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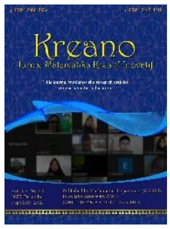

A Cross-Sectional Study on the Relationship Between Problem-Solving Ability and Types of Student Errors in Integral Calculus

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Abstract

Many undergraduate students still experience difficulties in solving integral calculus problems because learning tends to emphasize procedural manipulation rather than conceptual understanding. Previous studies have identified various types of errors in integral calculus; however, limited research has simultaneously examined the relationship between students' problem-solving ability (PSA) and specific error types based on Newman's Error Analysis (NEA) in integral calculus contexts. Therefore, this study aimed to analyze students' PSA, identify the dominant types of errors in solving integral calculus problems, and examine the relationship between PSA and NEA error types. This study employed a cross-sectional descriptive-correlational design involving 74 undergraduate students enrolled in an Integral Calculus course at a university in Indonesia. Data were collected using an integral calculus problem-solving test designed based on Krulik and Rudnick's problem-solving indicators and analyzed using Newman's Error Analysis (NEA). Descriptive statistics were used to determine students' PSA levels and dominant error types, while Spearman's rho correlation test was applied to examine the relationship between PSA and NEA scores. The findings revealed that students' PSA generally fell into the moderate category. Transformation error emerged as the most dominant error type, followed by process skill and comprehension errors, while reading and encoding errors were not observed. Transformation errors mainly occurred when students selected inappropriate integration techniques, such as applying substitution instead of integration by parts. Furthermore, the analysis showed a strong negative correlation between PSA and NEA scores ($\rho = -0.787, p < 0.01$), indicating that students with higher problem-solving ability tended to make fewer conceptual and procedural errors. These findings suggest that students' difficulties in integral calculus are closely related to limitations in conceptual understanding, strategic reasoning, and representation transformation processes. The study contributes to mathematics education research by demonstrating how specific NEA error patterns are associated with students' levels of problem-solving ability in integral calculus. The findings imply that integral calculus instruction should emphasize conceptual understanding, multiple mathematical representations, and structured problem-solving strategies to reduce dominant transformation and process skill errors. Future research is recommended to explore intervention-based or longitudinal designs to examine how instructional scaffolding and metacognitive training may improve students' problem-solving performance in calculus learning.

Keywords: Cross-sectional study; integral calculus; Newman's Error Analysis: problem-solving ability

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Abstrak

Banyak mahasiswa masih mengalami kesulitan dalam menyelesaikan soal kalkulus integral karena pembelajaran lebih menekankan prosedur dibandingkan pemahaman konseptual. Penelitian sebelumnya telah mengidentifikasi berbagai jenis kesalahan dalam kalkulus integral, tetapi masih terbatas penelitian yang secara simultan mengkaji hubungan antara kemampuan pemecahan masalah (problem-solving ability/PSA) dan jenis kesalahan berdasarkan Newman's Error Analysis (NEA). Penelitian ini bertujuan menganalisis kemampuan pemecahan masalah mahasiswa, mengidentifikasi jenis kesalahan dominan dalam penyelesaian soal kalkulus integral, serta mengkaji hubungan antara PSA dan jenis kesalahan berdasarkan NEA. Penelitian ini menggunakan desain cross-sectional dengan pendekatan deskriptif-korelasional yang melibatkan 74 mahasiswa pendidikan matematika yang menempuh mata kuliah Kalkulus Integral di salah satu universitas di Indonesia. Data dikumpulkan melalui tes pemecahan masalah kalkulus integral berdasarkan indikator Krulik dan Rudnick, kemudian dianalisis menggunakan Newman's Error Analysis (NEA). Analisis deskriptif digunakan untuk menentukan tingkat PSA dan jenis kesalahan dominan, sedangkan uji korelasi Spearman's rho digunakan untuk menguji hubungan antara PSA dan skor NEA. Hasil penelitian menunjukkan bahwa kemampuan pemecahan masalah mahasiswa secara umum berada pada kategori sedang. Transformation error menjadi jenis kesalahan paling dominan, diikuti process skill error dan comprehension error, sedangkan reading error dan encoding error tidak ditemukan. Transformation error terutama terjadi ketika mahasiswa memilih teknik integrasi yang tidak sesuai, seperti menggunakan metode substitusi pada soal yang seharusnya diselesaikan dengan integral parsial. Hasil analisis juga menunjukkan hubungan negatif yang kuat antara PSA dan skor NEA (ρ = -0,787; p < 0,01), yang berarti mahasiswa dengan kemampuan pemecahan masalah lebih tinggi cenderung melakukan lebih sedikit kesalahan. Temuan ini menunjukkan bahwa kesulitan mahasiswa dalam kalkulus integral berkaitan dengan keterbatasan pemahaman konseptual, penalaran strategis, dan kemampuan transformasi representasi matematis. Implikasi penelitian ini menegaskan pentingnya pembelajaran berbasis problem solving, penggunaan multiple representations, dan penguatan pemahaman konseptual untuk mengurangi transformation error dan process skill error. Penelitian selanjutnya disarankan menggunakan desain intervensi atau longitudinal untuk mengkaji efektivitas scaffolding dan pelatihan metakognitif dalam pembelajaran kalkulus integral.

