
ANALYSIS OF DIFFICULTIES IN UNDERSTANDING CALCULUS CONCEPTS: A CASE OF TEACHERS AND STUDENTS

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ABSTRACT

Calculus is a fundamental component of secondary mathematics education; however, students' conceptual understanding remains limited, particularly in abstract topics such as derivatives and integrals. These challenges are further exacerbated by low engagement and ineffective instructional practices. This study aims to analyze students' difficulties in learning calculus, identify factors influencing their learning interest, and examine teachers' instructional challenges. This study employed a descriptive qualitative approach involving 12 participants, consisting of 10 Grade XII students and 2 mathematics teachers at MAN 2 Padangsidimpuan. Data were collected through semi-structured interviews, classroom observations, and documentation of students' written work. The researcher acted as the primary instrument, supported by interview guidelines and documentation sheets. Data were analyzed using the interactive model of Miles and Huberman, including data reduction, data display, and conclusion drawing. To ensure trustworthiness, source and technique triangulation were applied. The findings indicate that students exhibit a moderate level of learning interest ($\approx 54.6\%$), yet experience significant difficulties in conceptual understanding and mathematical communication, particularly in trigonometric derivatives and integrals. These difficulties are primarily associated with weak prerequisite knowledge, reliance on procedural memorization, and limited use of visual learning media. Additionally, teacher-centered instruction and anxiety-inducing assessment practices contribute to low student engagement. In conclusion, calculus learning difficulties are multidimensional, involving cognitive, affective, and instructional factors. Therefore, a holistic instructional approach integrating conceptual understanding, interactive media, and student-centered strategies is essential to improve learning outcomes.

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INTRODUCTION

Calculus is a fundamental component of the secondary mathematics curriculum, serving as a gateway to advanced studies in disciplines such as engineering, natural sciences, economics, medicine, and computer science. Mastery of core concepts—including limits, derivatives, and

integrals—is essential for developing higher-order thinking skills, particularly analytical reasoning, abstraction, and problem-solving (Hiebert & Grouws, 2006). At the senior high school level, calculus not only functions as a body of knowledge but also as a tool for modeling real-world phenomena, thereby fostering students' mathematical literacy and readiness for higher education. Consequently, a strong conceptual understanding of calculus is crucial for students' academic success and long-term intellectual development (Gr. Voskoglou, 2017).

Despite its importance, empirical evidence indicates that students' understanding of calculus remains problematic both globally and in Indonesia. International assessments such as the Programme for International Student Assessment (PISA) 2022 reveal that Indonesian students scored 366 in mathematics, significantly below the OECD average of 472, indicating limited proficiency in higher-order problem-solving and abstract reasoning (OECD, 2023). Similarly, results from Trends in International Mathematics and Science Study demonstrate that Indonesian students perform at a low level in reasoning and application domains (Mullis, I.V.S. et al., 2019). At the national level, studies consistently report that students perceive mathematics—especially calculus—as difficult, abstract, and disconnected from real-life contexts (Suherman & Vidákovich, 2022).

These findings are consistent with recent research indicating that although students demonstrate relatively strong performance in solving derivative problems of low to moderate difficulty, their performance declines significantly when confronted with more complex tasks, such as those involving root functions and fractional exponents. Common errors include inaccuracies in the simplification process and difficulties in applying advanced differentiation rules, such as the product rule, quotient rule, and chain rule. This suggests that while students' procedural knowledge has been developed through routine practice, their conceptual understanding remains limited. This condition reinforces previous findings that students' low levels of reasoning and problem-solving abilities are not only reflected in international assessments but are also evident in classroom practices, particularly in the context of calculus learning (R. Siregar & Siregar, 2025). Therefore, more innovative instructional approaches are required, with a stronger emphasis on enhancing conceptual understanding and fostering students' critical thinking skills in mathematical problem-solving.

Specifically, in calculus learning, students tend to rely heavily on procedural memorization rather than conceptual understanding. Research shows that while students can execute derivative or integral calculations, they often fail to interpret meanings, connect representations, or apply concepts in contextual problems (Tall, 1993). This issue is also evident in Indonesian classrooms, where students struggle to relate algebraic manipulation to graphical or real-world interpretations (Deswita et al., 2021). Preliminary observations conducted at MAN 2 Padangsidempuan further confirm this condition: a significant number of Grade XII students experience difficulties in understanding limits and integrals, particularly when dealing with non-routine problems. Many students exhibit misconceptions, weak prerequisite knowledge (e.g., algebra and trigonometry), and low engagement during instruction.

