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ANALYSIS OF STUDENT ERRORS IN LEARNING THE INTEGRAL CALCULUS COURSE WITH THE HELP OF ARTIFICIAL INTELLIGENCE (AI)

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ABSTRACT

This study addresses a gap in mathematics education research concerning the use of artificial intelligence (AI) to analyze student errors in integral calculus. Error analysis in calculus is still commonly conducted manually by lecturers, making it time-consuming, potentially subjective, and difficult to implement consistently across an entire class. Although previous studies have examined student errors in calculus, limited research has explored AI as a systematic diagnostic tool, especially among non-mathematics students. Therefore, this study aims to identify the types of errors made by students in solving integral calculus problems using an AI-based system and to examine the role of AI in supporting more accurate and targeted diagnostic assessment. The participants were 30 second-semester students from the Biology Education Study Program at Universitas Indraprasta PGRI who were taking the Integral Calculus course. This study employed a descriptive qualitative approach. An AI-based system was used to analyze students' responses to a set of integral calculus problems and classify them into four categories: conceptual errors, procedural errors, technical errors, and errors in understanding the problem. The results showed that conceptual errors were the most dominant, occurring in 45% of students, particularly in misunderstanding the meaning of integrals and misusing integration limits. Procedural errors were found in 30% of students, technical errors in 15%, and problem-understanding errors in 10%. This study contributes empirical evidence on student error patterns, strengthens the role of AI as a systematic diagnostic tool, and provides a practical basis for lecturers to design more targeted remedial instruction in higher education settings.

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INTRODUCTION

Integral calculus is one of the most challenging subjects in university mathematics because it requires students to integrate prerequisite knowledge, procedural accuracy, and conceptual understanding at the same time. Difficulties in this course do not arise solely from the complexity of integral techniques such as indefinite integrals, definite integrals, substitution, and applications of integrals, but also from weaknesses in prior knowledge, particularly in algebra and differential calculus. As noted by Sumargiyani & Nafi (2020), inadequate mastery of prerequisite material contributes significantly to students' difficulty in learning integral calculus. This indicates that students' errors in integral calculus are not incidental, but are closely related to unresolved conceptual and procedural gaps from earlier learning.

These difficulties have academic and psychological consequences. When students repeatedly fail to solve integral problems correctly, they often experience reduced confidence, lower motivation, and increased anxiety toward mathematics learning. Suharyati (2023) argues that failure to understand mathematical material affects not only learning outcomes but also students' interest in learning. In this context, the problem in integral calculus is not simply that students answer incorrectly, but that their errors reflect deeper weaknesses that can accumulate if they are not identified and addressed early. Therefore, student error analysis becomes a critical part of the learning process because it provides evidence of where and why understanding breaks down.

However, in practice, the analysis of student errors is often carried out manually by lecturers, which creates several limitations. Manual analysis requires considerable time, is difficult to apply consistently to large numbers of students, and often delays feedback. Yusuf, Z., & Darmawan (2019) point out that manual error analysis tends to be inefficient and does not always provide immediate information that can be used for instructional improvement. As a result, lecturers may identify that students are making mistakes, but may not be able to systematically classify those mistakes or respond to them in a timely manner. This condition shows that the main issue is not only students' inability to solve integral problems, but also the limited capacity of conventional learning systems to diagnose those difficulties efficiently.

In this situation, the relevance of artificial intelligence lies not merely in its status as an emerging technology but in its analytical capacity to support diagnosis in learning. AI can be used to detect patterns in student responses, classify errors, and generate feedback more quickly than conventional methods. This makes AI potentially valuable in integral calculus learning, where student difficulties are often diverse and recurrent. Rather than replacing the lecturer's role, AI can function as a diagnostic support system that helps identify whether students' errors are conceptual, procedural, technical, or related to misunderstanding the problem. From this perspective, the role of AI is important because it addresses a concrete instructional need, namely the need for systematic, timely, and targeted identification of student weaknesses (Ferdiánová & Konečná, 2025).