INTRODUCTION

The concept of integrals in mathematics has a high epistemic complexity due to its multiple interrelated dimensions, yet it is often taught in isolation. Students frequently experience confusion in grasping the conceptual meaning of integrals and determining appropriate solution strategies. Many university students still tend to interpret integrals merely as procedural calculations rather than as concepts of area, accumulation, and functional relationships. Students also experience difficulties in connecting symbolic, graphical, and conceptual representations of definite integrals, particularly in interpreting integrals beyond the idea of "area under the curve" (Bajracharya et al., 2023; Nilsen & Knutsen, 2023). In addition, conceptual difficulties remain one of the dominant obstacles in integral calculus, often leading students to make procedural and strategic errors when selecting solution methods (Aziz et al., 2025; Lisa et al., 2024). Consequently, they tend to memorize procedures without understanding their underlying reasoning (Kouropatov & Dreyfus, 2014). This reflects a tendency for instruction to emphasize procedural over conceptual aspects, making it difficult for students to connect various representations and meanings of integrals (Mateus-Nieves & Moll, 2021).

Historically, the integral emerged from the need to calculate quantities such as area, volume, and curve length through the limiting process of summation, formalized later in the Riemann integral. Integrals involve interconnected ideas of accumulation, area, symbolic manipulation, and rate of change, making them conceptually demanding for many students (Mateus-Nieves & Moll, 2021). However, many students struggle to distinguish among integration techniques such as substitution, by parts, and partial fractions, leading to conceptual, procedural, or computational errors (Meika et al., 2023; Sumargiyani et al., 2021). Recent studies also indicate that students' conceptual weaknesses frequently lead to transformation and process skill errors when solving non-routine integral problems (Moradi et al., 2023; Nurrasa & Nurrohman, 2024). Weak mastery of prerequisite concepts, particularly algebra and trigonometry, further contributes to students' difficulties in mathematizing problems and selecting appropriate integration procedures (Mahadewsing et al., 2024; Nurhayati, et al., 2023), limited conceptual understanding, and low confidence also contribute to students' difficulties (Angco, 2021). Such errors may include mistakes in determining the limits of integration, incorrect graphs, miscalculations, or inappropriate final answers (Nurhasanah & Dollo, 2021).

From a pedagogical perspective, the sequence in which integrals are introduced in schools and universities also plays a role in the emergence of these learning difficulties. Historically, integrals evolved from the concept of area before being formalized through the theory of limits in the 18th century. However, in modern teaching, this order is often reversed: in secondary school, integrals are introduced as antiderivatives, while in universities, they are taught through the Riemann approach. This inconsistency results in students' shallow conceptual understanding, as they are immediately introduced to abstract symbols and calculus procedures (García-García et al., 2025; Nilsen & Knutsen, 2023). In integral calculus courses, around 80% of students exhibit misconceptions (Ijuddin et al., 2022). Consequently, when faced with non-routine problems, students tend to struggle in flexibly applying integral concepts, leading to various errors in the problem-solving process (Angco, 2021; Meika et al., 2023). These findings suggest that students' difficulties in integral calculus are closely associated with weaknesses in conceptual understanding and mathematical problem-solving ability.

In learning integral calculus, the problems encountered require students to adopt a perspective that emphasizes the logical interconnection between concepts, rather than merely memorizing solution procedures (Soesanto & Dirgantoro, 2021). Mathematical problem-solving ability is one of the essential competencies necessary to achieve optimal learning outcomes. In integral calculus, problem-solving ability involves interpreting mathematical representations, selecting suitable integration techniques, executing symbolic procedures accurately, and evaluating the validity of solutions (Purnomo et al., 2022; Tatira, 2025). As one of the process standards according to NCTM (2000), problem-solving ability is a central focus of the mathematics curriculum that must be developed. This ability is closely related to reflective thinking, that is awareness of one's own thought processes when dealing with complex mathematical situations (Cumhur & Tezer, 2020). Furthermore, problem-solving activities not only help in obtaining answers but also strengthen the structure of an individual's mathematical knowledge (Widiasih & Maarif, 2022).

From a theoretical perspective, mathematical problem solving involves several interconnected cognitive stages, including understanding problems, selecting strategies, executing procedures, and evaluating solutions. Polya's model emphasizes understanding the problem, devising a plan, carrying out the plan, and looking back, while Krulik and Rudnick elaborate these stages into more detailed strategic processes

(Apriska et al., 2022). However, these models primarily describe general problem-solving processes and provide limited diagnostic information regarding the specific types of errors students make during each stage. In contrast, Newman Error Analysis (NEA) systematically classifies errors into reading, comprehension, transformation, process skill, and encoding stages, enabling educators to identify students' cognitive difficulties more specifically (Tobar et al., 2025). This staged diagnostic capability is particularly relevant in integral calculus because solving integral problems requires students to interpret mathematical representations, transform verbal or graphical information into mathematical models, select suitable integration techniques, execute symbolic procedures accurately, and communicate final solutions correctly (Moradi et al., 2023; Tatira, 2025).