In addition to cognitive challenges, affective factors such as students' interest in learning also play a critical role. Learning interest significantly influences motivation, persistence, and depth of understanding (Santrock, 2009). However, calculus is often perceived as complex and intimidating, leading to reduced engagement and passive learning behavior. As a result, students are less likely to actively construct knowledge or explore alternative solution strategies, which further limits their conceptual development.

From the instructional perspective, teachers also face considerable challenges in delivering calculus content effectively. Many classrooms still rely on conventional lecture-based methods with limited use of visualizations, digital tools, or interactive learning media. This is

problematic because calculus concepts are inherently abstract and require multiple representations (symbolic, graphical, and numerical) to be fully understood (Zandieh, M., 2000). Studies indicate that the lack of instructional innovation and limited technological integration contribute to students' learning difficulties (Noverianto et al., 2024). Observations at MAN 2 Padangsidimpuan reveal that teaching practices are predominantly teacher-centered, with minimal use of visual aids such as graphing software or simulations, which are crucial for enhancing conceptual understanding.

Although numerous studies have investigated students' difficulties in learning calculus, most of them focus primarily on students' cognitive errors or misconceptions (Tall, 1993). Limited research has explored the challenges from both students' and teachers' perspectives simultaneously, particularly within the context of Islamic senior high schools (Madrasah Aliyah Negeri/MAN). This represents a significant research gap, as the learning process is influenced not only by students' internal factors but also by teachers' pedagogical practices, instructional design, and classroom constraints (Lester, 2013). Furthermore, contextual studies in MAN environments remain underrepresented in the literature, despite their unique curricular and socio-cultural characteristics (Haidar, 2025).

The novelty of this study lies in its comprehensive approach, which integrates the analysis of students' learning difficulties and teachers' instructional challenges in calculus. Unlike previous studies that tend to examine these aspects separately, this research provides a more holistic understanding of the teaching–learning process. By examining both perspectives, this study aims to uncover not only the cognitive barriers faced by students but also the pedagogical limitations experienced by teachers, including difficulties in explaining abstract concepts, limited use of instructional media, and students' low prior knowledge.

Given these conditions, this study is urgently needed to provide empirical evidence and practical insights for improving calculus instruction. Therefore, the main objectives of this study are:

1. To analyze students' difficulties in understanding calculus concepts,
2. To identify factors influencing students' interest in learning, and
3. To examine teachers' perspectives on the challenges encountered in teaching calculus.

The findings of this study are expected to contribute to the development of more effective instructional strategies, particularly those that integrate conceptual understanding, student engagement, and the use of appropriate learning media. Ultimately, this research aims to enhance the quality of mathematics education at the secondary school level and support students in achieving meaningful learning outcomes in calculus.

METHOD

This study employed a descriptive qualitative approach to explore in depth students' learning interest and mathematical communication skills in calculus, as well as teachers' perspectives on instructional challenges. A qualitative design was selected because it enables a comprehensive understanding of participants' experiences, perceptions, and difficulties within their natural classroom context (Creswell & Poth, 2018).

The participants of this study consisted of 12 informants, including 10 students of Grade XII IPA-4 and 2 mathematics teachers at MAN 2 Padangsidimpuan. The participants were selected using a purposive sampling technique, based on their involvement in calculus learning and their ability to provide relevant information regarding the research focus (Meleong, 1989). The students represented diverse academic abilities to capture a range of learning experiences.

The primary instrument in this study was the researcher, who functioned as the key instrument in collecting and interpreting qualitative data (Sugiyono, 2019). Supporting instruments included:

1. Semi-structured interview guidelines, used to obtain in-depth information from students and teachers regarding learning interest, conceptual understanding, and mathematical communication skills.
2. Documentation sheets, including students' written work, lesson plans, and classroom records, used to support and validate interview data.

