(JIML) JOURNAL OF INNOVATIVE MATHEMATICS LEARNING
Volume 9, No. 2, June 2026
P-ISSN 2621-4733
E-ISSN 2621-4741
https://dx.doi.org/10.22460/jiml.v9i2.p30746

ANALYSIS OF PROSPECTIVE MATHEMATICS TEACHERS DIFFICULTIES ON LEARNING CALCULUS

Sri Ulfah Afriani[1], Andi Mangaraja[2], Rama Nida Siregar[3]

[1]UIN Syahada Padangsidimpuan, Jl. T. Rizal Nurdin, Km. 4,5 Sihitang, Padangsidimpuan, Indonesia.
afrianisriulfah@gmail.com
[2]UIN Syahada Padangsidimpuan, Jl. T. Rizal Nurdin, Km. 4,5 Sihitang, Padangsidimpuan, Indonesia.
andimangaraja22@gmail.com
[3]UIN Syahada Padangsidimpuan, Jl. T. Rizal Nurdin, Km. 4,5 Sihitang, Padangsidimpuan, Indonesia.
ramanidasiregar575@uinsyahada.ac.id

ARTICLE INFO

Article history:

Received Dec 25, 2025
Revised Dec 28, 2025
Accepted Jun 02, 2026

Keywords:

Calculus
Learning Difficulties
Mathematics Teachers
Prospective Teachers

ABSTRACT

Calculus is a fundamental subject in mathematics education, yet it poses significant challenges for students, particularly prospective mathematics teachers. This study aims to analyze the difficulties faced by seventh-semester mathematics education students at the South Tapanuli Institute of Education in learning calculus, focusing on both cognitive and affective factors. Using a descriptive qualitative approach, data were collected via an online questionnaire distributed to five students who had completed a calculus course. The questionnaire investigated conceptual, procedural, and representational difficulties, as well as factors such as anxiety and inadequate academic support. The results revealed that students struggled most with conceptual understanding, particularly in limits, derivatives, and integrals, and with applying calculus rules in problem-solving. Representation difficulties were also noted, especially in connecting algebraic expressions with graphical interpretations. Contributing factors included insufficient mastery of prerequisite mathematical concepts, limited exposure to visual learning tools, and high levels of anxiety related to calculus. The study concludes that students' difficulties are not merely the result of the inherent complexity of calculus, but are also influenced by cognitive and emotional barriers. Recommendations include the integration of visual media and interactive tools, alongside improved instructional strategies and support systems to enhance students' conceptual understanding and reduce anxiety. The findings contribute to the development of more effective calculus teaching strategies in teacher education.

Copyright © 2026 IKIP Siliwangi.
All rights reserved.

Corresponding Author:

Sri Ulfah Afriani,
Masters Program in Mathematics Education,
UIN Syekh Ali Hasan Ahmad Addary Padangsidimpuan,
Jl. T. Rizal Nurdin, Km. 4,5 Sihitang, Padangsidimpuan, Indonesia
Email: afrianisriulfah@gmail.com

How to Cite:

Afriani, S. U., Mangaraja, A., & Siregar, R. N. (2026). Analysis of Prospective Mathematics Teachers Difficulties on Learning Calculus. *JIML*, 9(2), 457-470.

INTRODUCTION

Calculus is a fundamental discipline in mathematics education, serving as the cornerstone for advanced mathematical studies and real-world applications in fields such as engineering, economics, physics, and technology. Its concepts limits, derivatives, and integrals are not only central to understanding the dynamics of continuous change but are also crucial for the development of pedagogical content knowledge for prospective mathematics teachers. A deep

understanding of calculus allows future educators to teach these complex ideas effectively, connect abstract mathematical concepts to real-life applications, and address students' misconceptions (Capraro et al., 2005; Nortvedt & Siqveland, 2019; Sonnert et al., 2015; Toh, 2022). Despite its importance, learning calculus poses significant challenges for many students, especially prospective mathematics teachers.

Calculus is a cornerstone of undergraduate mathematics education, serving as a fundamental framework for understanding change, continuity, and accumulation in mathematical, scientific, and technological contexts. Concepts such as limits, derivatives, and integrals are not only essential for advanced mathematical studies but also play a critical role in modeling real-world phenomena across disciplines including physics, engineering, economics, and education. For students enrolled in mathematics education programs, calculus holds an even more strategic position, as mastery of its concepts contributes directly to the development of pedagogical content knowledge required for effective mathematics instruction (Capraro et al., 2005; Nortvedt & Siqveland, 2019; Sonnert et al., 2015; Toh, 2022).