To diagnose errors related to problem-solving ability in a more structured way, Newman's Error Analysis (NEA) serves as a relevant approach. According to Newman (1977), solving a mathematical problem involves five cognitive stages: reading, comprehension, transformation, process skill, and encoding. Errors can occur at one or more of these stages. The NEA model is considered more comprehensive than several general problem-solving models because it systematically identifies students' errors at each cognitive stage, including reading, comprehension, transformation, process skill, and encoding (Tobar et al., 2025). Such staged diagnostic analysis is highly relevant in integral calculus, where students must interpret representations, transform problems into mathematical expressions, apply integration techniques accurately, and communicate final solutions correctly. The concept of integrals has high epistemic complexity because it involves interconnected ideas such as accumulation, area, rate of change, symbolic manipulation, and multiple mathematical representations (Mateus-Nieves & Moll, 2021). However, integral calculus is often taught procedurally, causing students to memorize formulas and integration techniques without fully understanding their conceptual meaning (Kouropatov & Dreyfus, 2014). As a result, many students experience difficulties in connecting graphical, symbolic, and analytical representations of integrals, particularly when determining appropriate solution strategies (Bajracharya et al., 2023; Nilsen & Knutsen, 2023). These conceptual weaknesses frequently lead to procedural and computational errors in solving integral problems.

Research by Nurrasa & Nurrohman (2024) found that in solving integral problems, students most frequently made errors in the transformation, process skill, and encoding stages, particularly when applying substitution and integration by parts techniques. Several studies have reported that students commonly struggle to distinguish among integration techniques such as substitution, integration by parts, and partial fractions (Moradi et al., 2023; Nurrasa & Nurrohman, 2024). Weak mastery of prerequisite concepts, including algebra and trigonometry, further contributes to students' difficulties in selecting and applying appropriate procedures (Mahadewsing et al., 2024). Consequently, students often make errors in mathematizing problems, determining integration limits, manipulating symbolic expressions, and communicating final solutions correctly (Nurhayati, et al., 2023; Valdez & Taganap, 2024). Although previous studies have identified dominant error types in integral calculus, most have focused primarily on describing students' errors without simultaneously examining how those errors are related to students' mathematical problem-solving ability. Consequently, the relationship between students' problem-solving ability and specific error patterns in integral calculus remains insufficiently explored.

Therefore, this study aims to analyze students' errors in solving integral calculus problems based on Newman's Error Analysis (NEA) and to examine the relationship between students' problem-solving ability and the types of errors they produce. This study contributes to mathematics education research by providing a more comprehensive understanding of how conceptual and procedural difficulties interact during integral problem solving through the relationship between problem-solving ability and NEA error stages. Accordingly, the research questions of this study are: (1) What types of errors do students make in solving integral calculus problems based on the NEA framework? and (2) What is the relationship between students' problem-solving ability and the types of errors they make in solving integral calculus problems?

METHOD

This study employed a cross-sectional design with a quantitative descriptive-correlational approach. A cross-sectional design measures variables at a single point in time without intervention (Wang & Cheng, 2020). The study aimed to examine the relationship between students' problem-solving ability and error types in solving integral calculus problems based on Newman's Error Analysis (NEA). Problem-solving ability was assessed using indicators adapted from Krulik and Rudnick's problem-solving framework, including understanding the problem, planning a solution strategy, executing the solution process, and evaluating the obtained results.

The participants of this study were 74 first-year undergraduate students enrolled in the Integral Calculus course in the Mathematics Education Study Program at a public university in Indonesia during the 2024/2025 academic year. The course covered topics such as substitution, integration by parts, partial fractions, area, and volume integrals. All participants had previously completed prerequisite courses in basic calculus and algebra. Purposive sampling was employed to ensure that students had relatively similar learning experiences, including the same lecturer, instructional materials, and classroom environment.

The research instrument consisted of an integral calculus test containing five open-ended problems designed to measure students' problem-solving ability and identify error types based on the NEA framework. The problems involved several integral topics, including substitution, integration by parts, partial fractions, area, and volume applications. Students' problem-solving ability was assessed using indicators adapted from Krulik and Rudnick, namely understanding the problem, planning solution strategies, carrying out procedures, and evaluating solutions. The instrument was validated through expert judgment by two mathematics education lecturers specializing in calculus and mathematics evaluation. In addition, empirical validity testing showed that all item correlation coefficients exceeded the minimum validity threshold ($r > r_{table} = 0.229$) with significance values below 0.05, indicating that all test items were valid. Reliability testing using Cronbach's Alpha produced a coefficient of 0.786, which exceeded the acceptable reliability standard $(\alpha > 0.70)$. Therefore, the instrument was considered reliable and consistent in identifying students' errors in solving integral calculus problems.

The data obtained in this study were quantitative, derived from integral calculus test results. Data analysis was implemented in two stages: descriptive analysis and inferential analysis. In the descriptive analysis stage, problem-solving ability scores were examined using SPSS 26.0. Integral test scores were also computed, and error types were classified based on the NEA framework. The proportion and standard deviation of the proportion were subsequently calculated to illustrate the predominance of each type of student error.

The proportion of errors was calculated using:

$$p = \frac{x}{n}$$

where x represents the number of students who made an error employing a particular integral solution technique, and n denotes the total number of students analyzed.

The standard deviation of the proportion was calculated using the formula,

$$\sigma = \sqrt{p(1-p)}$$

both grounded in binomial distribution theory (Walpole et al., 2017). The proportion elucidates the ratio of students who made errors to the total number of respondents employing each integral technique, whereas the standard deviation of the proportion assesses the degree of variation or diversity of errors across techniques.

Interpretation of proportion values was conducted by referencing error level categories adapted from the descriptive analysis guidelines as per Riduwan (2009) and Sugiyono (2014) as delineated in Table 1 below.