The research was conducted through several systematic stages:

1. Preliminary observation: Identifying initial problems in calculus learning, particularly students' difficulties in understanding derivatives and integrals.
2. Participant selection: Determining students and teachers using purposive sampling based on research criteria.
3. Data collection through interviews: Conducting semi-structured interviews with 10 students and 2 teachers to explore their experiences, difficulties, and perceptions.
4. Documentation collection: Gathering relevant documents such as students' answers and instructional materials to support the findings.
5. Data organization: Classifying and preparing the collected data for analysis.

The data were analyzed using the interactive model of Miles and Huberman (Miles et al., 2014), which consists of three main stages:

1. Data reduction: Selecting, focusing, and simplifying raw data by eliminating irrelevant information to highlight key findings related to students' learning interest and mathematical communication skills.
2. Data display: Organizing the data in the form of narratives and tables to facilitate interpretation.
3. Conclusion drawing and verification: Interpreting the data and drawing conclusions while continuously verifying their validity.

To ensure the trustworthiness of the data, this study applied triangulation techniques, including source triangulation (comparing data from students and teachers) and technique triangulation (comparing interview results with documentation). These procedures were conducted to ensure that the findings accurately reflect the actual learning conditions in Grade XII IPA-4.

RESULTS AND DISCUSSION

Results

Based on data collected through semi-structured interviews, documentation (students' written work), and classroom observations, the findings indicate that students demonstrate a moderate level of learning interest, but still experience significant conceptual and communication difficulties in calculus, particularly in trigonometric derivatives and integrals.

The results are presented through a triangulation approach, integrating data from multiple sources to ensure validity and depth of analysis.

1. Students' Learning Interest in Calculus

a. Documentation Data

Table 1. Students' Learning Interest in Calculus (Class XII IPA-4)

No	Learning Interest Indicator	Percentage
1	Interest in calculus material	62%
2	Readiness to participate in learning	55%
3	Activeness in asking/discussing	48%
4	Seriousness in completing exercises	51%
5	Consistency in learning	57%

The average score ($\approx 54.6\%$) indicates that students' learning interest in calculus is at a moderate level, yet it remains suboptimal. The lowest indicator is observed in active participation (48%), suggesting that students tend to be passive during the learning process. Evidence from semi-structured interviews further reveals that although students demonstrate an emerging interest in learning calculus, this interest is not accompanied by adequate conceptual understanding. For instance, one student stated, "I am actually interested in learning calculus, but when it comes to trigonometric derivatives, I do not know where to start" (S3, personal communication, December 12, 2025), indicating a coexistence of interest and conceptual confusion. Similarly, another student reported, "When the teacher explains, I understand a little, but when I am asked to explain it again, I cannot" (S7, personal communication, December 12, 2025), highlighting that students' understanding remains superficial and insufficiently internalized, particularly in terms of mathematical communication.

No	Aspek/Fokus Wawancara	Pertanyaan	Jawaban
1	Pandangan Umum	Bagaimana pandangan kamu tentang pembelajaran kalkulus?	Terhadap materi kalkulusnya dan yang lainnya... ada yang seru
2	Minat Belajar	Apakah kamu menyukai pembelajaran kalkulus? Mengapa?	Suka dengan materinya. Suka materi yang menantang. Suka materi yang ada di pelajaran
3	Kesulitan Belajar	Bagian mana dari kalkulus yang paling sulit kamu rasakan?	Bagaimana cara menyelesaikan soal, ds. lain
4	Cara Belajar	Bagaimana cara kamu belajar kalkulus di rumah?	menonton video, membaca buku, dan lain-lain
5	Metode Guru	Menurutmu, apakah cara guru menjelaskan materi kalkulus sudah dipahami?	Ya, karena guru sudah menjelaskan dengan baik dan jelas
6	Media Pembelajaran	Apakah guru menggunakan alat bantu seperti media digital dalam pembelajaran?	Ya, karena guru sudah menggunakan media digital
7	Motivasi dan Keterarikan	Apakah yang membuat kamu semangat atau tertarik belajar kalkulus?	Karena materi yang diajarkan itu menarik dan seru
8	Dukungan Lingkungan Belajar	Apakah teman dan sekolah membantu kamu dalam memahami kalkulus?	Ya, karena teman-teman sudah membantu dalam memahami materi
9	Evaluasi Pembelajaran	Bagaimana menurut kamu cara guru menilai kemampuan dalam kalkulus?	Menurut saya, cara guru menilai kemampuan dalam kalkulus sudah baik
10	Harapan	Apakah harapanmu agar pembelajaran kalkulus lebih mudah dan menyenangkan?	Harapannya agar pembelajaran kalkulus lebih mudah dan menyenangkan

