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Analysis of Students' Errors in Solving Analytical Geometry Parabolic Problems

Reny Wahyuni[1], Efuansyah[2]*
[1]Department of Mathematics Education, Universitas PGRI Silampari, Indonesia
[2]Department of Mathematics Education, Universitas PGRI Silampari, Indonesia
***Corresponding author:** efuansyah22@email.com

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ABSTRACT

This study aims to analyze students' errors in solving parabola problems in conic sections based on Fong's scheme. The research employed a qualitative descriptive method involving students enrolled in the Analytical Geometry course. Data were collected through written tests and interviews. The instrument consisted of descriptive problems related to parabola equations, focus, directrix, axis of symmetry, direction of opening, and latus rectum length. Data analysis referred to Fong's scheme, which classifies errors into five first-level categories: (E1) no solution, (E2) inappropriate procedures, (E3) incomplete schema without solution, (E4) incomplete schema with errors, and (E5) complete schema with errors. The findings revealed that the most dominant errors were category (E4) at 33.33% and category (E2) at 30%. Category (E3) errors accounted for 16.67%, while categories (E1) and (E5) each contributed 10%. Based on the second-level analysis, students made language, operational, mathematical theme, and psychological errors. These errors were caused by limited conceptual understanding, inaccurate formula application, and lack of accuracy in algebraic operations. Therefore, analytical geometry instruction should emphasize conceptual understanding and visualization to improve students' systematic and accurate problem-solving abilities.

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1. INTRODUCTION

Analytical Geometry is one of the mathematical courses that integrates geometric and algebraic concepts in solving various mathematical problems. In the learning process, students are required to possess adequate skills in both geometry and algebra to achieve a comprehensive understanding of the concepts being studied. This is consistent with the views of Azka et al. (2021) and Sugandi et al. (2022), who stated that analytical geometry involves the mathematical analysis of geometric objects through an algebraic approach. Furthermore, research conducted by

Syahbana et al. (2025) indicated that students demonstrate a relatively good understanding of Analytical Geometry concepts; however, they experience considerable difficulties in understanding and solving problems related to spatial Analytical Geometry, particularly in the visualization of three-dimensional objects and the application of concepts in problem-solving. One of the important topics in analytical geometry is conic sections, which include the parabola, ellipse, and hyperbola. This material not only aims to enhance students' mathematical abilities but also develops logical, systematic, accurate, effective, and efficient thinking skills in addressing the challenges posed by scientific and technological advancement (Hartini, 2020).

Nevertheless, conic sections material is still considered difficult by most students. This difficulty arises because the material contains numerous abstract equations and formulas that require strong visualization skills for proper understanding (Suprapti, 2020). Dintarini, Budiarto, & Fuad (2025) revealed that spatial thinking plays an important role in solving problems related to conic sections. The results of their study showed that students with high spatial thinking abilities demonstrated strong mental visualization skills, whereas students with lower spatial thinking abilities experienced difficulties in visualizing complex objects and frequently misinterpreted spatial representations (Dintarini et al., 2025). In addition, the lack of instructional approaches capable of providing concrete representations of conic section concepts has resulted in uneven student learning outcomes (Endrian et al., 2020). In parabola material, for example, students often encounter difficulties in determining parabola equations, understanding the concepts of focus, directrix, and axis of symmetry, identifying the form of a parabola equation based on the direction of its opening, and determining the parabola equation when the length of the latus rectum is known. These difficulties represent common problems frequently encountered in learning conic sections (Sudihartinih & Purnianti, 2020). Furthermore, Dintarini, Fuad, & Budiarto (2024) added that students face challenges in the process of abstracting conic section concepts, particularly in visualizing conic section objects, thinking spatially, and using mathematical notation accurately (Dintarini et al., 2024). In addition, Sari & Roesdiana (2019) stated that many students are still unable to solve parabola problems correctly.