Previous studies have shown that AI has potential in educational contexts, particularly in supporting personalized learning and feedback. However, much of the discussion has tended to emphasize the general benefits of AI in education rather than its specific function in analyzing mathematical errors in integral calculus. This creates an important gap. Research on student errors in calculus already exists, and research on AI in education is also growing, but the integration of AI as a tool for systematic error analysis in integral calculus remains limited, especially in higher education contexts. Therefore, the use of AI in this study is positioned not simply as a technological innovation, but as a response to the instructional problem of how student errors can be identified more accurately and used as a basis for more targeted learning intervention (Zhang et al., 2025)

Based on this rationale, the use of AI in integral calculus learning is important because it can strengthen the diagnostic dimension of assessment. Through AI-assisted error analysis, lecturers can obtain more structured information about student weaknesses, while students can receive faster feedback on the nature of their mistakes. In other words, the value of AI in this context lies not in technology for its own sake, but in its potential to make learning evaluation more precise, efficient, and instructionally meaningful (Farrokhnia et al., 2026)

In the context of higher education in Indonesia, the use of artificial intelligence (AI) in mathematics learning remains limited, particularly in supporting the analysis of student errors in integral calculus. Existing studies have generally discussed the potential of AI in education at a broad level, but few have specifically examined how AI can be applied to identify and classify students' errors in integral calculus learning. This indicates a clear research gap, namely the lack of empirical studies that position AI not only as a learning technology, but also as a diagnostic tool for analyzing student difficulties in a systematic and targeted manner. Although challenges such as limited infrastructure and low technological literacy still hinder its implementation, AI has significant potential to improve the quality of learning when used appropriately (Ridwana et al., 2025). Based on this gap, this study aims to explore the application of AI in analyzing student errors in integral calculus learning. The contribution of this study is explicit in three respects: first, it provides empirical evidence on the patterns of student errors in integral calculus; second, it demonstrates the role of AI as a systematic tool for identifying and classifying these errors; and third, it offers a practical basis for improving teaching effectiveness through more targeted feedback and instructional intervention.

METHOD

This study employed a descriptive qualitative approach supported by artificial intelligence (AI) through the Poe application to examine student errors in integral calculus learning. The participants were 30 second-semester students from the Biology Education Study Program. In this study, Poe was used as an AI-based tool to assist in analyzing students' responses to integral calculus problems. The workflow consisted of four stages. First, students completed a set of integral calculus problems. Second, their written answers were collected and entered into the Poe application. Third, the AI output generated through Poe was used to identify and classify student errors into four categories: conceptual errors, procedural errors, technical errors, and errors in understanding the problem, based on predefined indicators developed from the literature. Fourth, the classification results were reviewed by the researcher to ensure that the AI analysis remained consistent with the intended error categories.

The qualitative data in this study consisted of students' written responses, classroom observations, and interview results. Observations were conducted to examine how students interacted with AI-assisted analysis, while interviews with students and lecturers were used to explore their perceptions of the usefulness and limitations of Poe in supporting error analysis and learning improvement. The percentages presented in this study were used only as descriptive statistics to show the frequency of each type of error and to support the qualitative interpretation. To examine the accuracy of the AI classification, the results generated through Poe were compared with manual classification conducted by the researcher based on the same error indicators.

RESULTS

This study uses the Error Analysis Theory from Hans-Georg Radatz (Supriyatin & Selvia, 2025), which divides mathematics learning errors into four types, namely conceptual, procedural, technical, and problem interpretation errors. Conceptual errors occur when students misunderstand the integral concept, procedural errors arise from the wrong sequence of steps, technical errors related to calculations, and misinterpretations of the questions occur when students misunderstand the meaning of the question. Based on this theory, the indicators used include: (1) understanding of integral concepts, (2) accuracy of completion procedures, (3) accuracy of calculations, and (4) ability to understand problems. With the help of AI, these indicators can be analyzed to effectively identify student error patterns.

This research was conducted on 30 2nd-semester students of the Biology Education Study Program, Indraprasta University PGRI, who were attending Integral Calculus lectures. By utilizing an artificial intelligence (AI)-based system, students' answers to integral questions are automatically analyzed to identify the type of error.