In the context of Indonesia, particularly at the South Tapanuli Institute of Education, the learning of calculus remains a major hurdle for students, with persistent difficulties observed even at the tertiary level. International research has highlighted high failure rates and difficulties in mastering calculus, often due to the subject's abstract nature, which requires students to conceptualize non-observable processes such as infinitesimal quantities and dynamic change students (Dibbs, 2019; Ellis et al., 2014; Eng et al., 2013; Treisman, 1992). In Indonesia, these challenges are compounded by insufficient academic support, limited learning resources, and a lack of interactive instructional tools, which hinder students' engagement and mastery of the material.

One major source of difficulty in learning calculus lies in the abstract nature of its concepts. Unlike elementary mathematics, calculus requires students to reason about dynamic processes, infinitesimal quantities, and limiting behavior, which are not directly observable. And emphasize that many students develop a fragile concept image of calculus concepts that is inconsistent with formal definitions, particularly in the case of limits and continuity (Menares-Espinoza et al., 2025; Moreno-Armella, 2021; Özbey & Dost, 2023; Tall & Katz, 2014). As a result, students often rely on intuitive or procedural reasoning that fails when confronted with non-routine problems.

From a theoretical perspective, students' difficulties in calculus can be understood through the distinction between conceptual and procedural knowledge. Conceptual knowledge refers to an integrated understanding of mathematical ideas and the relationships among them, whereas procedural knowledge involves the ability to carry out mathematical procedures and algorithms (Mohamed Elsayed, 2022; Wu & Yang, 2022). Numerous studies have shown that students tend to prioritize procedural fluency over conceptual understanding in calculus learning, leading to instrumental understanding rather than relational understanding (Skemp, 1976). This imbalance causes students to apply differentiation and integration rules mechanically without comprehending their underlying meanings.

In addition to conceptual and procedural challenges, representational competence plays a critical role in calculus learning. Duval (2006) argues that mathematical understanding requires the ability to coordinate multiple semiotic representations, such as symbolic expressions, graphs, tables, and verbal descriptions. In calculus, students are frequently required to translate between algebraic formulas and graphical representations to interpret rates of change, areas under curves, and functional behavior. However, research indicates that many students struggle to make these connections, resulting in fragmented understanding and misinterpretation of calculus concepts (Pier, Stolzenberg, & Tallman, 2017).

Beyond cognitive dimensions, affective factors also significantly influence students' success in learning calculus. Mathematics anxiety, fear of failure, and low self-confidence have been identified as barriers that hinder students' engagement and persistence when facing complex mathematical tasks (Ashcraft & Krause, 2007). These affective challenges are particularly evident in calculus courses, which are often perceived as intimidating and demanding. Students who experience repeated failure or confusion may develop negative attitudes toward calculus, leading to avoidance behaviors and reduced learning opportunities.

In response to these challenges, various instructional approaches have been proposed and implemented in calculus education. Technology-enhanced learning environments, such as dynamic visualization software and graphing tools, have been shown to support students' understanding of abstract concepts by providing visual and interactive representations (Zengin, Furkan, & Kutluca, 2012). Other studies advocate the use of contextual and applied problems to bridge the gap between formal calculus concepts and real-world applications, thereby increasing students' conceptual understanding and motivation. Active learning strategies, including problem-based learning, flipped classrooms, and collaborative learning, have also demonstrated positive effects on student engagement and achievement.

Despite these advancements, a critical limitation of existing research lies in its predominant focus on evaluating the effectiveness of specific instructional interventions. While such studies provide valuable insights into "what works" in calculus teaching, they often overlook the importance of conducting a thorough diagnostic analysis of students' learning difficulties prior to instructional redesign. Without a clear understanding of the types and sources of difficulties experienced by students, instructional innovations may fail to address the root causes of learning problems.

Moreover, much of the existing literature emphasizes cognitive dimensions of calculus learning while giving limited attention to the interplay between cognitive and affective factors. Few studies systematically examine how conceptual, procedural, and representational difficulties coexist with affective challenges such as anxiety and lack of persistence. In addition, empirical research conducted in smaller teacher education institutions and localized educational contexts remains underrepresented in international journals. These contexts may present unique challenges related to limited learning resources, instructional practices, and academic support systems, which are not adequately captured in studies conducted at large or well-resourced universities.

Addressing these gaps, the present study adopts a descriptive qualitative approach to provide a comprehensive analysis of calculus learning difficulties among mathematics education students. The novelty of this research lies in its integrated analytical framework, which simultaneously examines conceptual, procedural, and representational difficulties alongside contributing cognitive and affective factors within a teacher education context. Rather than evaluating a specific instructional intervention, this study focuses on diagnosing the nature and sources of students' difficulties as a foundation for future pedagogical improvement.

However, the existing body of research has largely focused on cognitive difficulties in calculus, often neglecting the role of affective factors such as mathematics anxiety and lack of confidence. Moreover, studies examining the specific challenges faced by mathematics education students, especially in smaller institutions, are scarce. To bridge this gap, this study adopts a descriptive qualitative approach to analyze the difficulties faced by prospective mathematics teachers in learning calculus. By exploring both cognitive and affective dimensions of learning difficulties, this research aims to provide a comprehensive understanding of the factors that hinder calculus learning. The findings will contribute to the

development of more effective instructional strategies, support systems, and professional development programs for future mathematics educators.