These difficulties indicate that students still make many errors in solving problems related to conic sections, particularly parabola problems. Recent studies have revealed that more than half of the student participants made errors in conic section material, with the most common error in parabola material being categorized as an incomplete schema with errors (E4) (Sudihartinih & Purnianti, 2020). Therefore, an error analysis is necessary to identify the forms and causes of the errors experienced by students. The results of the analysis can serve as evaluation material for educators in designing more appropriate teaching materials, instructional media, and learning methods to minimize students' errors in understanding conic section concepts.

Error analysis in mathematics learning can be conducted using various methods, such as Newman's, Watson's, Kastolan's, Polya's, Luneta's, and Fong's schemes. Among these methods, Fong's scheme is considered more specific and comprehensive in identifying students' errors (Sara et al., 2020; Rahmawati et al., 2018). Previous studies have also confirmed that Fong's schematic model is effective in analyzing students' errors across various mathematical topics, including procedural aspects, mathematical operations, conceptual understanding, and psychological factors (Mantik et al., 2025). Therefore, this study employs Fong's scheme as the framework for error analysis. According to Fong (1993), Fong's scheme consists of two levels of analysis. The first level includes five categories of errors: (E1) no solution, (E2) inappropriate solution procedures, (E3) incomplete schema without a solution, (E4) incomplete schema with errors, and (E5) complete schema containing errors. Furthermore, the second level consists of four categories of errors, namely language, operational, mathematical theme, and psychological errors. Language errors are related to misunderstandings of symbols, terms, or illustrations; operational errors are associated with calculation procedures; mathematical theme errors are related to the application of concepts or formulas; whereas psychological errors occur due to a lack of carefulness in solving problems. The categories at the second level function as subcategories of E2, E4, and E5 at the first level. Research has shown that, in parabola material, the most common second-level errors made by students are language and operational errors (Sudihartinih & Purnianti, 2021).

Research on error analysis in geometry has previously been conducted on various topics, including plane analytical geometry (Ikashum et al., 2021), the concepts of points and lines in a plane (Sudihartinih, 2018), line equations (Marits & Sudihartinih, 2022), circles (Salsabila et al., 2026), geometric problem-solving (Wahyuni et al., 2026), and spatial analytical geometry (Masud, 2020). In addition, the application of Fong's scheme in error analysis has also been implemented in studies on systems of linear equations in three variables (Sara et al., 2020), social arithmetic (Rahmawati et al., 2018), and the volumes of triangular prisms and cylinders (Hidayat, 2017). A systematic literature review revealed that research on error analysis using Fong's scheme was most commonly conducted among junior high school students, particularly on solid geometry topics, with procedural errors and incomplete conclusions identified as the most frequent types of errors (Gulvara et al., 2023). However, based on the review of previous studies, no research has specifically analyzed students' errors in conic section material using Fong's scheme. Therefore, this study is important for identifying the forms of students' errors in conic section material, particularly parabolas, so that the findings may serve as a basis for improving the analytical geometry learning process in higher education.

2. METHODS

This study employed a qualitative descriptive approach aimed at describing the types and causes of students' errors in solving problems related to conic sections, particularly parabolas, based on Fong's scheme. The qualitative descriptive approach was selected because the study focuses on an in-depth analysis of the processes and forms of errors made by students in solving mathematical problems. The use of qualitative descriptive approaches in mathematical error analysis has been widely adopted because it enables researchers to explore deeply the phenomena of errors and the factors causing them (Syahbana et al., 2025; Naibaho et al., 2025).

2.1 Research Design

This research used a qualitative descriptive design. The design was chosen because it allows researchers to analyze in depth the forms of students' errors and the factors causing those errors in solving parabola problems. The study focused on describing and interpreting students' problem-solving processes based on Fong's scheme. Qualitative descriptive approaches are widely applied in mathematics education research because they provide detailed insights into students' mathematical thinking and error patterns (Syahbana et al., 2025; Naibaho et al., 2025).

