


Revealing Students' Computational Thinking Error Patterns in Solving Two-Variable Linear Inequality Systems

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ABSTRACT

This study aims to identify and describe patterns of students' computational thinking errors in solving systems of linear inequalities in two variables. Specifically, it examines errors occurring at each stage of computational thinking, such as problem decomposition, pattern recognition, abstraction, and algorithm construction, as well as the underlying factors contributing to these errors. A qualitative descriptive approach was employed. The participants consisted of 36 tenth-grade students. Data were collected through written tests, observation, and semi-structured interviews to explore students' cognitive processes in depth. The data were analyzed through data reduction, data display, and conclusion drawing. The findings indicate that students experienced errors at all stages of computational thinking. Students encountered difficulties identifying relevant information during problem decomposition, recognizing conceptual relationships during pattern recognition, transforming problems into appropriate mathematical representations during abstraction, and constructing systematic solution procedures during algorithm construction. These errors were primarily attributed to insufficient conceptual understanding, difficulties in interpreting problem statements, and limitations in formulating effective problem-solution strategies. These findings provide valuable insights into students' learning difficulties and may serve as a foundation for designing more effective instructional strategies to enhance students' computational thinking skills.

Keywords: Computational Thinking, Error Analysis, Mathematics Learning, Student Error Patterns.

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Introduction

Education plays a pivotal role in developing students' intellectual, social, and personal competencies in the twenty-first century. In this context, learning is not merely oriented toward knowledge acquisition but also toward fostering higher-order thinking skills such as critical, logical, and systematic thinking (Liu et al., 2024; Ye et al., 2023). Mathematics, as a fundamental discipline, contributes substantially to these objectives because it functions as both a medium for reasoning and a structured language for expressing ideas precisely (Chai et al., 2023; Grover & Pea, 2018). Through mathematics instruction, students are expected to develop analytical reasoning and mathematical problem-solving skills that are essential for addressing real-world challenges.

Conceptual understanding is a fundamental component in mathematics learning because it underlies students' ability to solve problems effectively (Hiebert & Grouws, 2007; Rittle-Johnson et al., 2015). However, meaningful conceptual understanding

requires instructional approaches that actively engage students in structured cognitive processes. One instructional approach that has gained increasing scholarly attention is computational thinking. Computational thinking was first introduced by Jeannette Wing as a problem-solving approach encompassing abstraction, pattern recognition, decomposition, and algorithm design (Shute et al., 2017; Wing, 2017). These components enable learners to approach complex problems systematically and formulate efficient, logical, and structured solutions.

It is widely acknowledged that incorporating computational thinking into mathematics instruction improves students' critical thinking and problem-solving capabilities (Lockwood et al., 2016; Weintrop et al., 2015). Recent studies have demonstrated that computational thinking supports students in developing structured reasoning, strengthening conceptual understanding, and fostering creativity in mathematical problem-solving (Chai et al., 2023; Liu et al., 2024). Furthermore, computational thinking facilitates students' ability to construct mathematical models and organize solution procedures more systematically and effectively (Bower et al., 2017; Fagerlund, 2018).

Despite its significance, empirical evidence indicates that students' computational thinking skills remain relatively underdeveloped, particularly in mathematical contexts (Nurazizah et al., 2025; Zahid, 2025). Students frequently encounter difficulties in identifying relevant information, recognizing relationships among mathematical concepts, constructing mathematical models, and organizing coherent solution procedures (Suparman et al., 2024). These difficulties frequently lead to errors in problem-solving processes, especially in mathematical topics that require higher-order thinking skills, such as systems of linear inequalities in two variables.

Several previous studies have investigated computational thinking in mathematics education. Zahid (2025) reported that students experienced difficulties in decomposing problems and designing effective solution strategies. Other studies (Husna & Himmi, 2022; Suparman et al., 2024) revealed that students' errors commonly occur in problem comprehension, conceptual integration, and organization of solution procedures. In addition, systematic review studies (Ye et al., 2023; Zubainur et al., 2025) indicate that although computational thinking positively influences learning outcomes, its implementation in classroom practices remains suboptimal.