METHOD

This study used a descriptive qualitative research design to explore the difficulties faced by prospective mathematics teachers in learning calculus. A qualitative approach was chosen because the aim of the research was to describe and interpret the students' learning experiences and identify the factors contributing to these difficulties, rather than testing hypotheses or evaluating interventions. The research design focused on capturing the participants' perspectives on learning calculus through a survey method.

The participants in this study consisted of five seventh-semester students enrolled in the Mathematics Education Program at the South Tapanuli Institute of Education. These students were selected using purposive sampling based on the criterion that they had completed the calculus course, ensuring they had sufficient exposure to key concepts such as limits, derivatives, and integrals. Data were collected using a questionnaire developed based on relevant literature on calculus learning difficulties. The instrument included both closed-ended and open-ended items designed to explore conceptual and procedural difficulties, representational and visualization difficulties, and contributing factors encompassing cognitive and affective aspects. Conceptual and procedural indicators focused on students' understanding of fundamental calculus concepts and their ability to apply calculus rules accurately, while representational indicators examined students' ability to connect symbolic expressions with graphical representations.

To collect data, a structured online questionnaire was developed and distributed via Google Forms. The questionnaire included both closed-ended and open-ended questions designed to investigate the students' difficulties in three key areas: conceptual understanding (e.g., limits, derivatives, and integrals), procedural challenges (e.g., applying rules and methods), and representational difficulties (e.g., connecting algebraic expressions with graphical representations). Additionally, the questionnaire explored contributing cognitive and affective factors, such as students' anxiety levels and perceived difficulties.

The data collection process involved the following steps:

1. Developing and reviewing the research instrument to ensure clarity and alignment with the research objectives.
2. Distributing the online questionnaire to the selected participants.
3. Allowing the participants sufficient time to complete the questionnaire independently.
4. Collecting the responses digitally via Google Forms for easy organization and storage.

Data analysis followed a step-by-step approach:

1. Organizing and categorizing the responses according to predefined indicators related to conceptual, procedural, and representational difficulties.
2. Coding the responses to identify recurring patterns and themes within the data.
3. Using descriptive qualitative techniques to interpret the findings and provide insights into the underlying cognitive and affective factors contributing to students' difficulties.

This analysis aimed to offer a comprehensive understanding of the challenges faced by prospective mathematics teachers in learning calculus and to provide a basis for potential improvements in teaching strategies and academic support.

RESULTS AND DISCUSSION

Results

This study involved fifth-semester Mathematics Education students at the Institut Pendidikan Tapanuli Selatan. Five respondents participated by completing a structured questionnaire distributed via a Google Sheets link (https://docs.google.com/spreadsheets/d/1KvdeUwxYt-QBjPnnBC1gGmzJikQK_l2aUM_5dpzLWZQ/edit), which was complemented by students' written responses as qualitative documentation. The integration of these two data sources was used to ensure data triangulation and to strengthen the validity of the findings in addressing the research objectives, namely identifying students' difficulties in learning calculus, determining their causal factors, and formulating possible strategies or solutions to overcome them.

The analysis of the spreadsheet data revealed a consistent pattern of learning difficulties across all respondents, particularly in conceptual and procedural understanding, representation and visualization skills, and affective aspects of learning.

1. Types of Difficulties in Learning Calculus

Berdasarkan hasil angket dan jawaban tertulis mahasiswa, ditemukan dua kategori utama kesulitan, yaitu:

a. Conceptual and Procedural Difficulties

Students consistently reported difficulties in understanding fundamental calculus concepts. Based on their written responses (see student documentation), they experienced challenges in:

1) Understanding the conceptual boundaries within calculus topics,
2) Limited comprehension of integral concepts,
3) Difficulty applying differentiation rules to complex problems,
4) Inaccuracies in selecting appropriate solution methods for integral problems, and
5) Frequently forgetting procedural steps when solving problems.

The students' responses indicate consistent difficulties in both understanding and applying calculus concepts, particularly in integration and differentiation. One respondent stated:

"I understand the formula, but I do not really understand when and how to use it in different problems, especially in integration."

This statement suggests that students' difficulties are not merely related to memorizing formulas, but rather to their inability to connect concepts with appropriate contexts of use. In other words, their understanding remains procedural and mechanistic without strong conceptual comprehension.

Similarly, another respondent expressed a comparable experience in solving differentiation problems:

"I often forget the steps when doing derivatives, especially when the problems are combined or complex."

This indicates that students struggle to maintain procedural sequences when dealing with multi-concept or complex problems. The complexity of the questions leads to confusion in solution steps, showing that procedures have not been deeply internalized.