Table 1. Interpretation of Propotion Values

Proportion Interval (p)	**Interpretation**
$p \geq 0{,}30$	High
$0{,}10 \leq p < 0{,}30$	Moderate
$p < 0{,}10$	Low

Inferential analysis was employed to determine the relationship between problem-solving ability and student error types grounded in NEA scores. Prior to conducting the correlation test, data normality was assessed using the Kolmogorov-Smirnov test. The Kolmogorov–Smirnov normality test indicated that the data were not normally distributed, with significance values of 0.021 for problem-solving ability scores and 0.003 for NEA error scores ($p < 0.05$). Therefore, the Spearman's rho correlation test was employed; hence, correlation analysis was performed utilizing the Spearman's rho correlation test, a nonparametric technique for measuring the proximity of the relationship between two ordinal or interval variables that do not adhere to a normal distribution (Ghozali, 2021; Sugiyono, 2019).

Interpretation of correlation coefficient (r_s) values was based on the Guilford criteria as detailed in Sugiyono (2019), as shown in Table 2.

Table 2. Interpretation of Correlation Coefficient Values

Correlation Coefficient Interval (r_s)	**Interpretation**
$0{,}00 - 0{,}19$	Very low
$0{,}20 - 0{,}39$	Low
$0{,}40 - 0{,}59$	Moderate
$0{,}60 - 0{,}79$	Strong
$0{,}80 - 1{,}00$	Very strong

The significance value (Sig. 2-tailed) in the Spearman correlation test signifies the confidence level in the relationship between two variables. A significance value of < 0.05 $(p < 0.05)$ indicates a statistically significant relationship.

Conversely, if $p > 0.05$, the relationship is deemed insignificant, suggesting insufficient evidence of a relationship between the variables (Ghozali, 2021; Sugiyono, 2019).

Table 3 presents the types of errors along with their corresponding indicators based on Newman's Error Analysis (NEA) (Tobar et al., 2025).

Table 3. Error Indicators Based on Newman's Error Analysis (NEA)

Type of Error	Error Indicators
Reading Error	Failure to identify important information in the problem.
	Incorrect determination of given data.
	Use of self-created symbols without explaining their meaning.
Comprehension Error	Providing incorrect answers due to incomplete or inaccurate understanding of the problem's elements.
	Writing brief but unclear responses with insufficient argumentation regarding what needs to be solved.
Transformation Error	Errors in selecting and applying the appropriate technique.
	Inaccuracy in transforming information into mathematical formulas.
Process Skill Error	Errors in performing arithmetic operations.
	Incomplete procedural steps in the solution process.
Encoding Error	Incorrect presentation of the final answer.
	The answer does not correspond to the given context.
	Inaccurate or inconsistent conclusions.

For the inferential analysis of students' errors in solving integral problems, each student's response was coded according to the NEA framework, which encompasses five types of errors: reading, comprehension, transformation, process skill, and encoding errors. In certain problems, students might commit more than one type of error; therefore, each response item could contain a maximum of two recorded errors. The coding process was conducted independently by two raters using a predefined codebook. Inter-rater reliability was subsequently assessed using Cohen's Kappa. The test yielded a coefficient value of $\kappa = 0{,}875$ with $p < 0{,}05$, indicating a very high level of agreement between the two raters. Thus, the error coding involving multiple error types per problem was deemed consistent and reliable for use in the main data analysis.

RESULT AND DISCUSSION

Results

This section presents the results of data analysis conducted to determine the relationship between students' problem-solving ability (PSA) and the types of errors they made in solving integral problems based on the Newman's Error Analysis (NEA) framework. The analysis consisted of two stages: descriptive analysis, which aimed to describe the patterns of students' errors, and inferential analysis using the Spearman correlation test to examine the strength and direction of the relationship between the two variables.

Before analyzing the relationship between PSA and the types of student errors based on NEA, descriptive statistics were first presented to provide an overview of the data distribution for both variables. The summary of descriptive statistics is shown in Table 4 below.

Table 4. Descriptive Statistics of Students' Problem-Solving Ability and Newman's Error Analysis Scores

Statistic	Problem-Solving Ability	Newman's Error Analysis
Minimum	15	1
Maximum	90	5
Mean	39,5405	4,5000
Median	30	5
Mode	20	5
Std. Deviation	21,92215	,92529
Variance	480,581	,856

Table 4 shows the descriptive statistics for the two analyzed variables: PSA and NEA. The students' PSA scores ranged from 15 to 90, with a mean of 39.54 and a standard deviation of 21.92, indicating a considerable degree of variability among students. For the NEA variable, students' total error scores ranged from 1 to 5, with an average score of 4.5 and a standard deviation of 0.93. In this study, higher NEA scores indicate that students experienced a greater number of error types during the problem-solving process. Thus, the relatively high mean score suggests that most students encountered multiple forms of errors simultaneously when solving integral calculus problems, particularly at the transformation and procedural stages. This finding indicates that students' difficulties were not limited to isolated computational mistakes, but involved interconnected conceptual and strategic weaknesses throughout the solution process.

Students' final PSA scores were categorized into three levels, that is low, moderate, and high based on the mean ($\bar{X}$) and standard deviation (SD), following the classification guidelines by Arikunto (2013), The classification criteria and frequency distribution are presented in Table 5.