2.2 Participants and Setting

The research subjects consisted of 30 students enrolled in an Analytical Geometry course at PGRI Silampari University in the Odd Semester of 2025/2026. The participants were selected using purposive sampling based on the consideration that they had previously studied conic sections, particularly parabola material. From the total number of students participating in the written test, 3 students representing different categories of errors were selected for further analysis. The purposive sampling technique was used to obtain subjects capable of providing in-depth information regarding the types and causes of errors (Naibaho et al., 2025). The research was conducted in a university setting during the Analytical Geometry course. Ethical considerations were maintained throughout the study by ensuring that students participated voluntarily and that their identities remained confidential during the reporting of the findings.

2.3 Data Collection and Analysis

2.3.1 Instruments

The data collection techniques used in this study included written tests and interviews. The written test instrument consisted of essay questions designed to measure students' abilities in parabola material, including determining parabola equations, identifying the focus, directrix, and axis of symmetry, determining the form of the parabola equation based on the direction of its opening, and determining the parabola equation based on the length of the latus rectum. The test items were developed based on learning indicators and validated by experts to ensure content validity and clarity. In addition to the written tests, interviews were conducted to obtain deeper information regarding students' reasoning and thought processes in solving the problems. The combination of written tests and interviews enabled the researchers not only to identify the errors but also to understand the causes of those errors more accurately (Marits & Sudihartinih, 2022). The validity of the data was strengthened through triangulation techniques by comparing the results of the written tests with the interview findings. Triangulation was conducted to ensure that the data accurately represented the forms and causes of students' errors in solving parabola-related problems (Utaminingtyas & Prihastari, 2025).

2.3.2 Analysis Procedures

The research data were analyzed using Fong's scheme, which consists of two levels of analysis. The first level includes five categories of errors: (E1) no solution, (E2) inappropriate solution procedures, (E3) incomplete schema without a solution, (E4) incomplete schema with errors, and (E5) complete schema containing errors. The second level identifies the types of errors, including language, operational, mathematical theme, and psychological errors. The data analysis procedures were conducted through several stages: (1) examining students' written work, (2) classifying the errors based on Fong's scheme categories, (3) analyzing the causes of errors through interview results, and (4) drawing conclusions based on the findings. This procedure is consistent with qualitative data analysis methods commonly applied in mathematics education research, including data reduction, data presentation, and conclusion drawing (Mas'ud, 2021).

3. RESULTS AND DISCUSSION

Based on the results of the written tests and interviews conducted with students on parabola material in conic sections, various forms of errors were identified and analyzed using Fong's scheme. Students' errors were classified into five categories at the first level: (E1) no solution, (E2) inappropriate solution procedures, (E3) incomplete schema without a solution, (E4) incomplete schema with errors, and (E5) complete schema containing errors, as presented in Table 1. The results of the study showed that the most dominant errors made by students were categories (E2) and (E4). This finding is consistent with the study conducted by Sadidah & Sudihartinih (2023), which reported that the most common errors made by students in parabola material were incomplete schemas with errors, as well as operational and language errors. Other studies have also revealed that, at the first level of Fong's scheme, the most frequently identified errors were procedural errors (E2) and incomplete schemas with errors (E4), both of which require serious attention in mathematics learning (Gulvara et al., 2023). Meanwhile, at the second level, the dominant types of errors in parabola material included language and operational errors, in which language errors were related to the understanding of symbols and terms, whereas operational errors were associated with calculation procedures (Sadidah & Sudihartinih, 2023).

Table 1. Percentage of Student Error Based on Fong's Scheme

No	Categories of Fong Scheme Errors	Code	Number of Students	Percentage (%)
1	No solution	E1	3	10%
2	Inappropriate solution procedures	E2	9	30%
3	An incomplete scheme without a solution	E3	5	16,67%
4	Incomplete schema with errors	E4	10	33,33%
5	Complete schema but contains errors	E5	3	10%

Note, n = 30 students

Based on Table 1, the most dominant category of errors made by students was incomplete schemas with errors (E4), with a percentage of 33.33%. This finding indicates that most students attempted to solve the problems; however, their solution procedures remained incomplete and were accompanied by conceptual and calculation errors. According to Fong (1993), E4 category errors occur when students understand part of the solution procedure but are unable to solve the problem accurately and completely. These findings are consistent with the study conducted by Sadidah & Sudihartinih (2023), which reported that incomplete schemas with errors were the most common errors in parabola material at the first level of Fong's scheme. Research by Rahmawati et al. (2018) also revealed that students frequently make procedural errors because they do not adequately understand fundamental concepts and lack accuracy in performing mathematical operations.