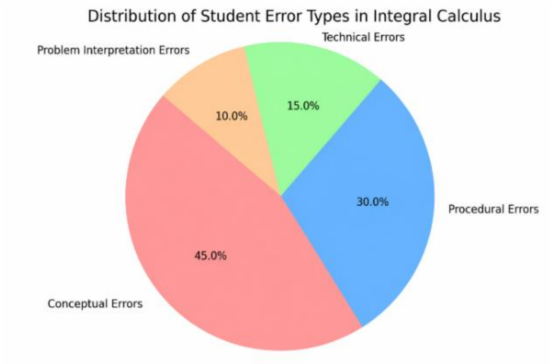


Figure 1. Types of Student Errors in Integral Calculus

Analysis of Students Making Conceptual Mistakes

Most students experienced conceptual errors, which amounted to 45% of the total respondents. These errors include a misunderstanding of the meaning of the integral as an area under the curve, as well as an error in understanding the boundaries of the integral. For example, some college students use the upper and lower bounds in reverse or consider integrals as ordinary algebraic operations. This shows that students still do not have a deep understanding of integral functions in geometric and applicative contexts.

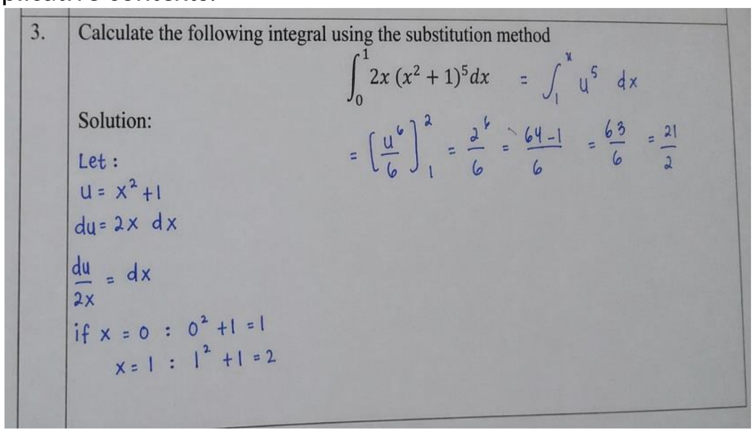
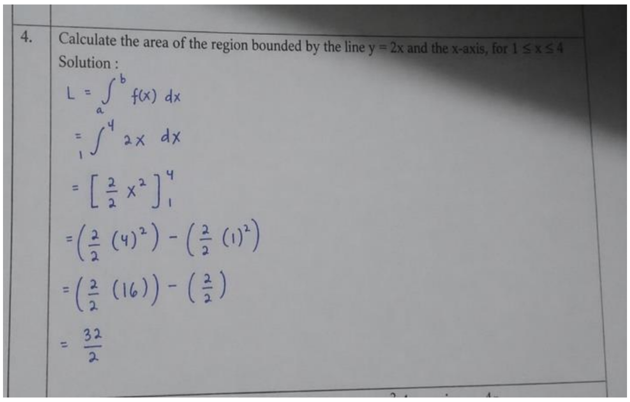


Figure 2. Answer to Question Number 3
Source: Researcher 2026

Based on the students' answers to question number 3, it can be seen that there is a conceptual error in the application of the substitution method to solve the integral. The student has made the substitution correctly, namely by setting u so that du = 2x. However, in the next stage, students immediately write the anti-derivative results as $\frac{u^6}{6}$ and change the boundaries without showing the integral process in its entirety. This shows that students understand substitution only as a process of replacing variables, but do not fully understand that substitution also aims to simplify the form of functions so that they can be integrated gradually. Thus, students have not shown a thorough understanding of the basic concept of integral substitution, especially regarding the importance of declaring anti-derivative forms as part of the integration process. This error is categorized as a conceptual error because it is directly related to the lack of understanding of the meaning and purpose of the substitution method in the integral.


4. Calculate the area of the region bounded by the line y = 2x and the x-axis, for 1 ≤ x ≤ 4
Solution :

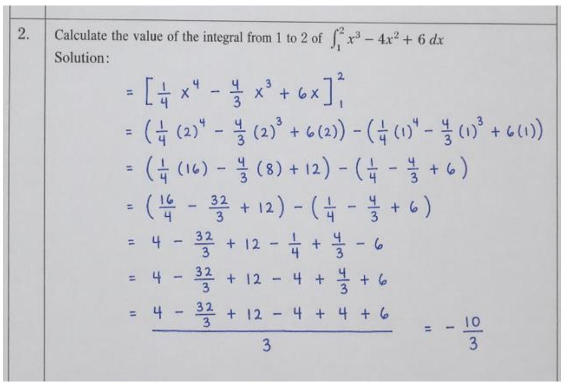
$$L = \int_a^b f(x)\,dx$$
$$= \int_1^4 2x\,dx$$
$$= \left[\frac{2}{2}x^2\right]_1^4$$
$$= \left(\frac{2}{2}(4)^2\right) - \left(\frac{2}{2}(1)^2\right)$$
$$= \left(\frac{2}{2}(16)\right) - \left(\frac{2}{2}\right)$$
$$= \frac{32}{2}$$