Table 5. Categorization of Students' Problem-Solving Ability

Category	Score Interval	Frequency
High	61,47 – 90	8
Moderate	17,62 – 61,46	64
Low	15 – 17,61	2

Based on the categorization in Table 5, the majority of students (64 out of 74) fell within the moderate category, with scores ranging from 17.62 to 61.46. Only eight students were classified as high, while two students were in the low category. These results suggest that most students possessed moderate PSA in integral calculus.

The following Table 6 presents the average percentage of student errors across the five NEA error types. The NEA data are nominal, as each error type was coded dichotomously (1 = error occurred, 0 = no error). For descriptive purposes, these nominal data were converted into proportions and percentages to illustrate the prevalence of each type of error across the stages of problem-solving.

Table 6. Average Percentage of Errors Based on Newman's Error Analysis

Type of Error	Average Percentage	p	σ	Interpretation
Reading Error	0%	0,0000	0,000	Low
Comprehension Error	12,97%	0,1297	0,336	Moderate
Transformation Error	58,11%	0,5811	0,492	High
Process Skill Error	22,97%	0,2297	0,421	Moderate
Encoding Error	0%	0,0000	0,000	Low

As shown in Table 6, the most frequent type of error made by students was transformation error, with an average percentage of 58.11% (high category). This indicates that many students experienced difficulties in selecting appropriate integration strategies and transforming problem information into correct mathematical procedures. One common example occurred in integration by parts problems, where several students incorrectly used substitution methods despite explicit instructions to apply integration by parts. This response demonstrates difficulties in identifying the mathematical structure of the problem and determining suitable solution strategies.

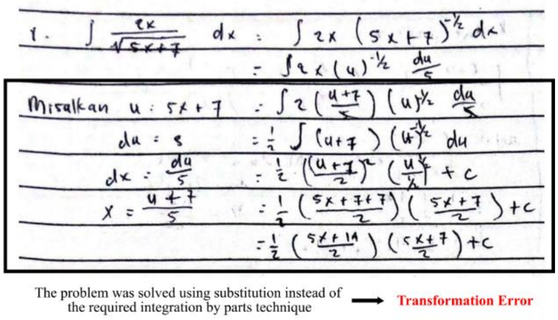

Figure 1. Example of a Transformation Error in Solving an Integration by Parts Problem

The Figure 1 illustrates a student's transformation error in solving an integral calculus problem. Although the problem required the use of integration by parts, the student applied the substitution method instead. This response indicates difficulty in selecting an appropriate integration strategy and transforming the problem into a suitable mathematical procedure. Such errors reflect weaknesses in conceptual understanding and strategic problem-solving during the transformation stage of Newman's Error Analysis (NEA).

The dominance of transformation error suggests that students' difficulties in integral calculus are more conceptual and strategic than merely computational. Many students appeared to memorize integration formulas procedurally without fully understanding when and why certain methods should be applied. Similar findings were reported by Machromah & Purnomo (2017), Moradi et al. (2023), Nurrasa & Nurrohman (2024) who found that transformation and process skill errors were the most dominant errors in solving integral problems. Meanwhile, reading and encoding errors were absent because students generally had no difficulty interpreting mathematical symbols or writing final answers in standard notation.

The process skill error (22.97%) and comprehension error (12.97%) fell into the moderate category, suggesting that a considerable proportion of students still struggled at the stages of understanding and executing problem-solving procedures. Meanwhile, reading and encoding errors both recorded 0%, indicating that students generally had no difficulty interpreting mathematical symbols or expressing answers in formal mathematical notation. This finding may be influenced by the participants' academic background as university students who had already completed prerequisite mathematics courses and were familiar with standard calculus terminology and symbolic representations. In the context of integral calculus, the main challenge therefore did not lie in reading the problem or writing the final answer, but rather in selecting appropriate integration strategies and transforming conceptual understanding into correct mathematical procedures. In the context of integral calculus at the undergraduate level, the problems used in this study employed familiar mathematical notation and standard answer formats. Consequently, students' difficulties tended to emerge not at the surface level of reading or answer presentation, but rather at deeper conceptual and strategic stages, especially when determining appropriate integration methods and constructing mathematical models.

Table 7. Spearman Correlation between KPM dan NEA

Correlation (ρ)	Sig. (2-tailed)	Interpretation
-0,787	0,000	Strong

As displayed in Table 7, the Spearman correlation analysis revealed a strong negative relationship between students' problem-solving ability (PSA) and the types of errors they committed in integral calculus based on the NEA framework, with a correlation coefficient of $r_s = -0{,}787$. This correlation is significant at the 0.01 level (2-tailed), indicating that the higher the students' problem-solving ability, the fewer errors they tend to make. According to Guilford's criteria as cited in Sugiyono (2019), this correlation coefficient falls within the "strong" category. This finding indicates that students with higher PSA tended to make fewer errors, particularly transformation and procedural errors. Substantively, students with strong problem-solving ability were more likely to apply systematic and reflective thinking strategies when selecting integration methods and evaluating solution steps. In contrast, students with lower PSA tended to rely on memorized procedures without sufficient conceptual understanding. These findings strengthen previous NEA studies by showing that dominant transformation errors are closely associated with students' moderate problem-solving ability in integral calculus.