The E4 category errors identified in this study occurred when students attempted to solve the problems but used incomplete procedures and still made conceptual and calculation errors. For example, in problems requiring students to determine a parabola equation when the focus and directrix were known, several students correctly identified the vertex but incorrectly determined the parabola parameter values, resulting in incorrect final answers.

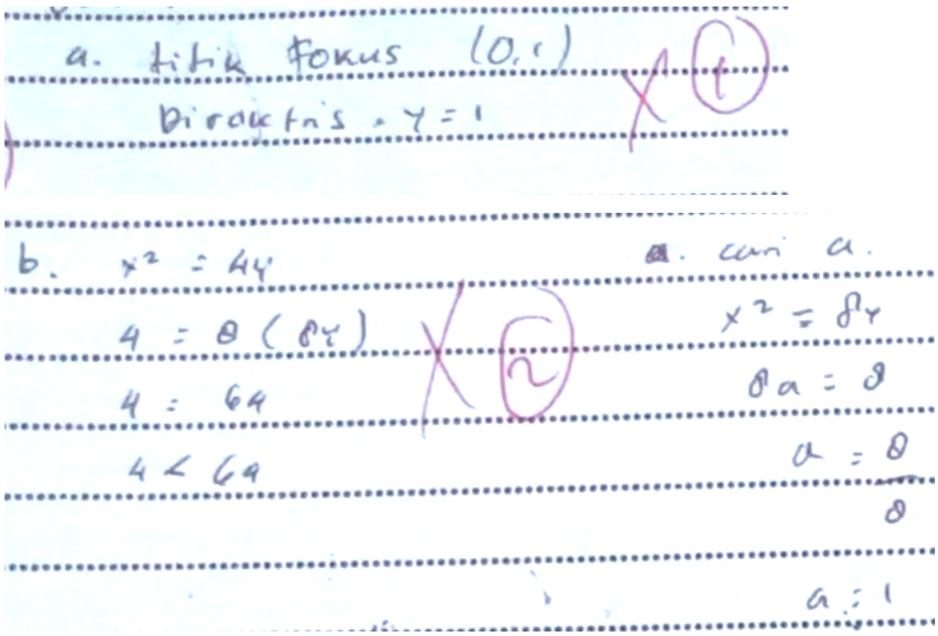

Figure 1. Student Error Category E4

Based on Figure 1, these errors are classified as mathematical theme and operational errors. Interview results indicated that students were often confused when applying parabola formulas because they had to understand multiple equation forms. This condition is consistent with the findings of Suprapti (2020), who stated that conic section material contains numerous formulas and abstract concepts that are difficult to understand without clear visualization. Sadidah & Sudihartinih (2023) also found that, at the second level of Fong's scheme, the dominant errors in parabola material were language and operational errors. In addition to conceptual errors, psychological errors were identified in the form of students' lack of accuracy when performing algebraic operations. Some students incorrectly applied positive and negative signs when simplifying equations, indicating that they did not recheck their work. Rahmawati et al. (2018) stated that operational errors frequently arise because of students' low accuracy in performing mathematical calculations. Similar findings were obtained in this study, in which students generally understood the solution procedures but still produced incorrect answers because of calculation errors.

