPACK integration and the aspect of learning time efficiency each received scores of 90%, indicating the successful and harmonious integration of technology, pedagogy, and content (Hidayat et al., 2025; Sahrudin et al., 2025; Yazmin & Amini, 2023).

Overall, the results of this study confirm that the TPACK-based e-module for differential equations is effective in improving the conceptual and procedural abilities of pre-service mathematics teachers, while simultaneously reducing misconceptions found in the initial phases. This is in line with research by Kurniansyah et al. (2022), Sakinah et al. (2019), and Sulistiawati et al. (2015), which stated that technology-based e-modules can be an effective strategy to address misconceptions and strengthen meaningful learning in higher education environments.

4. CONCLUSION

This study concludes that the TPACK-based e-module for differential equations that was developed has fulfilled the criteria of being valid and effective, and it is capable of enhancing the pedagogical competence of pre-service mathematics teachers. The findings also show that students generally experience challenges in conceptual, procedural, and computational aspects when learning differential equations. Through the Design-Based Research (DBR) approach using the Plomp development model covering the stages of preliminary study, prototype development, and assessment the resulting e-module demonstrated strong validation across material, language, and media components. Trial implementation indicated noticeable improvements in students' understanding, with the e-module showing an effective level of support for learning. The aspects of implementation quality and the integration of TPACK emerged as the most prominent strengths.

Overall, the TPACK-based e-module for differential equations is proven to integrate technology, pedagogy, and content in a coherent and synergistic manner, support deeper conceptual and procedural comprehension, and reinforce the pedagogical competence of pre-service mathematics teachers, thereby enabling them to facilitate technology-enhanced learning more effectively and innovatively. For future research, it is recommended that researchers explore the implementation of this e-module in boarder contexts, including different student populations and educational levels, and evaluate its effectiveness using diverse assessment methods. Stakeholders, such aas curruculum developers and tacher educators, are encouraged to adopt and adapt the e-module to enchance techlology integrated teaching practices across various learning environments.

Acknowledgments

The authors express deep gratitude for the financial support provided through the Fundamental Research Scheme from the Ministry of Education, Culture, Research, and Technology. This funding played a crucial role in supporting the implementation of this study, including experimental activities, data collection, and the development of scientific knowledge in the field of Mathematics Education. The authors also convey sincere appreciation for the support and facilities provided by the Ministry, which enabled this study to be successfully implemented and completed.

Declarations

Author Contribution	: IM: Conceptualization, Formal analysis, Writing - original draft, and Writing - review & editing; NSS: Formal analysis, and Writing - review & editing; AS: Methodology, and Validation; HA: Investigation; ISW: Supervision, and Validation; RM: Data curation, and Software; H: Visualization.
Funding Statement	: This research was funded by the Director General of Strengthening Research and Development with the Ministry of Research, Technology and Higher Education of the Republic of Indonesia for supporting and funding this research in 2025.
Conflict of Interest	: The authors declare no conflict of interest.
Additional Information	: Additional information is available for this paper.

REFERENCES

Aisha, B., Abedalaziz, N. A. M., Ahmad, M., & Satti, U. (2018). Factors affecting differential equation problem solving ability of students at pre-university level: A conceptual model. *MOJES: Malaysian Online Journal of Educational Sciences*, *5*(4), 13–24.

Alyusfitri, R., Gistituati, N., Yerizon, Y., Fauzan, A., & Yarman, Y. (2024). The effectiveness and relationship of student responses toward learning outcomes using interactive multimedia-based e-modules in elementary schools. *International Electronic Journal of Elementary Education*, *16*(5), 573–584. https://doi.org/10.26822/iejee.2024.354

Asmara, A. S., Waluya, S. B., Suyitno, H., Junaedi, I., & Ardiyanti, Y. (2024). Developing patterns of students' mathematical literacy processes: Insights from cognitive load theory and design-based research. *Infinity Journal*, *13*(1), 197–214. https://doi.org/10.22460/infinity.v13i1.p197-214