However, most existing studies primarily focus on measuring students' computational thinking abilities rather than analyzing the specific patterns of errors at each stage of the computational thinking process (Grover & Pea, 2018; Shute et al., 2017). Furthermore, previous research tends to emphasize learning outcomes without

thoroughly examining the cognitive processes that lead to errors (Fagerlund et al., 2021). Another limitation is the lack of focus on specific mathematical topics, particularly systems of linear inequalities in two variables, which require robust conceptual understanding and systematic mathematical reasoning (Lockwood et al., 2016). Therefore, there is a need for research that explores students' computational thinking errors in depth within a specific mathematical context (Chai et al., 2023; Zubainur, 2025).

Preliminary observations indicate that students often struggle when solving problems involving systems of linear inequalities in two variables. These difficulties include identifying relevant information, constructing mathematical models, and applying systematic procedures. These errors reflect deficiencies in computational thinking processes, such as algorithm creation, decomposition, pattern identification, and abstraction. Analyzing these errors is essential for understanding students' learning difficulties and for designing more effective instructional strategies (Sari & Mawarni, 2025).

Thus, the purpose of this study is to identify and characterize patterns of computational thinking errors made by students when solving systems of linear inequalities in two variables. In particular, this study investigates the causes of errors at every stage of computational thinking, including problem decomposition, pattern recognition, abstraction, and algorithm construction. The findings are expected to provide deeper insights into students' difficulties and serve as a basis for improving mathematics instruction, particularly in enhancing students' computational thinking skills.

Methods

This study employed a qualitative descriptive design to analyze students' computational thinking error patterns in solving systems of linear inequalities in two variables. The research was conducted at Budi Murni 2 Catholic Private Senior High School in Medan. Qualitative research allows researchers to gain a comprehensive understanding of students' thinking processes and to interpret the meaning behind their responses in a natural context (Creswell & Creswell, 2021; Merriam & Tisdell, 2021).

Participants or Data Sources

The participants consisted of 36 tenth-grade students (aged approximately 15–16 years) from one intact class. A total sampling technique was applied, meaning that all students in the class were included as research participants. The selection was based

on the consideration that students had already studied the relevant mathematical topic.

Research Instruments

The instruments employed in this study included observation sheets, interview protocols, and a written test. The written test consisted of four questions designed based on computational thinking indicators, including problem deconstruction, pattern recognition, abstraction, and algorithm construction. These indicators are widely recognized as essential components of computational thinking in mathematics education and are crucial for examining students' problem-solving processes (Grover & Pea, 2018; Ye et al., 2023). Furthermore, semi-structured interviews were conducted to explore students' reasoning processes and to identify the underlying causes of the errors they made.

For the interview phase, a subset of students was selected using purposive sampling based on their test results. Students representing high, moderate, and low levels of performance were chosen to capture variations in computational thinking error patterns. Not all students were interviewed; instead, selected participants were interviewed to obtain in-depth information regarding their reasoning process and difficulties encountered in solving the problems (Etikan et al., 2015).

In addition to tests and interviews, observations were conducted during the learning process to capture students' behaviors and strategies when solving problems. Observation enables researchers to directly examine how students identify problems, construct solution procedures, and respond to difficulties encountered during problem-solving activities. This method strengthens the validity of the findings by complementing the test and interview data with contextual information (Flick, 2022).

The validity of the research instruments was established through content validity using expert judgment. The validation process involved two experts in mathematics education who evaluated the instruments based on their relevance, clarity, and alignment with computational thinking indicators. The experts provided feedback on content accuracy, language, and the suitability of each item in measuring the intended constructs. Based on the experts' evaluation, the instruments were categorized as valid and appropriate for use in the study after minor revisions had been made. All suggestions provided by the validators were incorporated to improve the quality of the instruments before data collection. This process ensured that the instruments adequately represented the research objectives and computational thinking components being measured. Expert validation is considered an essential step in

ensuring the quality and appropriateness of research instruments in educational studies (Taherdoost, 2025).

Research Procedures

The research procedure consisted of four stages. In the preparation stage, the researcher conducted preliminary observations to identify students' difficulties in solving systems of linear inequalities in two variables. After identifying the problem, the researcher designed research instruments consisting of four test questions, interview guidelines, and observation sheets based on computational thinking indicators, namely problem decomposition, pattern recognition, abstraction, and algorithm construction.

In the implementation stage, the researcher administered the written test to 36 tenth-grade students during mathematics class. Students were given sufficient time to complete the four essay questions individually. During the test session, the researcher conducted classroom observations to examine how students identified problem information, organized solution steps, and responded to difficulties encountered during problem-solving activities. After the test results were collected, several students with different levels of achievement were purposively selected for semi-structured interviews to explore their reasoning processes and the causes of their errors in greater depth.