Figure 3. Answer to Question Number 4
Source: Researcher 2026

Based on the students' answers to the question that asked to calculate the area limited by the line graph to the x-axis in a certain interval, it was seen that the students did not experience conceptual errors. Students understand that to find the area under the curve to the x-axis, the integral concept of the given function can be used. He also recognized that the function in question was a linear line, so the form of the function was a simple algebraic function. The completion steps carried out show that students understand that the result of the integral is a broad value that is calculated through the anti-derivative function, then evaluated at the lower and upper limits according to the interval given in the problem. There is no error in the understanding of the concept of integral as broad, nor in the selection of the right methods and functions to be substituted. Therefore, it can be concluded that in this answer, there are no conceptual errors, because students have understood and applied integral concepts of the course well according to the meaning and context of the question.

Analysis of students making procedural errors

As many as 30% of students make procedural errors, namely errors in the work steps, even though the basic concept is known. Common examples are errors in the use of substitution methods, errors in partial integral rules, or forgetting to add an integration constant. This error shows that students need more practice in implementing settlement procedures in a consistent and structured manner.


2. Calculate the value of the integral from 1 to 2 of $\int_1^2 x^3 - 4x^2 + 6\,dx$
Solution:

$$= \left[\frac{1}{4}x^4 - \frac{4}{3}x^3 + 6x\right]_1^2$$
$$= \left(\frac{1}{4}(2)^4 - \frac{4}{3}(2)^3 + 6(2)\right) - \left(\frac{1}{4}(1)^4 - \frac{4}{3}(1)^3 + 6(1)\right)$$
$$= \left(\frac{1}{4}(16) - \frac{4}{3}(8) + 12\right) - \left(\frac{1}{4} - \frac{4}{3} + 6\right)$$
$$= \left(\frac{16}{4} - \frac{32}{3} + 12\right) - \left(\frac{1}{4} - \frac{4}{3} + 6\right)$$
$$= 4 - \frac{32}{3} + 12 - \frac{1}{4} + \frac{4}{3} - 6$$
$$= 4 - \frac{32}{3} + 12 - 4 + \frac{4}{3} + 6$$
$$= \frac{4 - \frac{32}{3} + 12 - 4 + 4 + 6}{3} = -\frac{10}{3}$$

Figure 4. Answer to Question Number 2
Source: Researcher 2026

Based on the student's answer to question number 2, namely calculating the integral of the course from the observation of procedural errors in the work stage. Students start right, namely, by looking for anti-derivatives from each function tribe. However, procedural errors arise at the stage of applying the integral formula, of course, especially when students compile and calculate the final value of the boundary substitution. Students do not seem to make a clear distinction between the substitution of the upper and lower limits, and do not write down the complete form of the anti-derivative reduction between the limits, i.e., F(2) - F(1), systematically. As a result, the arrangement of substitution values becomes ambiguous, which then leads to errors in calculating the final result.

An example of a procedural error occurs when students subtract two expressions of function values without clear parentheses, thus confusing whether the subtraction operation is performed on all F(1) results or only on some tribes. In addition, students seem to mix the process of substitution and simplification in one line without structured steps, thus making the final calculation non-transparent and prone to errors.

Although the final result of the integral is written as $-\frac{10}{3}$, the process to the result is not in accordance with the standard procedural steps in solving the definite integral. This error is classified as a procedural error because it relates to irregularities in applying the steps of a certain integral solution, not to the understanding of basic concepts or ordinary calculation errors. Thus, it can be concluded that students have made mistakes in the preparation of integral completion steps, certainly systematically and consistently.

Analysis of students making technical errors

As many as 15% of errors fall into the technical or calculation category. Students make arithmetic mistakes, such as incorrectly summing, multiplying, or simplifying algebraic forms. This error, although seemingly simple, can have an impact on the wrong end result and indicate a lack of precision in solving math problems.