In addition, other written responses revealed that students often feel uncertain when determining the correct solution method, especially when problems are presented in forms

that differ from previously learned examples. This reinforces the finding that students tend to rely heavily on familiar problem patterns. When variations appear, they face difficulties in adapting their problem-solving strategies.

Overall, these findings indicate that students' difficulties are not limited to procedural aspects such as forgetting steps, but are rooted in weak conceptual understanding. The inability to connect concepts, formulas, and problem contexts results in difficulties in developing flexible and adaptive problem-solving strategies in calculus.

b. Representation and Visualization Difficulties

Another difficulty identified in this study is students' low ability to represent and visualize calculus concepts, particularly in connecting algebraic expressions with their graphical representations. Based on the questionnaire results, written responses, and brief interviews, most students indicated that they had not yet been able to construct a coherent understanding across different mathematical representations, such as symbolic, graphical, and verbal forms.

More specifically, students reported several key challenges: (1) difficulty in interpreting calculus formulas or expressions into appropriate graphical forms, (2) limitations in visualizing function changes during differentiation and integration processes, and (3) an inability to conceptually link symbolic (algebraic) representations with graphical representations. These findings suggest that students' understanding tends to remain procedural rather than conceptual and visual.

In addition, many students admitted that they only understood the computational steps mathematically without truly grasping the geometric or visual meaning of the operations. This is reflected in one student's statement:

"I cannot imagine how the graph changes when a function is differentiated or integrated."

This statement indicates that the transformation of functions in calculus has not yet been fully internalized as a visual concept within students' cognitive structures. As a result, students struggle to interpret changes in graphical forms, such as the slope of a tangent line in differentiation or the area under a curve in integration.

These findings confirm that mathematical representation skills, particularly in graphical visualization within calculus topics, remain relatively low among prospective mathematics teachers. This condition indicates that calculus instruction at the university level needs to be strengthened through approaches that emphasize connections among multiple representations, such as the use of visual media, mathematical software, and problem-based learning approaches that encourage students to construct deeper conceptual understanding.

2. Factors Causing Learning Difficulties

The synthesis of questionnaire data and students' written responses indicates that difficulties in learning calculus are not caused by a single factor, but rather result from the interaction of multiple interrelated aspects. These factors can be categorized into cognitive factors, affective factors, and instructional as well as learning environment factors.

a. Cognitive factors

From a cognitive perspective, the main difficulty experienced by students lies in their weak mastery of fundamental calculus concepts, which serve as the foundation for understanding more advanced topics. Many students have not yet developed a strong understanding of core concepts such as limits, derivatives, and integrals, which leads to difficulties when they are required to engage in higher-order reasoning tasks. In addition,

it was found that some students still lack adequate mastery of prerequisite knowledge, particularly in algebra, functions, and symbolic manipulation.

This condition is further aggravated by students' negative perceptions of calculus. A number of students already perceive calculus as a difficult subject from the beginning of instruction. Such perceptions may affect their cognitive readiness to engage with new material and hinder the development of deeper conceptual understanding.

b. Affective factors

From an affective perspective, emotional and psychological factors also play a significant role in influencing students' learning difficulties. Many students experience anxiety when dealing with calculus problems, which in turn reduces their ability to think calmly and systematically. Fear of failure and low self-confidence are also dominant barriers in the problem-solving process in mathematics.

In addition, there is a tendency for students to give up easily when facing difficulties, especially when dealing with complex problems or those requiring multiple solution steps. This indicates that students' motivation and learning persistence (grit) still need to be strengthened.

This condition is reflected in one student's statement:

"I feel afraid when I see calculus problems because I think I will not be able to solve them."

This statement indicates that psychological factors, particularly mathematics anxiety, directly contribute to students' low academic performance in calculus courses.

c. Instructional and environmental factors

In addition to internal factors, learning difficulties are also influenced by external factors related to the instructional process and the academic learning environment. This study found that the use of visual media in calculus instruction is still limited, resulting in students having fewer concrete experiences in understanding abstract calculus concepts.

Furthermore, academic support services such as tutoring, which are expected to assist students experiencing learning difficulties, are not yet optimal. The lack of additional learning resources beyond textbooks also causes students to rely heavily on materials provided solely by lecturers during classroom instruction.

On the other hand, teaching methods that are still predominantly teacher-centered also contribute to limited student engagement in the knowledge construction process. This condition leads to a one-way learning environment, where students have fewer opportunities to actively explore and develop concepts independently.

Overall, these findings indicate that difficulties in learning calculus do not only stem from internal student factors, but are also strongly influenced by the quality of the learning environment and the instructional strategies employed.

3. Strategies for Overcoming Difficulties in Learning Calculus

Based on the analysis of students' responses from both research instruments, namely questionnaires and written responses, several strategies were identified as effective for overcoming difficulties in learning calculus. These strategies reflect students' need for more meaningful, contextualized learning supported by interactive media and innovative instructional approaches.