Figure 1. Documentation of Semi-Structured Interview Instrument

These findings are reinforced by classroom observations, which show that only a small proportion of students actively participate in learning activities, such as asking questions or engaging in discussions. The majority of students tend to adopt a passive role, relying heavily on teacher explanations without attempting to independently explore or solve problems. This condition indicates that the instructional process is still largely dominated by a teacher-centered approach, which limits opportunities for students to construct knowledge actively.

Based on the triangulation of interview, observation, and documentation data, it can be concluded that although students possess a certain degree of interest in learning calculus, this interest has not effectively translated into active engagement. This phenomenon can be attributed to low self-confidence and weak conceptual understanding. Students tend to hesitate in asking questions, participating in discussions, or expressing their ideas due to

their perception of insufficient mastery of the material. Consequently, learning interest alone is not sufficient to ensure effective learning outcomes. In other words, without strong conceptual understanding and adequate self-confidence, learning interest does not automatically contribute to improved achievement or meaningful engagement.

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No	Aspek/ Fokus Wawancara	Pertanyaan	Jawaban
1	Pandangan Umum	Bagaimana pandangan Bapak/Ibu tentang pembelajaran kalkulus di Tingkat SMA/MA?	Menyenangkan
2	Tujuan Pembelajaran	Apa tujuan yang ingin dicapai dalam mengajar materi kalkulus?	Mengahami konsep dasar untuk apa digunakan - Mengetahui ke mana lain
3	Metode Pembelajaran	Metode apa yang biasanya Bapak/Ibu gunakan dalam mengajar kalkulus?	Berbagai metode (ceramah, diskusi, praktik)
4	Media Pembelajaran	Media atau alat bantu apa yang sering digunakan dalam pembelajaran kalkulus?	Aplikasi Geogebra, Power point, video
5	Kesulitan Guru	Apa kendala yang Bapak/Ibu alami dalam mengajar kalkulus?	Siswa sulit memahami konsep basic turunan
6	Kesulitan Siswa	Berdasarkan pengalaman, bagian mana yang paling sulit bagi siswa dalam memahami kalkulus?	Integral, turunan fungsi trigonometri
7	Motivasi Belajar Siswa	Bagaimana cara Bapak/Ibu memotivasi siswa agar tertarik belajar kalkulus?	Mendajak bercerita.
8	Evaluasi Pembelajaran	Bagaimana cara Bapak/Ibu menilai hasil belajar kalkulus siswa?	Ujian formatif, kerajinan < math>
9	Dukungan Sekolah	Apakah sekolah memberikan dukungan terhadap pembelajaran kalkulus?	Ya.
10	Harapan	Apa harapan Bapak/Ibu terhadap pembelajaran kalkulus ke depan?	Siswa lebih tertarik → Janson ikut

Figure 2. Teacher Interview Documentation

Further analysis of students' conceptual and procedural difficulties was conducted based on documentation and interview data. One of the given problems required students to determine the derivative of the function $y = \sin(2x) + x^2 \cos x$. Students in the high-ability category were able to solve the problem correctly by applying the chain rule to $\sin(2x)$ and the product rule to $x^2 \cos x$, resulting in $y' = 2\cos(2x) + (2x\cos x - x^2 \sin x)$. Interview data support this finding, as a student explained, "I used the chain rule and the product rule, then checked again to make sure there were no mistakes." This demonstrates not only procedural fluency but also conceptual understanding and metacognitive awareness.

In contrast, students in the medium-ability category exhibited partial conceptual understanding but inconsistent procedural accuracy. Their responses indicated an awareness that differentiation was required; however, errors occurred in applying the chain and product rules. This finding is supported by interview data, where a student admitted, "I know it has to be differentiated, but sometimes I forget which rule to use." This reflects fragmented understanding, where students recognize general procedures but fail to integrate concepts effectively.