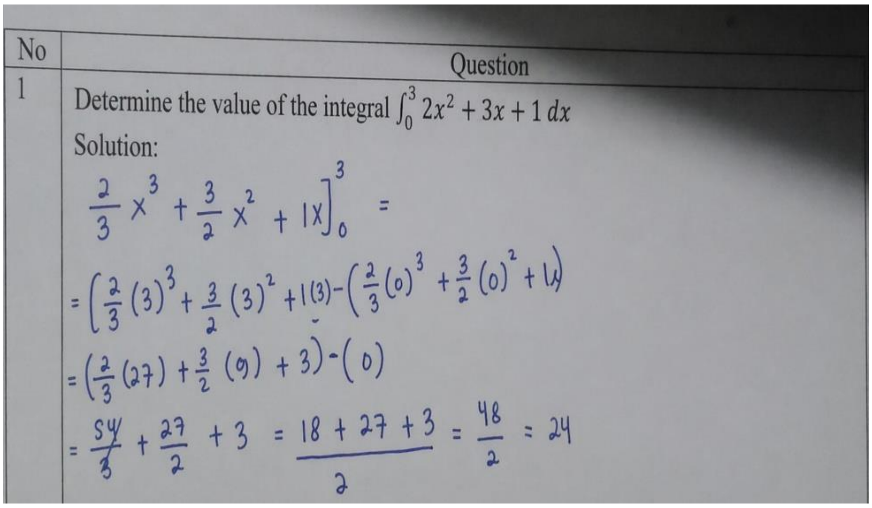


Figure 5. Answer to Question Number 1
Source: Researcher 2026

Based on the analysis of the students' answers to question number 1, namely calculating the integral of the course from the function, it can be concluded that the student has shown a good understanding of the concept. Students are able to determine the anti-derivatives of each function term precisely, and understand that to calculate the integrals, of course, it is necessary to substitute the upper and lower limits. This shows that there are no conceptual or procedural errors in the settlement process. However, in the final stage of calculation, there was a technical error in performing fraction counting operations. Students write the result of 3/2.9 correctly as 27/2, but then add it incorrectly with the values of 18 and 3, resulting in a total of 48, which is then divided by 2 to 24. Though the actual number of 18+13.5+318+13.5+3 is 34.5 instead of 48. This technical error shows that even though the concepts and procedures have been mastered, the precision in performing the final calculations still needs to be improved. In the context of research indicators, these errors fall into the category of technical errors, while indicators of concept understanding, procedural accuracy, and problem understanding have been fulfilled well (Jefrizal et al, 2021)

Students have a misunderstanding of the

A small part, namely 10% of students, experience errors in understanding the meaning of the question. This can be seen from the answers that are irrelevant to the question or errors in identifying what is being asked. This mistake shows that students' ability to read and interpret math problems still needs to be improved, especially in the context of story or application problems.