The second most dominant error category was inappropriate solution procedures (E2), with a percentage of 30%. These errors indicate that students still experience difficulties in determining appropriate procedures for solving parabola problems, particularly in identifying the focus, directrix, axis of symmetry, and the form of the parabola equation based on its direction of opening. Sudihartinih & Purnianti (2020) stated that students often experience misconceptions regarding parabola material because they do not understand the relationship between the form of a parabola equation and its geometric elements. In addition, Suprapti (2020) explained that the large number of formulas in conic section material causes students to memorize formulas without understanding the underlying concepts. In a study on improving learning achievement through the discovery learning model, Suprapti (2020) revealed that many students study mathematics reluctantly and perceive mathematics as a difficult and intimidating subject, resulting in suboptimal learning processes and learning outcomes below the established graduation standards.

The E2 category errors occurred when students used solution procedures that were inconsistent with the appropriate parabola concepts. These errors were frequently found in problems involving the determination of the focus, directrix, and form of parabola equations based on the direction of opening. Some students directly determined the focus value without first identifying the standard form of the parabola equation.

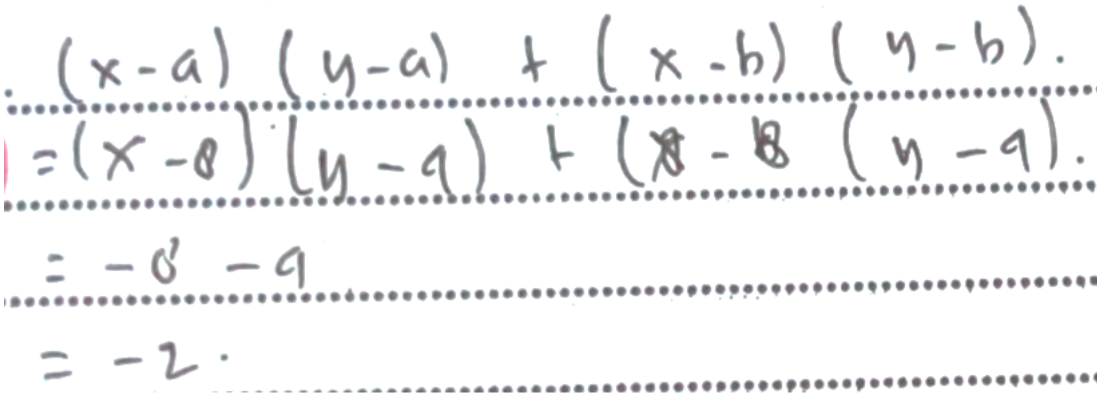

Figure 2. Student Error Category E2

Based on Figure 2, these errors indicate that students have not fully understood the relationship between the general form of the parabola equation and its geometric elements. According to Fong (1993), these errors are categorized as mathematical theme errors because students do not understand the fundamental concepts and appropriate use of formulas. In addition, operational errors were also identified in the form of incorrect algebraic manipulations. These findings are supported by the study conducted by Sudihartinih & Purnianti, which reported that students frequently experience difficulties in determining the form of parabola equations based on the direction of opening and in identifying the focus and directrix of a parabola.

Interview results further revealed that students were still confused about distinguishing between parabolas that open to the right, left, upward, and downward. Some students admitted that they merely memorized formulas without understanding the geometric meaning of each parabola element. This condition indicates that the learning process experienced by students remains procedural and does not sufficiently emphasize conceptual understanding. Hartini (2020) stated that learning conic sections should develop logical and systematic thinking skills rather than merely training students to apply formulas mechanically. To address these problems, Suprapti (2020) recommended implementing a discovery learning model that enables students to construct their own understanding, while teachers function as facilitators who provide opportunities for active learning. In addition, some students incorrectly determined the axis of symmetry because they did not understand the relationship between the vertex and the direction of the parabola's opening. This finding indicates that students still experience misconceptions regarding the fundamental structure of a parabola.

The incomplete schema without a solution category (E3) accounted for 16.67% of the total errors. This type of error indicates that students were only able to write down some information or the initial steps of the solution without continuing the process until a final answer was obtained. According to Endrian et al. (2020), students' low ability to solve conic section problems is caused by insufficient visualization skills and limited conceptual understanding during the learning process. As a result, students experience difficulties in connecting previously learned concepts to solve problems comprehensively. E3 category errors occurred when students merely wrote down information provided in the problem or only part of the solution procedure without continuing to the final solution.