Students in the low-ability category demonstrated fundamental conceptual and procedural difficulties. Instead of performing differentiation, they merely rewrote the original function, indicating a failure to recognize the nature of the task. One student stated, "I do not know what to do; I forgot all the formulas," suggesting a heavy reliance on memorization without conceptual comprehension. This reflects a fundamental conceptual failure, where students are unable to initiate problem-solving processes due to a lack of basic understanding.

From the teachers' perspective, several challenges in teaching calculus were identified through interviews and observations. Teachers reported that many students lack foundational knowledge in algebra and trigonometry, which are essential prerequisites for understanding calculus. Additionally, instruction is still predominantly lecture-based, with limited use of visual or technological learning media. This makes abstract concepts difficult for students to grasp. Assessment strategies, such as unannounced quizzes, were found to have dual effects: while they may enhance readiness, they also induce anxiety and fear among students.

These findings are corroborated by classroom observations, which reveal that learning remains teacher-centered, with minimal student interaction. The limited use of visual and technology-based media further contributes to students' difficulties in understanding abstract concepts. Moreover, opportunities for discussion and interactive engagement are scarce, resulting in low levels of student participation.

Overall, the triangulated data indicate three major challenges in calculus instruction: (1) students' weak mastery of prerequisite concepts, particularly in algebra and trigonometry; (2) limited use of instructional media to support conceptual visualization; and (3) teachers' difficulty in effectively explaining abstract concepts to students with diverse ability levels. These interconnected challenges contribute to the overall low effectiveness of calculus learning in the classroom.

Table 2. Triangulation of Findings

Aspect	Documentation	Interview	Observation	Interpretation
Conceptual understanding	Errors in derivatives	"Confused about the concept"	Hesitation in solving	Weak mastery
Mathematical communication	No explanation steps	"Unable to explain"	Passive participation	Low communication skill
Learning interest	Moderate (~55%)	"Interested but afraid"	Low participation	Interest \neq ability
Teaching method	Procedural answers	Lecture dominant	Teacher-centered	Lack of interaction
Learning media	Not evident	Not used	No visualization	Abstract learning

Table 2 presents the results of data triangulation derived from documentation, interviews, and classroom observations, which were systematically analyzed to produce a comprehensive interpretation of the conditions of calculus learning. In terms of conceptual understanding, the documentation data reveal a high frequency of errors in solving derivative problems. This finding is reinforced by interview responses in which students explicitly reported being "confused about the concepts." Furthermore, classroom observations indicate that students often hesitate when initiating and completing problem-solving tasks. Taken together, these findings suggest that students' conceptual mastery remains weak.

With regard to mathematical communication, the documentation shows that most students are unable to present systematic and coherent solution steps. This is further supported by interview data, where students stated that they were "unable to explain" the processes they had carried out. Observational data also indicate that students tend to be passive during classroom activities. Therefore, it can be concluded that students' mathematical communication skills are still underdeveloped.

In terms of learning interest, the data indicate that students' interest is at a moderate level (approximately 55%). However, interview findings reveal an ambivalent attitude, as students expressed that they were "interested but afraid." This condition is also reflected in classroom observations, which show low levels of participation. These findings suggest that learning interest does not necessarily correspond to students' abilities or their active engagement in the learning process.

From the perspective of instructional methods, documentation data indicate that students' responses are predominantly procedural in nature. Interviews with teachers reveal that

instruction is still largely dominated by lecture-based methods. This is further confirmed by observational findings, which show that the learning process is teacher-centered. Such conditions limit classroom interaction and reduce opportunities for students to actively construct their understanding.

Finally, in terms of learning media, documentation data show no evidence of the use of supporting instructional tools. Both interviews and observations confirm that visual and technological media have not been optimally utilized. As a result, learning tends to remain abstract and difficult for students to comprehend. Overall, the triangulation findings demonstrate that these aspects are interconnected and collectively contribute to the low effectiveness of calculus learning in the classroom.

Based on the overall data analysis, this study successfully addresses the research questions through three major findings. First, regarding students' difficulties, it was found that most students have weak prerequisite knowledge, particularly in algebra and trigonometry. This limitation directly affects their ability to understand more complex calculus concepts. In addition, students experience difficulties in connecting conceptual understanding with procedural knowledge, leading them to solve problems mechanically without grasping the underlying relationships between concepts. Another prominent issue is students' inability to explain solution steps, which reflects low mathematical communication skills and shallow conceptual understanding.