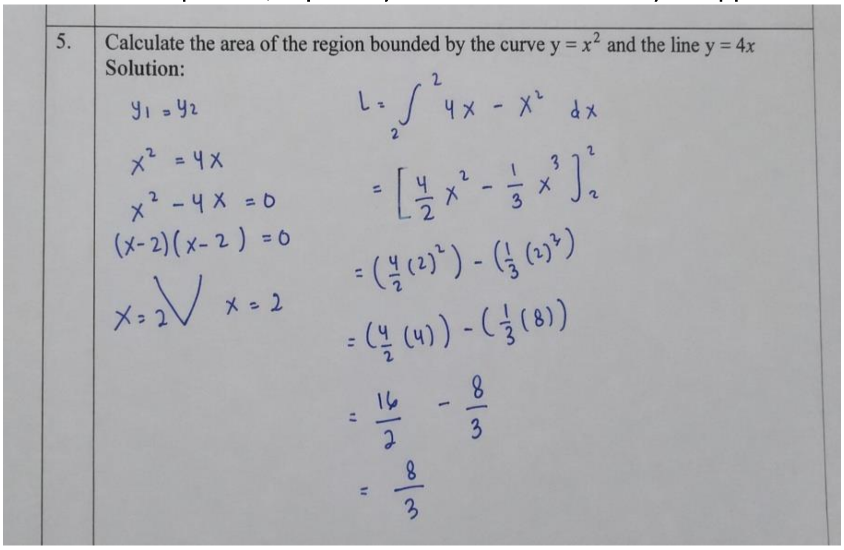


Figure 6. Answer to Question Number 5
Source: Researcher 2026

Based on the students' answers to the question that asked to calculate the area bounded by curves and straight lines, it was seen that students had errors in understanding the meaning of the question. The problem actually requires the calculation of the area of the closed area between the two functions, where it is necessary to identify which functions are above and which are below in the appropriate intervals. However, students do not show the process clearly. It doesn't explain the top and bottom functions, and the boundaries used in the integration are also imprecise. This shows that students do not understand that calculating the area between the two curves must requires paying to the sequence of function reduction and boundaries that cover all the closed areas in question. Although the final result appears to be calculated procedurally, the initial error in understanding the context of the question causes the process to be inappropriate. Therefore, this student's answer indicates an error in understanding the content and intent of the question, which is included in the category of misinterpretation of the question (Jefrizal et al, 2021)

Summary of the Results of the Questionnaire on the Use of AI in Integral Calculus Learning in the form of diagrams