First, students emphasized the importance of providing calculus textbooks or learning materials that are simpler, more systematic, and easier to understand. Highly theoretical and complex textbooks were considered to hinder students' understanding of fundamental concepts; therefore, learning resources should be more communicative and accompanied by practical examples.

Second, students suggested that calculus concepts should be more frequently connected to real-life phenomena. This contextual approach is believed to help students understand abstract concepts such as derivatives and integrals in more concrete situations, making learning more meaningful and less procedural.

Third, the use of visual media and educational technology was strongly highlighted as a key strategy. Students recommended the use of applications such as GeoGebra, interactive animations, and digital simulations to help visualize abstract calculus concepts, particularly function graph changes, gradients, and areas under curves. Visual media are considered highly effective in bridging the gap between symbolic and graphical representations.

Fourth, the implementation of active learning models such as the flipped classroom was also seen as beneficial in enhancing student engagement. With this model, students can independently study basic materials before class, allowing classroom time to be focused on discussion, problem-solving, and deeper conceptual understanding.

Fifth, the provision of contextual problem-solving tasks related to daily life was also suggested as a way to improve students' mathematical problem-solving skills. Such tasks enable students to apply calculus concepts in real-world situations rather than solely in symbolic forms.

Sixth, students highlighted the importance of supporting services such as mathematics laboratories and tutoring programs. These facilities are expected to assist students who experience learning difficulties through more intensive and structured academic support outside regular class hours.

Seventh, training for lecturers in developing innovative, technology-based teaching methods is considered essential. This is important to ensure that calculus instruction is not solely lecture-centered, but also incorporates more interactive and visual approaches.

One student explicitly stated the importance of technology in calculus learning:

"Learning would be easier if graphs could be directly visualized using software like GeoGebra, rather than only being imagined."

This statement reinforces the finding that technology-based visualization plays a crucial role in helping students understand abstract calculus concepts. Therefore, the combination of contextual approaches, technological integration, and innovative teaching methods constitutes the main strategy for overcoming difficulties in learning calculus.

4. Synthesis of Questionnaire and Written Interview Responses (Triangulation Results)

The integration of data from the questionnaire and students' written responses (documented screenshots) reveals a strong consistency in the findings. Overall, both data sources reinforce each other and illustrate a relatively uniform pattern of calculus learning difficulties among the respondents.

First, students who reported conceptual difficulties in the questionnaire also demonstrated similar confusion in their written responses, particularly when asked to independently explain basic calculus concepts. This indicates that their conceptual understanding remains unstable and underdeveloped.

Second, students who reported anxiety and fear toward calculus in the questionnaire also exhibited hesitation, low confidence, and a tendency to avoid answering questions in their written responses. This condition strengthens the evidence of affective factors influencing their cognitive processes during problem-solving.

Third, students who indicated difficulties in representation were also unable to properly explain graphical interpretations, either verbally or symbolically, in their written responses. This reflects a weak connection between symbolic and visual representations of mathematical concepts.

Overall, the triangulation results indicate that the learning difficulties experienced by students are not incidental or sporadic in nature. Instead, they represent a consistent and systematic pattern that is experienced by most respondents across multiple forms of collected data.

Discussions

This study was conducted to examine the nature of calculus learning difficulties experienced by mathematics education students and to identify the factors underlying these difficulties. Overall, the findings suggest that calculus learning challenges among preservice mathematics teachers are not merely technical or procedural in nature, but reflect deeper conceptual, representational, and affective issues. These results support the view that calculus is a cognitively demanding subject requiring high levels of abstraction, conceptual integration, and metacognitive control (Zandieh, M., 2000). Consequently, student learning outcomes are strongly influenced by how instructional practices facilitate conceptual understanding rather than procedural memorization.

The predominance of conceptual and procedural difficulties suggests that student challenges stem from incomplete conceptual understanding rather than isolated computational errors. Calculus concepts such as limits, derivatives, and integrals require students to coordinate abstract reasoning with procedural fluency. When conceptual understanding is weak, procedural knowledge tends to become fragmented and easily forgotten. This interpretation is consistent with previous studies showing that students often apply rules mechanically without understanding their underlying meaning (Hiebert & Grouws, 2006). However, this study extends previous findings by showing that these difficulties persist even in the later stages of undergraduate studies, suggesting that prolonged exposure to calculus content does not automatically lead to conceptual internalization (Tall, 2008).