Bibi, A., Ahmad, M., Shahid, W., Zamri, S. N. S., & Abedalaziz, N. A. M. (2019). An evolving research to tackle teaching and learning challenges during differential equations course: A combination of non-routine problems and teacher training. *International Electronic Journal of Mathematics Education*, *15*(1), 647–656. https://doi.org/10.29333/iejme/5777

Falloon, G. (2020). From digital literacy to digital competence: the teacher digital competency (TDC) framework. *Educational Technology Research and Development*, *68*(5), 2449–2472. https://doi.org/10.1007/s11423-020-09767-4

Farlina, E., Rachmawati, T. K., Ariany, R. L., Widiastuti A, T. T., & Sobarningsih, N. (2018). Ordinary differential equations: students' difficulty in solve the algorithm of the initial value problem with the integrating factor method. *IOP Conference Series: Materials Science and Engineering*, *434*(1), 012010. https://doi.org/10.1088/1757-899x/434/1/012010

Fralish, Z. D., Hallmark, N., & Marshall, J. (2021). Using differential equations to model phoretic parasitism as part of SCUDEM challenge. *International Electronic Journal of Mathematics Education*, *16*(2), em0631. https://doi.org/10.29333/iejme/10889

Guo, W. (2021). The Laplace transform as an alternative general method for solving linear ordinary differential equations. *STEM Education*, *1*(4), 309–329. https://doi.org/10.3934/steme.2021020

Guo, W. (2024). Special tutorials to support pre-service mathematics teachers learning differential equations and mathematical modelling. *European Journal of Science and Mathematics Education*, *12*(1), 71–84. https://doi.org/10.30935/scimath/13831

Harisman, Y., Noto, M. S., & Hidayat, W. (2020). Experience student background and their behavior in problem solving. *Infinity Journal*, *9*(1), 59–68. https://doi.org/10.22460/infinity.v9i1.p59-68

Harisman, Y., Noto, M. S., & Hidayat, W. (2021). Investigation of students' behavior in mathematical problem solving. *Infinity Journal*, *10*(2), 235–258. https://doi.org/10.22460/infinity.v10i2.p235-258

Haryonik, Y., & Bhakti, Y. B. (2018). Pengembangan bahan ajar lembar kerja siswa dengan pendekatan matematika realistik [Development of student worksheet teaching materials with a realistic mathematics approach]. *MaPan*, *6*(1), 40–55. https://doi.org/10.24252/mapan.2018v6n1a5

Hidayat, W., & Aripin, U. (2023). How to develop an e-LKPD with a scientific approach to achieving students' mathematical communication abilities? *Infinity Journal*, *12*(1), 85–100. https://doi.org/10.22460/infinity.v12i1.p85-100

Hidayat, W., Aripin, U., & Widodo, S. A. (2025). Integration of ethno-modelling and 3N: An innovative digital worksheet framework to enhance students' mathematical critical thinking skills. *Infinity Journal*, *14*(4), 1019–1042. https://doi.org/10.22460/infinity.v14i4.p1019-1042

Istunıngsıh, W., Baedhowı, B., & Sangka, K. B. (2018). The effectiveness of scientific approach using e-module based on learning cycle 7E to improve students' learning outcome. *International Journal of Educational Research Review*, *3*(3), 75–85. https://doi.org/10.24331/ijere.449313

Johnson, P., Almuna, F., & Silva, M. (2022). The role of problem context familiarity in modelling first-order ordinary differential equations. *Journal on Mathematics Education*, *13*(2), 323–336. https://doi.org/10.22342/jme.v13i2.pp323-336

Kamal, M. (2020). Research and development (R&D) tadribat/drill madrasah aliyah class x teaching materials arabic language. *Santhet (Jurnal Sejarah Pendidikan Dan Humaniora)*, *4*(1), 10–18.