Discussion

Students' Problem-Solving Ability in Solving Integral Calculus Problems

The results of the analysis revealed that the mean score of students' problem-solving ability (PSA) was 39.54, with a standard deviation of 21.92. Based on the categorization approach using the mean and standard deviation proposed by Arikunto (2013), students were grouped into three ability levels. A total of 8 students were classified in the high category (score range 61.47–90), 64 students in the moderate category (17.62–61.46), and 2 students in the low category (15–17.61). These findings indicate that students' problem-solving ability in integral calculus remains suboptimal, with the majority not yet reaching the high level.

The moderate level of students' PSA found in this study reflects the theoretical issue highlighted in the introduction, namely the tendency of integral calculus instruction to emphasize procedural manipulation rather than conceptual understanding. Although students had completed integral calculus instruction, many still relied on memorized algorithms without fully understanding the underlying meanings of integration concepts. Consequently, students were generally able to perform routine procedures in familiar contexts but struggled when confronted with problems requiring conceptual interpretation, representation transformation, and strategic flexibility. This finding supports Mateus-Nieves & Moll (2021), who argued that fragmented teaching of symbolic procedures limits students' ability to connect graphical, conceptual, and analytical meanings of integrals. Similar concerns were reported by Thompson & Harel (2021), who emphasized that many students fail to develop foundational calculus ideas such as accumulation, covariation, and functional reasoning, leading to superficial procedural performance. Hernandez-Martinez et al. (2024) further noted that students frequently demonstrate procedural fluency without coherent conceptual integration when solving advanced mathematical tasks. In addition, Borji & Martínez-Planell (2023) highlighted that students often experience cognitive overload in calculus because they rely heavily on memorized procedures rather than conceptual structures. Collectively, these findings indicate that students' moderate PSA may stem from instructional experiences that prioritize algorithmic execution over conceptual mathematization and reflective reasoning.

Students' problem-solving ability in integral calculus is often hindered by difficulties in connecting symbolic, graphical, and conceptual representations of integrals. Recent studies have shown that instructional approaches emphasizing reasoning, conceptual connections, and multiple representations can significantly improve students' mathematical problem-solving performance (Borji & Martínez-Planell, 2023; García-García et al., 2025). In addition, many students still demonstrate limited metacognitive awareness, particularly in identifying problem characteristics, evaluating solution procedures, and selecting appropriate integration strategies (Lisa et al., 2024; Tatira, 2025). Research by Mahadewsing et al. (2024) further revealed that students generally perform better in understanding problem statements than in executing and verifying procedural steps, especially in complex integral applications. Students' prior mathematical knowledge and conceptual understanding also strongly influence their ability to solve integral problems effectively (Aziz et al., 2025). Furthermore, the ability to select suitable problem-solving strategies plays an important role during the analytical and transformational stages of integral problem solving (Jufri et al., 2025; Moradi et al., 2023). These findings suggest that instructional interventions emphasizing conceptual reasoning, metacognitive reflection, and structured problem-solving practices are essential for improving students' PSA in integral calculus.

Students' Errors in Solving Integral Calculus Problems

Based on the analysis, transformation error emerged as the most dominant error type, followed by process skill and comprehension errors. This pattern indicates that students' primary difficulty did not lie in reading mathematical information, but rather in transforming conceptual understanding into an appropriate mathematical strategy. Compared with previous NEA studies in integral calculus contexts (Nurrasa & Nurrohman, 2024), the present study similarly found that students frequently failed in selecting suitable integration techniques. However, this study further demonstrates that the predominance of transformation error is strongly associated with students' moderate problem-solving ability, suggesting that weaknesses in mathematization and strategic reasoning are central contributors to students' calculus difficulties.

The dominance of transformation errors may also stem from learning experiences that prioritize procedural fluency over conceptual exploration. Students are often trained to memorize formulas and recognize surface-level patterns without understanding why a particular integration method is appropriate for a given problem structure. Consequently, when encountering non-routine or contextual integral problems, students struggle to connect symbolic forms with conceptual representations, leading to incorrect strategy selection.

Similar findings were reported by Moradi et al. (2023), who observed that engineering students frequently selected inappropriate integration methods despite understanding the overall problem context. Tatira (2025) also found that undergraduate students experienced major difficulties when applying integral calculus concepts in kinematics contexts because they tended to remain at procedural levels rather than conceptual reasoning stages. In addition, Sobrinho et al. (2024) emphasized that many students fail to coordinate mathematical representations during calculus problem solving, which contributes directly to transformation-related difficulties. These findings reinforce the argument that transformation errors are strongly linked to limitations in conceptual modeling and strategic problem-solving processes.

The analysis showed that transformation errors were predominant, referring to mistakes in converting the understanding of a problem into an appropriate mathematical model leading to a solution. These errors were primarily related to the selection of the correct integration technique. Although most students understood the problem context, many were uncertain whether to apply substitution, integration by parts, partial fractions, or geometric approaches (Aziz et al., 2025; Moradi et al., 2023). Students also experienced difficulties in conceptual understanding, procedural reasoning, and strategic decision-making when solving integral problems, particularly in determining and applying suitable integration methods (Lisa et al., 2024; García-García et al., 2025). These findings indicate that distinguishing among integration techniques remains a major challenge in integral calculus learning.