The identification of representational and visualization difficulties highlights the inherent complexity of calculus learning, particularly as students struggle to connect symbolic expressions with graphical representations, thereby limiting their ability to construct geometric meaning. From a cognitive perspective, effective calculus learning requires the coordination of multiple forms of representation—symbolic, graphical, numerical, and verbal—yet such competence does not qɯɲq automatically and instead demands explicit instructional support and carefully designed learning experiences. These findings align with research on Realistic Mathematics Education (RME), which demonstrates that contextual and meaningful learning approaches enhance not only cognitive understanding but also affective dimensions such as self-esteem. Limited representational ability may negatively influence students' confidence in mathematics, whereas the implementation of RME has been shown to improve self-esteem through positive student responses and strengthened self-perception (Siregar et al., 2022). Therefore, representational difficulties should be understood as both cognitive and affective challenges, suggesting that the development of representational competence must be integrated with efforts to foster students' self-esteem in order to achieve more effective and meaningful calculus learning.

Beyond cognitive aspects, the findings of this study highlight the crucial role of affective factors in shaping students' experiences in learning calculus. Feelings of anxiety, fear, and low self-confidence were found to interact with cognitive difficulties, leading students to lose interest or give up when confronted with challenging calculus problems. These findings are consistent with previous research indicating that mathematics anxiety negatively affects students' problem-solving performance and persistence . Furthermore, this study emphasizes(Laili Nurhidayati, 2024) that the lack of institutional support, such as academic tutoring or structured guidance, can intensify these affective barriers.

These results are further supported by studies on students' difficulties in understanding integral concepts, which reveal that affective challenges—such as anxiety and low self-confidence—significantly hinder students' performance. In addition, dominant conceptual difficulties, particularly in understanding integrals as area and accumulation processes, are closely associated with procedural and representational errors. This confirms that difficulties in learning calculus are multidimensional and involve the interaction of cognitive and affective aspects (Aziz et al., 2025). Therefore, instructional approaches should not only emphasize conceptual reinforcement and the use of multiple representations but also foster a supportive learning environment to reduce anxiety and enhance students' confidence.

Relating to the aims outlined in the Introduction, these findings confirm that calculus learning difficulties among mathematics education students are multifaceted and interrelated. Conceptual, procedural, representational, and affective difficulties do not operate independently; rather, they reinforce each other and collectively shape students' learning experiences. This integrated interpretation provides a more comprehensive explanation of why calculus remains a challenging subject, even for students preparing to become mathematics teachers. Compared with previous studies that often examined these difficulties separately, this study emphasizes the importance of a holistic perspective in understanding students' difficulties in calculus.

In relation to the objectives of this study, the findings confirm that difficulties in learning calculus are multidimensional and interconnected. Conceptual, procedural, representational, and affective difficulties do not operate independently; rather, they reinforce one another in shaping students' learning experiences. This provides a more comprehensive explanation of why calculus remains a challenging subject, even for prospective mathematics teachers.

These findings are further supported by research on students' mathematical understanding of algebraic function derivatives, which indicates generally low levels of understanding, as evidenced by frequent conceptual and procedural errors, particularly in selecting appropriate operations and classifying mathematical objects(Mulyani & Siregar, 2025). This suggests that weaknesses in foundational understanding contribute significantly to students' difficulties in learning calculus. Therefore, students' challenges are not solely due to the inherent complexity of the material but also stem from limitations in integrating multiple aspects of mathematical understanding. Accordingly, more adaptive and targeted instructional strategies are needed to address these difficulties in a comprehensive manner.

This study found that students faced significant difficulties in understanding core calculus concepts, particularly limits, derivatives, and integrals. This aligns with previous studies, such as those by Eko Susilo et al. (2022) and Supriyatin & Syafa'atun (2025), who also identified weak conceptual understanding as a major hurdle for students. However, this study goes further by showing that these difficulties are not limited to early stages of learning but persist into advanced levels, highlighting the need for more thorough conceptual integration throughout the calculus curriculum.

One of the most common difficulties reported in this study was students' inability to apply procedural rules effectively, especially when solving complex derivative and integral problems. This finding is consistent with Ellis et al. (2014), who found that students often rely on mechanical rule application without fully understanding the underlying principles. Similarly, Dibbs (2019) pointed out that procedural challenges are frequently seen in students who focus more on memorizing rules than on gaining a deeper understanding of the material. This study contributes to the discussion by demonstrating that these procedural difficulties are intertwined with conceptual misunderstandings, which affect students' overall performance in calculus.

Representation and visualization difficulties, especially in connecting algebraic expressions with graphical representations, were another prominent challenge identified in this study. These findings corroborate the work of Duval (2006), who emphasized the importance of representational competence in mathematics learning. However, while previous research has mostly focused on secondary education, this study highlights that these difficulties persist even in higher education, particularly among prospective teachers, which suggests that representational skills should be explicitly taught and reinforced throughout the curriculum, rather than assumed to develop automatically as students progress.

Mathematics anxiety was reported as a significant barrier to learning calculus, with students expressing fear and lack of confidence when dealing with complex problems. This aligns with previous studies by Ashcraft & Krause (2007) and Hembree (1990), who found that affective factors such as anxiety significantly hinder students' ability to perform in mathematics, particularly in advanced topics like calculus. While much of the existing literature highlights the impact of anxiety on students' engagement and problem-solving ability, this study adds a new layer by showing how anxiety is compounded by the lack of academic support systems, such as tutoring and mentoring, which further exacerbate students' difficulties.