Kurniansyah, M. Y., Hidayat, W., & Rohaeti, E. E. (2022). Development of combined module using contextual scientific approach to enhance students' cognitive and affective. *Infinity Journal*, *11*(2), 349–366. https://doi.org/10.22460/infinity.v11i2.p349-366

López-Reyes, L. J. (2022). Collaborative learning of differential equations by numerical simulation. *World Journal on Educational Technology: Current Issues*, *14*(1), 56–63. https://doi.org/10.18844/wjet.v14i1.6637

Makamure, C., & Jojo, Z. M. (2022). An analysis of errors for pre-service teachers in first order ordinary differential equations. *Eurasia Journal of Mathematics, Science and Technology Education*, *18*(6), em2117. https://doi.org/10.29333/ejmste/12074

Mariscal, L. L., Albarracin, M. R., Mobo, F. D., & Cutillas, A. L. (2023). Pedagogical competence towards technology-driven instruction on basic education. *International Journal of Multidisciplinary: Applied Business and Education Research*, *4*(5), 1567–1580. https://doi.org/10.11594/ijmaber.04.05.18

Meika, I., Sartika, N. S., Sujana, A., Jarinah, J., Hakim, Z., Windiarti, I. S., & Hendra, H. (2025). E-didactics design of differential calculus based on TPACK to overcome learning obstacles for mathematics pre-service teachers. *Infinity Journal*, *14*(3), 733–752. https://doi.org/10.22460/infinity.v14i3.p733-752

Meika, I., Solikhah, E. F. F., & Yunitasari, I. (2023). Pengembangan bahan ajar materi trigonometri melalui pendekatan realistic mathematics education [Development of trigonometry teaching materials through a realistic mathematics education approach]. *SJME (Supremum Journal of Mathematics Education)*, *7*(1), 93–106. https://doi.org/10.35706/sjme.v7i1.7190

Meika, I., & Sujana, A. (2026). Analysis of differential equation misconceptions among pre-service mathematics teachers. *SJME (Supremum Journal of Mathematics Education)*, *10*(1), 167–180. https://doi.org/10.35706/sjme.v10i1.13319

Mobo, F. D., & Rahmat, A. (2021). The impact of video conferencing platform in all educational sectors amidst COVID-19 pandemic. *Aksara: Jurnal Ilmu Pendidikan Nonformal*, *7*(1), 15–17. https://doi.org/10.37905/aksara.7.1.15-18.2021

Msomi, A. M., & Bansilal, S. (2022). Analysis of students' errors and misconceptions in solving linear ordinary differential equations using the method of Laplace transform. *International Electronic Journal of Mathematics Education*, *17*(1), em0670. https://doi.org/10.29333/iejme/11474

Musyrifah, E., Dahlan, J. A., Cahya, E., & Hafiz, M. (2022). Analisis learning obstacles mahasiswa calon guru matematika pada konsep turunan [Analysis of learning obstacles for prospective mathematics teacher students on the concept of derivatives]. *FIBONACCI: Jurnal Pendidikan Matematika Dan Matematika*, *8*(2), 187–196. https://doi.org/10.24853/fbc.8.2.187-196

Muthohir, M. (2019). Perancangan media promosi produk unggulan UKM Kendal berbasis web dengan metode R&D [Designing web-based promotional media for superior products of Kendal SMEs using the R&D method]. *Pixel: Jurnal Ilmiah Komputer Grafis*, *12*(2), 13–20.

Nindiasari, H., Pranata, M. F., Sukirwan, S., Sugiman, S., Fathurrohman, M., Ruhimat, A., & Yuhana, Y. (2024). The use of augmented reality to improve students' geometry concept problem-solving skills through the STEAM approach. *Infinity Journal*, *13*(1), 119–138. https://doi.org/10.22460/infinity.v13i1.p119-138

Nurhasanah, F., Sumarni, S., & Riyadi, M. (2022). Pengembangan e-modul materi barisan dan deret untuk memfasilitasi kemampuan pemecahan masalah matematis [Development of e-modules on sequences and series to facilitate mathematical problem-solving skills]. *SIGMA*, *14*(2), 104–117.

Ogueda-Oliva, A., & Seshaiyer, P. (2024). Literate programming for motivating and teaching neural network-based approaches to solve differential equations. *International Journal of Mathematical Education in Science and Technology*, *55*(2), 509–542. https://doi.org/10.1080/0020739x.2023.2249901

Puspita, E., Suryadi, D., & Rosjanuardi, R. (2023). The effectiveness of didactic designs for solutions to learning-obstacle problems for prospective mathematics teacher students: Case studies on higher-level derivative concepts. *Mathematics Teaching Research Journal*, *15*(3), 5–18.