Transformation errors occur when students fail to translate problem information into an appropriate mathematical representation, especially when selecting the correct integration strategy. For example, several students used substitution methods in problems that explicitly required integration by parts, indicating weaknesses in strategy selection and conceptual transformation. Such difficulties are closely related to insufficient mastery of integral concepts, limited procedural flexibility, and weak mathematical reasoning skills (Mahadewsing et al., 2024; Tatira, 2025). When the initial transformation stage is incorrect, subsequent procedural (process skill) errors are also likely to occur because students continue operating based on an inappropriate solution structure (Jufri et al., 2025). Similar patterns were reported by Valdez & Taganap (2024) and Tobar et al. (2025), who found that inaccurate mathematization and ineffective problem analysis significantly contribute to dominant transformation errors in mathematical problem solving.

In addition, process skill errors frequently occur when students face difficulties in algebraic manipulation or basic arithmetic operations, as well as other procedural mistakes resulting from an incomplete understanding of precalculus concepts (Machromah & Purnomo, 2017; Moradi et al., 2023). Mahadewsing et al. (2024) emphasized that weak mastery of prerequisite topics, such as algebra and trigonometry, is a dominant factor contributing to procedural errors, while inaccuracy and limited conceptual understanding further exacerbate these issues.

Comprehension errors occur when students fail to interpret and reorganize problem information into forms that facilitate integration, particularly in problems involving area and volume applications. Students often experience difficulties in identifying the meaning of integral expressions, determining limits of integration, and relating graphical representations to appropriate solution procedures (Bajracharya et al., 2023; Borji & Martínez-Planell, 2023). These errors indicate weaknesses in conceptual understanding of integrals and their applications, especially when students are required to connect symbolic, graphical, and contextual representations simultaneously (García-García et al., 2025). Meanwhile, reading and encoding errors were either very low or absent because the integral problems used in this study employed familiar mathematical notation and structured procedural formats commonly encountered in calculus instruction. As a result, most students were able to identify the given information and present final answers appropriately, even when conceptual or transformational mistakes occurred during intermediate solution stages (Aziz et al., 2025; Valdez & Taganap, 2024).

Overall, the findings of this study not only confirm previous research regarding the predominance of transformation errors in integral calculus, but also extend the existing literature by demonstrating how these errors are strongly associated with students' moderate problem-solving ability (PSA). Previous studies generally examined NEA error types descriptively (Jufri et al., 2025; Machromah & Purnomo, 2017; Nurrasa & Nurrohman, 2024), while this study specifically reveals that students with moderate PSA tend to experience difficulties in selecting and constructing appropriate integration strategies, particularly when distinguishing among substitution, integration by parts, and other integration techniques. This finding suggests that transformation errors are not merely procedural mistakes, but are closely related to limitations in conceptual understanding, strategic reasoning, and metacognitive decision-making during problem solving. In the context of Indonesian mathematics education, this study contributes empirical evidence that the dominance of transformation errors reflects the continuing tendency of integral calculus instruction to emphasize procedural execution over conceptual mathematization. Thus, the novelty of this study lies in integrating PSA analysis with the NEA framework to explain how different levels of problem-solving ability relate to specific patterns of student errors in integral calculus learning.

The Relationship Between Problem-Solving Ability and Students' Errors in Solving Integral Calculus Problems

Based on the data analysis, the Spearman correlation coefficient between students' problem-solving ability (PSA) and the number of errors according to Newman's Error Analysis (NEA) was found to be $\rho = -0,787$ with $p = 0,000$, indicating a strong and significant negative correlation at the $0,01$ (2-tailed). This means that the higher the students' problem-solving ability, the fewer errors they made when solving integral calculus problems, and vice versa.

The strong negative correlation between students' problem-solving ability (PSA) and NEA error types indicates that students with higher PSA tend to apply more systematic and reflective thinking when solving integral calculus problems. These students are more capable of identifying relevant information, selecting appropriate integration techniques, monitoring procedural steps, and evaluating the correctness of their final solutions. In contrast, students with lower or moderate PSA often rely on memorized algorithms without fully understanding the conceptual structure of the problem, which increases the likelihood of transformation and process skill errors. This finding supports Radmehr & Drake (2020), who emphasized that metacognitive awareness plays an important role in recognizing problem types, evaluating solution strategies, and verifying mathematical procedures. Similarly, Thompson & Harel (2021) argued that weak foundational calculus reasoning limits students' ability to flexibly connect symbolic procedures with conceptual meanings.

The findings also suggest that transformation errors are closely associated with insufficient strategic reasoning rather than merely computational weaknesses. Students with moderate PSA were generally able to understand the problem context, yet they frequently failed to determine the most appropriate integration strategy, such as distinguishing between substitution and integration by parts. This indicates that the difficulty lies not only in executing procedures, but also in constructing suitable mathematical representations and solution plans. Similar patterns were reported by Hernandez-Martinez et al. (2024), Borji & Martínez-Planell (2023), and Moradi et al. (2023), who found that students often demonstrate procedural fluency while lacking coherent conceptual integration during advanced calculus problem solving. Similar findings were also reported by Wilcox & Corsiglia (2019) and Tatira (2025), who found that students frequently struggle to activate appropriate integral concepts and strategies when solving non-routine calculus problems.

The novelty of this study lies not only in identifying a statistical relationship between PSA and NEA errors, but also in demonstrating how specific types of errors are connected to different levels of students' problem-solving ability in integral calculus. Previous studies commonly analyzed students' errors descriptively or examined problem-solving ability separately (Nurrasa & Nurrohman, 2024; Purnomo et al., 2022). In contrast, this study integrates PSA and NEA analyses to show that the predominance of transformation errors among students with moderate PSA reflects limitations in conceptual mathematization, strategic flexibility, and metacognitive regulation. This finding contributes to mathematics education research by providing a more comprehensive explanation of how students' problem-solving characteristics influence the emergence of particular error patterns in integral calculus learning.