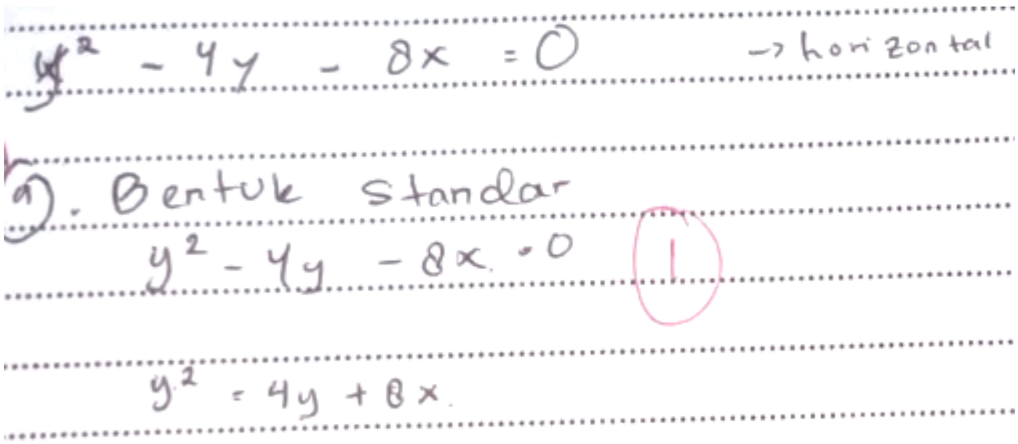

Figure 3. Student Error Category E3

For example, in problems requiring students to determine the parabola equation based on the length of the latus rectum, some students only wrote down the basic parabola formula without continuing with the substitution of values into the equation. Several students even wrote only the known information without attempting any further solution process. Based on the interview results, the students admitted that they were confused about determining the next step after writing down the initial information. This finding indicates that students were unable to systematically connect concepts related to parabolas. According to Endrian et al. (2020), the lack of instructional approaches that provide visualization and conceptual

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understanding makes it difficult for students to understand the relationships among concepts in conic section material. Consequently, students are unable to construct a complete solution procedure. This category of error demonstrates that students' understanding of parabola concepts remains partial. Although students understand certain concepts, they are unable to integrate them comprehensively in problem-solving.

Meanwhile, the no solution category (E1) and the complete schema containing errors category (E5) each accounted for 10% of the total errors. E1 category errors indicate that some students did not understand the fundamental concepts of parabolas and were therefore unable to begin the problem-solving process. This finding is consistent with the study conducted by Sari & Roesdiana (2019), which stated that many students still experience difficulties in solving parabola problems because the material is abstract and requires strong visualization skills.

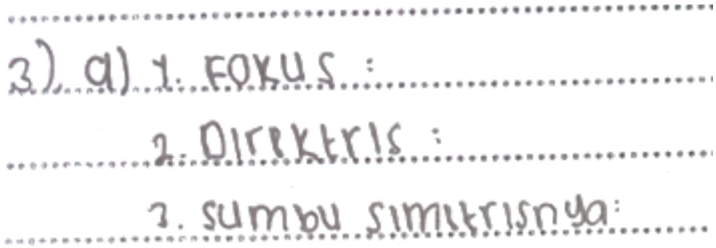

Figure 4. Student Error Category E1

Based on Figure 4, E1 category errors were identified in students who did not provide any answers at all. Based on the interview results, these students admitted that they did not understand the purpose of the questions and did not know which formulas should be applied. These errors indicate that some students still possess a very limited understanding of basic parabola concepts. Students perceive conic section material as difficult because it involves many different equation forms. Sari and Roesdiana (2019) also stated that many students are unable to answer parabola problems correctly. This finding is reinforced by the study conducted by Sadidah & Sudihartinih (2023), which found that more than half of the participants made errors in conic section material, with incomplete schemas containing errors, as well as language and operational errors at the second level, being the most dominant forms of error.