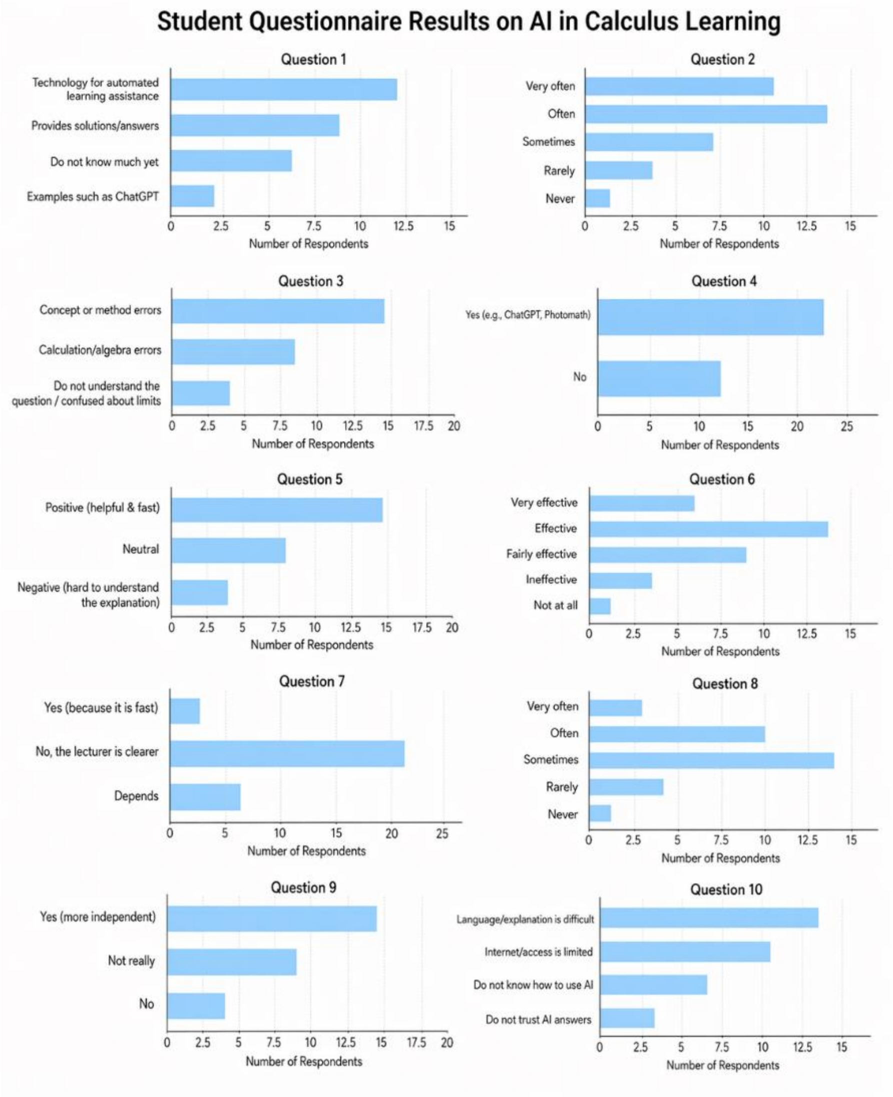


Figure 7 . Query result diagram
Source: Researcher 2026

The results of this study indicate that the AI-based system was able to classify student errors in integral calculus in a structured manner and reveal a clear pattern of learning difficulties. Among the 30-second-semester students of the Biology Education Study Program, conceptual errors were the most dominant (45%), followed by procedural errors (30%), technical errors (15%), and errors in understanding the problem (10%). This distribution suggests that the main difficulty in integral calculus does not primarily lie in arithmetic computation, but in students' limited conceptual understanding of integral meaning, the selection of appropriate methods, and the interpretation of mathematical relationships in the problem. In other words, many students experienced failure at the level of understanding before they reached the stage of correct execution.

The proportion of procedural errors further strengthens this interpretation. Although some students appeared to recognize the relevant concept, they were not always able to apply the correct sequence of steps consistently. This indicates that partial understanding was often insufficient to produce accurate solutions. In contrast, technical errors appeared less frequently, which suggests that computational inaccuracies were not the central source of difficulty. Likewise, the relatively low proportion of errors in understanding the problem indicates that most students were generally able to read the questions, but still struggled to transform that understanding into correct conceptual and procedural responses. These findings point to a hierarchy of difficulty in which weak conceptual understanding contributes directly to procedural failure, while technical mistakes tend to emerge as secondary consequences.

From an instructional perspective, these results imply that improvement in integral calculus learning should not focus only on repetitive practice or final-answer accuracy. Greater emphasis is needed on strengthening conceptual understanding, clarifying the meaning of integrals, and guiding students through the logic behind each solution step. In this context, the AI-based system was useful not merely because it produced percentages, but because it helped reveal the dominant areas of student weakness in a more systematic way. Therefore, the contribution of this study lies in showing that AI-assisted error analysis can support lecturers in identifying where student understanding breaks down and in designing more targeted remedial strategies in calculus learning.

DISCUSSION

The predominance of conceptual errors suggests that the central difficulty in integral calculus lies in students' failure to construct mathematical meaning rather than in their inability to carry out algebraic manipulation. This finding is consistent with Wladis et al. (2020), in the *International Journal of STEM Education*, who reported that students often misunderstand integrals as isolated algebraic procedures rather than as representations of area and accumulation. A similar pattern was also identified by Qetrani et al. (2021), particularly among non-mathematics students whose understanding of integrals remains weak at the geometric level. In the present study, this weakness was evident when some students were able to perform substitution mechanically but were unable to use it meaningfully to transform and complete the solution. This indicates that procedural appearance should not be interpreted as evidence of conceptual mastery.

Procedural errors also require deeper interpretation. The fact that many students failed to organize valid solution steps suggests that their difficulties were not limited to isolated mistakes but reflected unstable mathematical reasoning. This interpretation is supported by Nguyen and Rebello (2019) in the *Journal of Research in Mathematics Education*, who found that students often lose procedural coherence when they assume they already understand the task. Dorner et al. (2026), as well as Anwar and Salma (2021), likewise emphasized that symbolic fluency and procedural structure in calculus must be developed explicitly through structured and contextualized practice. Therefore, the procedural errors identified in this study should be interpreted as evidence that partial conceptual understanding often fails to develop into consistent procedural competence.

Although technical errors were less dominant, they remain pedagogically important because they can distort otherwise valid reasoning and reduce student confidence. (Ekamornaroon et al., 2024), In *Educational Studies in Mathematics* argued that even simple arithmetic mistakes may undermine the credibility of the entire solution when the final result becomes incorrect. Meanwhile, errors in understanding the problem indicate a weakness in mathematical literacy, especially in interpreting verbal statements, graphs, and area-related situations. In this study, such errors were visible when students failed to interpret tasks involving the area enclosed by two curves even when no major procedural mistake was initially apparent. This suggests that the challenge was not merely computational, but also representational, since students struggled to translate problem situations into appropriate mathematical models.