Putri, M. A. N., & Dwikoranto, D. (2022). Implementation of STEM integrated project based learning (PjBL) to improve problem solving skills. *Berkala Ilmiah Pendidikan Fisika*, *10*(1), 97–106. https://doi.org/10.20527/bipf.v10i1.12231

Sahrudin, A., Pamungkas, A. S., Pagiling, S. L., & Rosdianwinata, E. (2025). Integration of abstraction theory and TPACK framework in geometry learning to optimize prospective mathematics teachers’ spatial abilities. *Infinity Journal*, *14*(4), 899–918. https://doi.org/10.22460/infinity.v14i4.p899-918

Sakinah, E., Darwan, D., & Haqq, A. A. (2019). Desain didaktis materi trigonometri dalam upaya meminimalisir hambatan belajar siswa [Didactic design of trigonometry material in an effort to minimize student learning obstacles]. *Suska Journal of Mathematics Education*, *5*(2), 121–130. https://doi.org/10.24014/sjme.v5i2.7421

Santos, J. M., & Castro, R. D. R. (2021). Technological pedagogical content knowledge (TPACK) in action: Application of learning in the classroom by pre-service teachers (PST). *Social Sciences & Humanities Open*, *3*(1), 100110. https://doi.org/10.1016/j.ssaho.2021.100110

Sulistiawati, S., Suryadi, D., & Fatimah, S. (2015). Desain didaktis penalaran matematis untuk mengatasi kesulitan belajar siswa SMP pada luas dan volume limas [Didactic design of mathematical reasoning to overcome learning difficulties of junior high school students on the area and volume of pyramids]. *Kreano, Jurnal Matematika Kreatif-Inovatif*, *6*(2), 135–146. https://doi.org/10.15294/kreano.v6i2.4833

Supriyadi, E., Turmudi, T., Dahlan, J. A., & Juandi, D. (2024). Development of Sundanese gamelan ethnomathematics e-module for junior high school mathematics learning. *Malaysian Journal of Learning and Instruction*, *21*(2), 139–178. https://doi.org/10.32890/mjli2024.21.2.6

Taopan, L. L., Drajati, N. A., & Sumardi, S. (2020). TPACK framework: Challenges and opportunities in EFL classrooms. *Research and Innovation in Language Learning*, *3*(1), 1–22. https://doi.org/10.33603/rill.v3i1.2763

Toh, T. L., Toh, P. C., Teo, K. M., & Zhu, Y. (2022). On pre-service teachers' content knowledge of school calculus: An exploratory study. *European Journal of Mathematics and Science Education*, *3*(2), 91–103. https://doi.org/10.12973/ejmse.3.2.91

Toshtemirovich, R. Z. (2019). Development of professional competence of educator. *European Journal of Research and Reflection in Educational Sciences*, *7*(10), 99–106.

Vajravelu, K. (2018). Innovative strategies for learning and teaching of large differential equations classes. *International Electronic Journal of Mathematics Education*, *13*(2), 91–95. https://doi.org/10.12973/iejme/2699

Vathanophas, V., & Thai-ngam, J. (2007). Competency Requirements for Effective Job Performance in Thai Public Sector. *Contemporary Management Research*, *3*(1), 45–70. https://doi.org/10.7903/cmr.49

Yarman, Y., Murni, D., & Tasman, F. (2025). Implementation of SOLO taxonomy and Newman error analysis in first-order differential equation. *Infinity Journal*, *14*(3), 695–710. https://doi.org/10.22460/infinity.v14i3.p695-710

Yazmin, P. F., & Amini, R. (2023). Pengembangan E-LKPD berbasis problem based learning menggunakan book creator di kelas V sekolah dasar [Development of E-LKPD based on problem based learning using book creator in grade V of elementary school]. *Jurnal Elementaria Edukasia*, *6*(2), 518–528. https://doi.org/10.31949/jee.v6i2.5378