In addition, the abstract nature of parabola material makes it difficult for students to construct a visual representation of the parabola and its elements. Consequently, students encounter difficulties even at the initial stage of problem-solving. In general, students' errors are caused by a lack of understanding of fundamental parabola concepts, inaccuracies in the application of formulas, and low accuracy in performing algebraic operations. Furthermore, interview results revealed that most students still tend to memorize formulas rather than understand the underlying concepts of parabolas comprehensively.

In the E5 category, students completed the entire solution procedure but still produced incorrect final answers because of a lack of accuracy in calculations. According to Rahmawati et al. (2018), operational errors such as sign errors, incorrect value substitutions, and algebraic simplification errors are among the most common errors in solving mathematical problems. This finding indicates that students' accuracy in performing calculation operations still needs improvement. In the E5 category, the errors identified generally involved calculation operation errors, value substitution errors, and mistakes in writing the final answer. For example, students were able to determine the standard form of the parabola correctly but made mistakes when simplifying algebraic expressions, resulting in incorrect focus coordinates.

These errors indicate that students actually understood the basic concepts of parabolas but lacked accuracy during the calculation process. According to Fong (1993), these errors are categorized as operational and psychological errors. Interview results showed that some students felt confident in their answers and therefore did not reexamine their work. This finding is consistent with the study conducted by Zuliana et al. (2025), which reported that students often make mistakes because they work hastily, are not accustomed to reviewing their answers, and tend to feel overly confident in their solutions (Zuliana et al., 2025). In addition, some students admitted that they experienced difficulties when the questions were presented in forms different from the examples provided by lecturers. This finding suggests that students still lack flexibility in mathematical thinking when solving parabola problems.

Overall, the results of this study indicate that students' errors in parabola material are caused not only by weak algebraic operation skills but also by limited understanding of fundamental parabola concepts. Therefore, analytical geometry instruction should place greater emphasis on conceptual understanding and visualization rather than solely on formula memorization. The use of visualization-based learning media, such as dynamic geometry applications and parabola graphs, may help students understand the relationships among parabola equations, focus, directrix, axis of symmetry, and direction of opening. In addition, lecturers should provide varied practice problems so that students become accustomed to solving problems presented in different forms. Lecturers also need to encourage students to reexamine their work in order to minimize operational and psychological errors. Sadidah & Sudihartinih (2023) recommended that educators design instructional materials capable of facilitating students' understanding of conic section topics in order to minimize errors. Thus, the results of error analysis using Fong's scheme may serve as an evaluation basis for improving the analytical geometry learning process, particularly in parabola material within conic sections.

4. CONCLUSION

Based on the results of the study and discussion, it can be concluded that students still experience various errors in solving problems related to parabola material in conic sections. Students' errors included language, operational, mathematical theme, and psychological errors. Mathematical theme errors occurred because students did not understand the fundamental concepts of parabolas, such as the relationship between the form of a parabola equation and its focus, directrix, axis of symmetry, and direction of opening. Operational errors arose due to inaccuracies in performing algebraic manipulations and calculation procedures. Meanwhile, psychological errors occurred because of students' lack of accuracy in reading the questions and reviewing their work. Perform conceptual interventions for error category E2, and increase step-by-step algebraic exercises for error category E4.

Analytical geometry instruction, particularly on parabola material, should place greater emphasis on conceptual understanding and visualization rather than solely on formula memorization. The use of visualization-based learning media, varied practice problems, and the habituation of students to reexamine their solution processes may help reduce students' errors. Thus, the results of error analysis using Fong's scheme are expected to serve as evaluation material for lecturers in designing more effective learning strategies for conic section material.

DECLARATIONS

Author Contributions: RW: Conceptualisation, Writing-Review & Editing, Data Curation, Formal Analysis, and Methodology; E: Writing-Original Draft, Investigation, Resources, Validation, and Formal Analysis.

Conflict of Interest: The authors declare that they have no competing interests.

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