In the data processing stage, the researcher examined students' written answers and categorized them based on computational thinking indicators and types of errors. The interview recordings were transcribed and matched with students' written responses to identify consistency between students' verbal explanations and their solution processes. Observation notes were also reviewed to support the interpretation of students' behaviors and difficulties during the problem-solving activities.

Result and Discussions

This section presents the findings related to students' computational thinking skills in solving two-variable linear inequality systems. Data analysis was conducted descriptively and quantitatively using percentage techniques to determine the level of student achievement in each computational thinking indicator, that is, problem decomposition, abstraction, pattern recognition, and algorithm construction. The results of the analysis were then discussed in depth to identify emerging error patterns and factors influencing students' difficulties in solving the problems. The sample responses presented below illustrate patterns of students' answers (Figure 1).

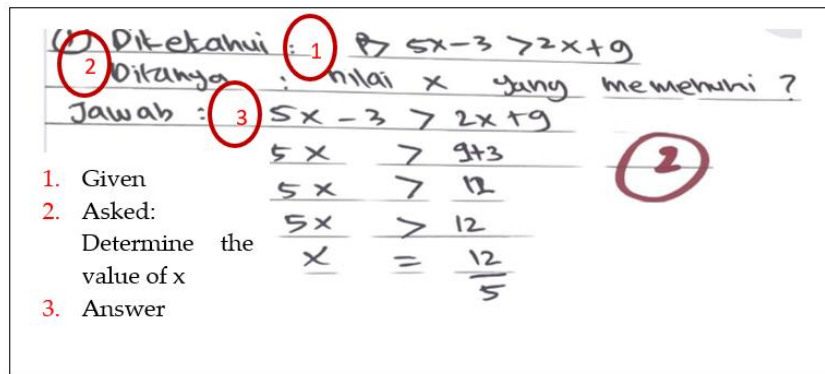


Figure 1. Solution to Mini Test Question Number 1

Based on the test results (Figure 1), some students obtained varying scores on the problem decomposition indicator. Some students obtained a score of 4, indicating that they were able to identify and describe the problem completely and systematically. However, there were still students who obtained scores of 3 and 2, indicating that they were only able to identify partial information but were unable to explain the problem coherently. In addition, there were also students who obtained scores of 1 and 0, indicating that they were not able to comprehend and solve the problem appropriately. These findings suggest that students' problem decomposition skills still require significant improvement.

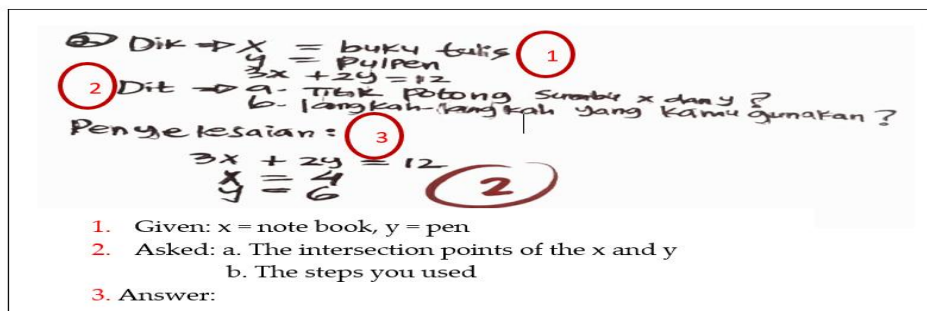


Figure 2. Solution to Mini Test Question Number 2

On the algorithm indicator (Figure 2), several students received low scores of 1 and 2, indicating that they were unable to systematically organize the solution steps. Students who obtained scores of 3 and 4 were able to organize the solution procedures; however, they still demonstrated inaccuracies or incompleteness in several computational steps. Students who received a score of 0 indicated that they were unable to formulate the solution procedures entirely. These findings indicate that algorithmic thinking constitutes one of the students' primary weaknesses in solving systems of linear inequalities in two variables.

3. Diketahui : $x = \text{Apel}$
 $y = \text{Jeruk}$
 $2x + y = 5$ (Persamaan)
 Kombinasi A (2,1)
 Kombinasi B (4,0)

2. Ditanya : a) Kombinasi memenuhi aturan ?
 b) Jelaskan alasannya dari hasil hitung-

3. Penyelesaian : 1
 a) Iya, memenuhi

- Given: $x = \text{apples}$ and $y = \text{oranges}$
 Combination A: (2,1)
 Combination B: (4,0)
- Questions:
 - Determine whether each combination satisfies the equation.
 - Explain your reasoning based on the calculation
- Answer: Yes, it satisfies the equation.