Second, several factors influencing students' learning interest were identified. Although students demonstrate some degree of interest in calculus, their perception of the subject as difficult and abstract becomes a major barrier to active engagement. Moreover, the lack of visual learning media makes it difficult for students to concretely understand abstract concepts. Another contributing factor is the anxiety caused by assessment methods, such as pop quizzes, which leads to increased pressure and reduced confidence among students.

Third, from the teachers' perspective, several key challenges were identified in the teaching of calculus. Teachers face the issue of students' low foundational knowledge, which often requires revisiting prerequisite concepts before introducing new material. In addition, the limited use of instructional media, particularly those based on visual and technological approaches, hinders effective explanation of abstract concepts. Teachers also encounter difficulties in delivering complex calculus content in ways that are accessible to students with diverse levels of ability. Overall, these findings indicate that the challenges in calculus learning are multidimensional, involving student-related factors, instructional strategies, and limitations in the teaching process itself.

Discussions

The findings of this study indicate that students demonstrate a moderate level of learning interest ($\approx 54.6\%$), yet they continue to experience significant difficulties in conceptual understanding and mathematical communication, particularly in trigonometric derivatives and integrals. These results reveal a critical gap between students' interest in learning and their cognitive ability to deeply comprehend calculus concepts. This condition reinforces the argument that learning interest alone does not automatically translate into academic success, especially when it is not supported by strong conceptual understanding and effective instructional strategies.

First, with regard to learning interest, the findings show that although students express an interest in learning calculus, they tend to remain passive during classroom activities. This result is consistent with the study of Liebendörfer and Schukajlow, which highlights that students' interest does not necessarily lead to active engagement, particularly in teacher-centered learning

environments (Liebendörfer & Schukajlow, 2017). Furthermore, interest contributes to learning outcomes only when it is supported by self-regulated learning processes, such as goal setting and self-monitoring, as emphasized by Paul R. Pintrich (Pintrich, 2004). In the present study, low self-confidence and weak conceptual understanding emerge as key barriers that limit students' engagement, despite their expressed interest.

Second, in terms of conceptual understanding, the findings indicate that most students experience difficulties in integrating conceptual knowledge with procedural skills. This is consistent with Phelps (Phelps, 2010), who found that students often develop misconceptions in calculus due to insufficient foundational understanding. Similarly, Tall argues that conceptual failure occurs when students rely solely on procedural knowledge without grasping the underlying meaning (Tall, 2008). Notably, this study extends previous findings by showing that such difficulties are not limited to low-achieving students; even those in the moderate category demonstrate procedural instability when applying concepts.

These findings can also be linked to students' academic aspirations, particularly their intention to become mathematics teachers. Prior research suggests that such aspirations are a key factor in choosing mathematics education programs. However, strong aspirations are not always accompanied by adequate conceptual readiness. This indicates a gap between intrinsic motivation and cognitive ability, where students, despite having clear professional goals, still struggle to understand calculus concepts deeply (R. N. Siregar, 2024). Therefore, strengthening conceptual understanding is essential not only for improving academic competence but also for supporting the achievement of students' professional aspirations in mathematics education.

Third, the difficulties encountered in trigonometric derivatives support the findings of Maher Zandieh, who argues that the concept of derivatives is inherently complex due to its multiple representations (symbolic, graphical, and conceptual) (Gr. Voskoglou, 2017). Further empirical evidence by Orton also indicates that students often struggle with calculus concepts due to weak algebraic foundations (Chroscicki & Kemp, 1983). This suggests that challenges in learning calculus are deeply rooted in prior mathematical understanding.

Fourth, regarding mathematical communication, this study finds that students experience difficulties in explaining their problem-solving processes. This is consistent with Kazemi and Stipek, who emphasize the importance of mathematical discourse in developing conceptual understanding (Patrick et al., 2001). This finding is further supported by the National Council of Teachers of Mathematics, which identifies communication as a core standard in mathematics education. However, this study highlights an additional factor, namely students' low self-confidence, which limits their ability to effectively communicate mathematical ideas. These findings are reinforced by research on critical thinking, which indicates that students continue to struggle with the evaluation and explanation stages when solving derivative problems. This suggests that weaknesses in mathematical communication are closely linked to limited critical thinking abilities. Furthermore, gender-based differences in problem-solving strategies are evident, although both groups demonstrate difficulties in providing in-depth explanations. Therefore, instructional approaches should not only promote mathematical communication but also foster adaptive development of students' critical thinking skills (Astuti et al., 2025).