More importantly, these findings clarify why AI offers advantages over traditional analysis when used as a diagnostic tool. Conventional lecturer-led analysis usually relies on manual checking and tends to focus on whether the final answer is correct. Such an approach may identify that a response is wrong, but it does not always reveal the specific source of the error in a systematic and timely manner, especially when many student responses must be reviewed simultaneously. In contrast, AI enables faster and more consistent classification of conceptual, procedural, technical, and problem-comprehension errors across multiple responses. This is consistent with Pargmann et al. (2025), in *Computers & Education*, who emphasized the contribution of AI to real-time formative assessment, and with Farrokhnia et al. (2026), who highlighted its value in reducing the burden of manual evaluation while improving the precision of feedback. Thus, AI is not pedagogically superior because it replaces the lecturer, but because it extends the lecturer's diagnostic capacity beyond what is usually feasible through traditional manual analysis alone.

However, the educational value of AI is not automatic. The questionnaire results show that many students had already used AI-based tools such as ChatGPT, Photomath, or Wolfram Alpha and generally perceived them positively because they were fast, accessible, and helpful for checking solutions. At the same time, students did not regard AI as an unconditional substitute for lecturer feedback. This contrast is important because it reveals the complementary, rather than competitive, relationship between AI and lecturers. AI is stronger in speed, availability, and pattern detection, whereas lecturers remain stronger in providing interactive, contextual, and adaptive explanations. Ummah (2019) helps explain why some students still had limited understanding of AI as a learning technology, while Farhan & Zulkarnain (2019) support the observation that conceptual and procedural difficulties continue to dominate in integral calculus learning. Therefore, AI should not be positioned as a self-sufficient instructional solution, but as a support system whose effectiveness depends on pedagogical integration.

The pedagogical implications of this study are clear. First, AI should be used as an early diagnostic instrument to identify dominant error patterns before lecturers design follow-up instruction. Second, because conceptual and procedural errors were more dominant than technical ones, calculus teaching should give greater emphasis to conceptual clarification, interpretation of integral meaning, and guided reasoning rather than relying mainly on repetitive exercises. This is in line with Alghadari (2022), who argued that technology becomes educationally meaningful only when supported by appropriate pedagogical intervention. Third, the barriers reported by students, such as difficulty understanding AI explanations, limited internet access, and limited familiarity with AI features, indicate that digital literacy support is still necessary. In this respect, the lecturer's role becomes more strategic, not less. Islamiyah et al. (2023) support the use of technology to identify student errors more efficiently. Upu et al. (2022) support more targeted concept-centered instruction, and Mufidah, M., Sadiani, N., Akina, A., Nuraini, N., & Khairunnisa (2023) support the importance of examining student thinking processes rather than focusing solely on final answers.

Overall, the contribution of this study lies not simply in showing that AI can be used in calculus learning, but in demonstrating how AI can strengthen the diagnostic dimension of assessment. AI makes it possible to identify where student understanding breaks down with greater speed and structure than conventional final-answer checking. Nevertheless, meaningful improvement in learning still depends on how lecturers interpret those diagnostic results and transform them into conceptual clarification, procedural guidance, and targeted remedial teaching. Therefore, AI should be integrated into integral calculus learning as a diagnostic partner for lecturers, while lecturers remain the central agents in shaping meaningful mathematical understanding.

CONCLUSION

Based on the findings of this study, artificial intelligence (AI) can be used as a supportive tool to assist the analysis of student errors in Integral Calculus learning, particularly in identifying recurring error patterns in a more structured manner. The results showed that conceptual errors were the most dominant type of error, indicating that students' main difficulty was related more to understanding the meaning and application of integral concepts than to computation alone. In this context, the use of AI was helpful in organizing student responses and classifying error types, which may support lecturers in providing more focused feedback. However, these findings do not suggest that AI independently improves learning effectiveness. Rather, its value lies in supporting the diagnostic process so that lecturers can recognize student difficulties more efficiently and respond with more targeted instructional strategies. Therefore, the integration of AI in Calculus learning should be accompanied by lecturer guidance, student training, and periodic evaluation to ensure that the technology is used appropriately and remains relevant to students' learning needs, including support for Indonesian-language explanations.

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The researcher did not use the help of AI in completing this article and the researcher is the only one who is fully responsible for this article.

INFORMED CONSENT

The authors have obtained informed consent from all participants.

CONFLICT OF INTEREST

The researcher stated that there was no conflict of interest in any form.

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