Figure 3. Solution to Mini Test Question Number 3

On the pattern recognition indicator (Figure 3), several students scored 2 and 3, indicating they had begun to recognize mathematical patterns but were not yet fully accurate in generalizing relationships among variables. Students who scored 4 demonstrated a strong ability to identify patterns and apply them effectively in solving the problems. However, several students still obtained scores of 1 and 0, indicating they were unable to identify relationships among the mathematical information presented in the problem.

4. Dit : $x = \text{laki-laki}$
 $y = \text{Perempuan}$
 $x + y = 6$

titik (6,0) dan (0,6)

Jawab : (6,0) dan (0,6)

3. Dit : Mengapa kedua titik tersebut dapat digunakan untuk menggambar grafik ?
 bisa dipakai buat grafik.

- Given: $x = \text{male}$ and $y = \text{female}$
 $2x + y = 5$
- Questions: Why can both points be used to draw the graph?
- Answer: The points (6,0) and (0,6) can be used to draw the graph

Figure 4. Solution to Mini Test Question Number 4

On the abstraction and generalization indicators (Figure 4), most students obtained low scores of 1 and 2. This finding indicates that students still experienced difficulties in simplifying mathematical problems and formulating generalized conclusions. Students who obtained scores of 3 and 4 were relatively limited in number, suggesting that only a small proportion of students demonstrated adequate abstraction skills.

Meanwhile, students who obtained a score of 0 indicated that they were unable to generalize the given problem mathematically.

The observation results conducted during the learning and problem-solving activities revealed that students demonstrated varying levels of computational thinking skills across each stage. Based on observations, approximately 66.7% of students were able to understand the information presented in the problems during the decomposition stage. These students were capable of identifying both the known and the required information appropriately. This finding indicates that most students had a relatively good initial understanding of the given problems before proceeding to the next stages of problem-solving.

Furthermore, around 46.7% of students were able to determine the initial steps of the solution correctly. In the pattern recognition stage, 46.7% of students were able to identify relationships between variables and recognize patterns related to the problem context. However, students still experienced difficulties in connecting these patterns to broader mathematical concepts. This finding supports the test results, which showed that some students were still inconsistent in recognizing relationships and applying appropriate strategies.

At the abstraction stage, only 40% of students were able to transform the problems into correct mathematical models. Many students experienced difficulties in simplifying information and representing the problems symbolically. These difficulties affected their ability to continue the solution process effectively. In the algorithm stage, approximately 53.3% of students were able to arrange the solution steps systematically, while 60% were able to perform calculations correctly.

Nevertheless, several students were still unable to complete all stages of computational thinking comprehensively, particularly in pattern recognition and abstraction. As a result, errors were still found in the problem-solving process, especially in identifying relationships between variables and constructing appropriate mathematical models. These findings indicate that higher-order computational thinking skills still need to be improved through more structured and interactive learning approaches.

The interview results involving students with high, medium, and low levels of ability showed that computational thinking skills differed significantly across student categories. Students with high ability demonstrated good understanding in identifying problems, recognizing patterns, constructing mathematical models, and determining appropriate solution steps. Although minor calculation errors were still

found, these students generally showed more systematic and logical thinking processes compared to other groups.

Students with moderate ability were relatively capable of understanding the problems and organizing solution procedures. However, they still experienced difficulties in identifying relationships between variables and transforming the problems into mathematical models accurately. These students often understood the problem context partially but struggled when required to generalize or represent the information symbolically. As a result, procedural errors frequently occurred in the later stages of problem-solving.

Meanwhile, students with low ability experienced difficulties in almost all stages of computational thinking. Most of them struggled to identify important information, recognize relationships between variables, and organize systematic solution steps. In many cases, students relied on guessing strategies rather than logical reasoning. This condition caused students to produce incomplete or incorrect solutions.

Overall, the interview findings indicate that the most dominant computational thinking errors occurred in the pattern recognition and abstraction stages, particularly among students with moderate and low abilities. These findings strengthen the results obtained from the written test and observation data, showing that students still experience considerable difficulties in developing higher-order computational thinking skills in solving systems of linear inequalities in two variables.