Overall, the results of this study affirm that enhancing students' problem-solving ability can directly reduce the frequency of errors in solving integral problems. Therefore, instructional strategies that emphasize the development of analytical skills, conceptual understanding, and systematic problem-solving practices are crucial for improving the quality of students' performance in integral calculus.

Students' difficulties in integral calculus are closely related to their prior learning experiences. Most students are accustomed to perceiving integrals as antiderivatives since high school, which means that the historical, symbolic, and conceptual meanings of integrals are not fully understood (García-García et al., 2025; Nilsen & Knutsen, 2023). This limitation becomes problematic when students encounter problems not directly related to antiderivatives, such as improper integrals, area integrals, or volume integrals (Khounphia et al., 2020; Nurhayati, et al., 2023). Teaching that overemphasizes mechanical formulas without conceptual context further increases students' cognitive load, as they are required to memorize procedural steps without understanding the reasoning behind them.

Students are seldom given opportunities to build an understanding of integrals as the accumulation of infinitesimal changes into a total quantity (Palha & Spandaw, 2019). Moreover, tasks that promote integrated conceptual connections are crucial for developing a deeper understanding of integral concepts (García-García et al., 2025). Learners who are accustomed to single representations often struggle with problems that require multiple representations (Dinçer, 2022). The coherent integration of geometric, symbolic, and procedural meanings of integrals can significantly enhance students' conceptual understanding (Mateus-Nieves & Moll, 2021). Using multiple representations, that is graphical, symbolic, and verbal, simultaneously helps students build stronger conceptual connections (Vasu, 2017). This perspective aligns with Bruner's theory of representation, which suggests that mathematical understanding develops through enactive, iconic, and symbolic modes (Bruner & Kenney, 1965). In the context of integral calculus, this means that learners should first experience integrals through concrete or visual representations before abstracting them into formal symbolic expressions. Such progression supports deeper conceptual learning and reduces students' reliance on rote procedural methods.

Unlike previous studies that primarily focused on identifying isolated error types in integral calculus, this study demonstrates that dominant transformation errors are strongly associated with students' moderate levels of problem-solving ability. This finding provides a more integrated perspective by showing that students' errors are not merely procedural failures, but are closely related to limitations in conceptual reasoning, strategy selection, and mathematical transformation processes in integral calculus learning.

Implication

The findings of this study imply that integral calculus instruction should move beyond procedural practice toward learning approaches that strengthen conceptual understanding, strategic reasoning, and metacognitive reflection. The dominance of transformation and process skill errors indicates that many students are still unable to appropriately translate problem situations into mathematical representations and select suitable integration techniques. This finding is closely related to the theoretical gap identified in the introduction, namely that integral learning tends to emphasize algorithmic procedures rather than conceptual mathematization. Therefore, lecturers should design instructional activities that explicitly train students to analyze problem structures, compare multiple integration strategies, and justify the selection of particular methods such as substitution or integration by parts.

In addition, the prevalence of process skill errors suggests the need for stronger reinforcement of prerequisite knowledge, particularly algebraic manipulation and trigonometric reasoning, which are essential for successful integral problem solving. The use of multiple representations, like graphical, symbolic, and verbal, can also help students build deeper conceptual connections and reduce dependence on memorized formulas. From a pedagogical perspective, the integration of NEA-based diagnostic assessment into calculus instruction may assist lecturers in identifying students' difficulties more specifically at each stage of problem solving. Thus, this study provides practical implications for developing calculus learning environments that not only improve procedural fluency, but also enhance students' conceptual reasoning and strategic problem-solving abilities.

Limitation

This study has several limitations that should be considered when interpreting the findings. First, the sample was limited to 74 undergraduate students from a single institution, which may restrict the generalizability of the relationship between problem-solving ability (PSA) and NEA error types to broader contexts. Second, the cross-sectional design only captured students' performance at one point in time; therefore, the significant negative correlation found in this study should be interpreted as associative rather than causal. Third, the analysis relied mainly on written responses, which may not fully reveal students' metacognitive reasoning or strategy selection processes underlying transformation and process skill errors. Finally, instructional and environmental factors, such as prior calculus experience and teaching approaches, were not fully controlled and may have influenced students' performance. Future research is recommended to use longitudinal or mixed-method approaches involving interviews or think-aloud protocols to provide deeper insights into students' reasoning processes in integral calculus problem solving.

CONCLUSION

This study concludes that students' difficulties in integral calculus are predominantly rooted in weaknesses at the transformation stage, particularly in selecting and translating appropriate integration strategies into mathematical procedures. The strong negative relationship between problem-solving ability and NEA error types indicates that students with stronger analytical and metacognitive problem-solving skills tend to construct more systematic solution pathways and commit fewer conceptual and procedural errors. The findings reinforce the argument that difficulties in integral calculus are not solely caused by computational limitations, but also by the dominance of procedural learning practices that insufficiently develop conceptual understanding and mathematical representations. This study contributes to mathematics education research by demonstrating that NEA can function not only as an error classification framework but also as a diagnostic lens for understanding how problem-solving ability influences students' mathematical reasoning processes in integral calculus learning.

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