The findings of this study highlight the absence of adequate academic support services as a major factor contributing to students' difficulties in learning calculus. This is consistent with the findings of Eng et al. (2013), who found that the lack of sufficient academic guidance and support services in some institutions exacerbates students' difficulties in mastering complex subjects like calculus. Furthermore, this study found that students often resorted to avoidance behaviors when facing difficult calculus problems, which suggests that more robust academic support systems are essential in helping students overcome these barriers and persist through challenging material.

The results of this study confirm and expand upon existing research, providing a nuanced understanding of the difficulties prospective mathematics teachers face in learning calculus. While previous studies have emphasized conceptual and procedural difficulties, this research highlights the critical role of representation skills and affective factors such as anxiety. Additionally, the study underscores the need for stronger academic support systems to help students navigate these challenges. By drawing on a localized context, this research adds valuable insights to the broader discourse on calculus education and suggests targeted improvements in instructional strategies, support systems, and teacher preparation programs to address students' difficulties more effectively.

Overall, the discussion suggests that improving calculus learning outcomes requires more than simply revising content delivery or increasing practice opportunities. Effective calculus instruction must prioritize conceptual coherence, encourage the coordinated use of multiple representations, and foster a supportive learning environment that reduces anxiety and encourages persistence (Tall, 2013; Duval, 2006). By situating student difficulties within a broader cognitive-affective framework, this study contributes to a deeper understanding of the challenges of calculus learning in teacher education.

CONCLUSION

This study concludes that the difficulties faced by prospective mathematics teachers in learning calculus are multidimensional, encompassing conceptual, procedural, representational, and affective factors. The findings reveal that these difficulties are not merely a result of computational weaknesses but are deeply rooted in incomplete conceptual understanding and limitations in representational abilities. These challenges persist even after students have completed calculus courses, underscoring the need for a deeper focus on foundational concepts and the ability to represent mathematical ideas across different formats.

The research also emphasizes the interconnection between cognitive and affective dimensions of learning. While much of the existing literature has examined these factors separately, this study highlights how conceptual and procedural difficulties are intertwined with anxiety, lack of confidence, and insufficient academic support. Additionally, the findings suggest that representation and visualization challenges play a crucial role in mediating students' understanding and performance in calculus, an aspect that remains significant even at the university level.

Based on these findings, it is recommended that future calculus instruction place a stronger emphasis on conceptual coherence, the integration of multiple representations (such as symbolic, graphical, and numerical), and the creation of a supportive learning environment to reduce affective barriers such as anxiety. In terms of future research, this study opens several avenues, including studies with larger and more diverse sample sizes, experimental research on effective instructional interventions, and longitudinal studies that explore how students' conceptual understanding and affective responses to calculus evolve over time. Such research will be essential in refining teaching strategies and developing support systems to enhance students' learning experiences in calculus education.

ACKNOWLEDGMENTS

The author expresses sincere appreciation and gratitude to all parties who have played a role in the completion of this research. Special appreciation is extended to the lecturers and academic supervisors for their scientific guidance, methodological direction, and continuous constructive input throughout the research process. The author also expresses gratitude to the seventh-semester students of the Mathematics Education Study Program at the South Tapanuli Institute of Education who have voluntarily participated and contributed very meaningful data through their reflective and sincere responses. Furthermore, appreciation is extended to colleagues and colleagues for their productive academic discussions, technical assistance, and support in the development of research instruments and data analysis. This research was conducted without specific financial support from government, commercial, or non-profit funding institutions.

REFERENCES

Aziz, I. R., Harahap, N. S. R., & Siregar, R. N. (2025). Analysis of Students' Difficulties on Understanding Integral Concepts. *(JIML) JOURNAL OF INNOVATIVE MATHEMATICS LEARNING*, *8*(4), 850–862. https://doi.org/10.22460/jiml.v8i4.30135

Capraro, R. M., Capraro, M. M., Parker, D., Kulm, G., & Raulerson, T. (2005). The mathematics content knowledge role in developing preservice teachers' pedagogical content knowledge. *Journal of Research in Childhood Education*, *20*(2), 102–118. https://doi.org/10.1080/02568540509594555

Dibbs, R. (2019). Forged in failure: Engagement patterns for successful students repeating calculus. *Educational Studies in Mathematics 2019 101:1*, *101*(1), 35–50. https://doi.org/10.1007/S10649-019-9877-0

Ellis, J., Kelton, M. L., & Rasmussen, C. (2014). Student perceptions of pedagogy and associated persistence in calculus. *ZDM 2014 46:4*, *46*(4), 661–673. https://doi.org/10.1007/S11858-014-0577-Z