Fifth, from the perspective of instructional strategies, the findings indicate that the learning process remains predominantly teacher-centered, with very limited use of visual media and technology. This is consistent with Mayer, who demonstrates that multimedia-based learning significantly enhances students' understanding of abstract concepts (Mayer, 2009). Empirical support is also provided by Hwang and Wu, who argue that technology integration can improve both student engagement and comprehension in mathematics learning. In contrast, the limited

use of such media in this study contributes to students' difficulties in understanding abstract calculus concepts (Wang et al., 2018).

These findings are further supported by research on cognitive flexibility, which reveals that students' ability to apply multiple strategies and generate diverse interpretations in mathematical problem-solving remains varied, with some students categorized as less flexible. This suggests that monotonous and less interactive instructional approaches may hinder the development of students' cognitive flexibility (R. N. Siregar et al., 2022). Therefore, more innovative and technology-integrated instructional strategies are needed to promote the exploration of multiple representations and solution strategies, thereby enhancing both conceptual understanding and students' cognitive flexibility in solving mathematical problems.

Fifth, from the perspective of instructional strategies, the findings indicate that learning remains predominantly teacher-centered, with minimal use of visual or technological media. This is consistent with Richard E. Mayer (Mayer, 2009), who demonstrates that multimedia learning significantly enhances understanding of abstract concepts. Empirical support is also provided by Gwo-Jen Hwang and Wu, who show that technology integration can improve both engagement and comprehension in mathematics learning. In contrast, the limited use of such media in this study contributes to students' difficulties in understanding abstract calculus concepts (Wang et al., 2018).

Sixth, regarding assessment practices, the use of pop quizzes is found to have a dual effect: while it increases students' readiness, it also induces anxiety. This finding is in line with David W. Putwain who reports that assessment pressure can trigger academic anxiety and negatively affect performance (Putwain, 2007). However, this study reveals that, in the context of calculus learning, the negative impact of anxiety tends to outweigh its benefits, indicating the need for more supportive and formative assessment approaches.

Finally, when viewed in a broader context, these findings reflect global trends reported by the Organisation for Economic Co-operation and Development (2023), which indicate that Indonesian students' performance in higher-order thinking and problem-solving remains relatively low (OECD, 2023). This suggests that the issues identified in this study are not merely local but are part of a broader systemic challenge in mathematics education.

Overall, this discussion demonstrates that the findings not only confirm previous research but also provide new insights into the complex relationship between learning interest, conceptual understanding, mathematical communication, and instructional practices. This study highlights that effective calculus instruction requires a holistic approach, including strengthening prerequisite knowledge, integrating visual and technological learning media, promoting active student engagement, and implementing assessment strategies that foster confidence and reduce anxiety.

CONCLUSION

This study concludes that calculus learning among Grade XII students at MAN 2 Padangsidempuan remains suboptimal due to interconnected cognitive, affective, and instructional challenges. Although students demonstrate a moderate level of learning interest ($\approx 54.6\%$), this interest does not translate into active engagement or meaningful understanding. Students experience significant difficulties in conceptual understanding and mathematical communication, particularly in trigonometric derivatives and integrals, primarily due to weak prerequisite knowledge in algebra and trigonometry and a tendency to rely on procedural memorization rather than conceptual reasoning.

From an instructional perspective, the persistence of teacher-centered practices, limited use of visual and technological learning media, and challenges in explaining abstract concepts further

constrain students' learning. In addition, assessment practices such as unannounced quizzes contribute to increased anxiety, which negatively affects students' confidence and participation.

Overall, the findings highlight that difficulties in calculus learning are multidimensional, involving the interaction between students' prior knowledge, learning interest, communication skills, and instructional strategies. Therefore, effective calculus instruction requires a holistic approach that integrates the strengthening of foundational concepts, the use of interactive and visual learning media, the promotion of active student engagement, and the implementation of supportive assessment strategies. Such an approach is essential to foster deeper conceptual understanding and improve the overall quality of mathematics learning.

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