Eng, T. H., Li, V. L., & Julaihi, N. H. (2013). Lecturers' Perceptions, Students' Problems and Solutions for Handling High-failure Rate Mathematics Courses. *Procedia - Social and Behavioral Sciences*, *90*, 853–861. https://doi.org/10.1016/J.SBSPRO.2013.07.161

Hiebert, J., & Grouws, D. (2006). *The Effects Of Classroom Mathematics Teaching On Students ' Learning*. https://www.semanticscholar.org/paper/THE-EFFECTS-OF-CLASSROOM-MATHEMATICS-TEACHING-ON-%E2%80%99-Hiebert-Grouws/3b2e2aabd07c64bb65408a3891902be4b7277cd6

Laili Nurhidayati. (2024). Kecemasan Matematika (Math Anxiety) Dan Dampaknya Terhadap Prestasi Belajar. *Jurnal Ilmiah IPA Dan Matematika (JIIM)*, *2*(3), 61–66. https://doi.org/10.61116/jiim.v2i3.477

Menares-Espinoza, R., Gaona, J., & Henríquez-Rivas, C. (2025). Pre-service teachers' mathematical work on a calculus task that connects school and university. *Eurasia Journal of Mathematics, Science and Technology Education*, *21*(9), em2702. https://doi.org/10.29333/EJMSTE/16861

Mohamed Elsayed, S. A. (2022). The Effectiveness of Learning Mathematics according to the STEM Approach in Developing the Mathematical Proficiency of Second Graders of the Intermediate School. *Education Research International*, *2022*(1), 5206476. https://doi.org/10.1155/2022/5206476

Moreno-Armella, L. (2021). The theory of calculus for calculus teachers. *ZDM – Mathematics Education 2021 53:3*, *53*(3), 621–633. https://doi.org/10.1007/S11858-021-01222-9

Mulyani, S., & Siregar, R. N. (2025). Analysis of Students' Mathematical Understanding of Derivatives Algebraic Function on Islamic Boarding High School. *(JIML) JOURNAL OF INNOVATIVE MATHEMATICS LEARNING*, *8*(1), 173–187. https://doi.org/10.22460/jiml.v8i1.27159

Nortvedt, G. A., & Siqveland, A. (2019). Are beginning calculus and engineering students adequately prepared for higher education? An assessment of students' basic mathematical knowledge. *International Journal of Mathematical Education in Science and Technology*, *50*(3), 325–343. https://doi.org/10.1080/0020739X.2018.1501826

Özbey, M., & Dost, Ş. (2023). Concept Images of University Students for Geometric Representation of the Double Integral Concept. *Necatibey Faculty of Education Electronic Journal of Science and Mathematics Education*, *17*(1), 66–98. https://doi.org/10.17522/BALIKESIRNEF.1274911

Siregar, R. N., Suryadi, D., Prabawanto, S., & Mujib, A. (2022). Improving Students' Self-Esteem in Learning Mathematics through a Realistic Mathematic Education. *Jurnal Pendidikan MIPA*, *23*(3), 1262–1277. https://doi.org/10.23960/jpmipa/v23i3.pp1262-1277

Sonnert, G., Sadler, P. M., Sadler, S. M., & Bressoud, D. M. (2015). The impact of instructor pedagogy on college calculus students' attitude toward mathematics. *International Journal of Mathematical Education in Science and Technology*, *46*(3), 370–387. https://doi.org/10.1080/0020739X.2014.979898

Tall, D. (2008). The transition to formal thinking in mathematics. *Mathematics Education Research Journal*, *20*(2), 5–24. https://doi.org/10.1007/BF03217474

Tall, D., & Katz, M. (2014). A cognitive analysis of Cauchy's conceptions of function, continuity, limit and infinitesimal, with implications for teaching the calculus. *Educational Studies in Mathematics 2014 86:1*, *86*(1), 97–124. https://doi.org/10.1007/S10649-014-9531-9

Toh, T. L. (2022). Teachers' instructional goals and their alignment to the school mathematics curriculum: A case study of the calculus instructional material from a Singapore Pre-University Institution. *Mathematics Education Research Journal 2022 34:3*, *34*(3), 631–659. https://doi.org/10.1007/S13394-022-00419-9

Treisman, U. (1992). Studying Students Studying Calculus: A Look at the Lives of Minority Mathematics Students in College. *The College Mathematics Journal*, *23*(5), 362–372. https://doi.org/10.1080/07468342.1992.11973486

Wu, W. R., & Yang, K. L. (2022). The relationships between computational and mathematical thinking: A review study on tasks. *Cogent Education*, *9*(1). https://doi.org/10.1080/2331186X.2022.2098929

Zandieh, M. (2000). *A theoretical framework for analyzing student understanding of the concept of derivative | Request PDF*. ResearchGate. https://www.researchgate.net/publication/290852352_A_theoretical_framework_for_analyzing_student_understanding_of_the_concept_of_derivative