The results of this study indicate that students' abilities in problem decomposition varied significantly across different performance levels. Based on the scoring rubric, a score of 4 indicates that students were able to identify relevant information completely and decompose the problem systematically, whereas a score of 3 indicates that students identified most of the important information, although their explanations were not yet fully coherent and systematic. A total of 36.1% of students achieved the highest score, demonstrating strong proficiency in problem decomposition. Meanwhile, 30.5% of students obtained a score of 3, suggesting that they possessed relatively good understanding but still demonstrated inconsistencies in organizing the problem-solving process. These findings indicate that a considerable proportion of students have begun to develop adequate problem decomposition skills, although further improvement remains necessary.

On the other hand, several students still experienced difficulties in this indicator, as reflected by those who obtained scores of 2 (25%), 1 (5.5%), and 0 (2.8%). Students in this category were generally unable to fully comprehend the problem, identify

essential information, or distinguish between relevant and irrelevant data. This condition indicates that some students still struggle with the initial stage of mathematical problem-solving, which is fundamental to subsequent computational thinking processes. Difficulties in identifying relevant information and understanding problem contexts are considered important indicators of students' learning difficulties in mathematics problem solving (Tambychik & Meerah, 2010; Ye et al., 2023). Furthermore, students who experience difficulties during the decomposition stage tend to encounter obstacles in subsequent computational thinking processes, such as abstraction and algorithm construction (Grover & Pea, 2018). Therefore, weaknesses in problem decomposition may negatively influence students' performance across other computational thinking indicators.

The test results previously described based on computational thinking indicators are summarized in the following graph (Figure 5). The graph illustrates the distribution of students' scores across each computational thinking indicator, including problem decomposition, algorithm construction, pattern recognition, and abstraction and generalization, in order to provide a clearer representation of students' computational thinking performance.

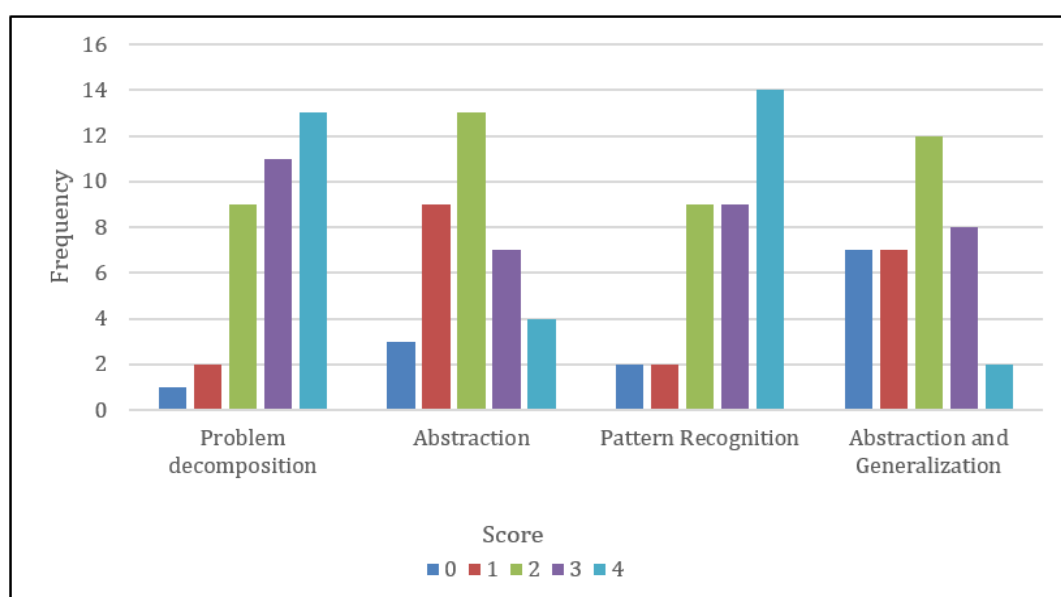


Figure 5. Distribution of Students' Scores Across Computational Thinking Indicators

Overall, the findings indicate that students' computational thinking abilities were predominantly categorized in the moderate level. The average score of 60.58 reflects that students possess a basic understanding of computational thinking; however, their competencies have not yet been fully developed. Based on the score distribution, 47.2% of students were categorized at the moderate level, followed by 38.9% at the low level,

while only 13.9% were classified at the high level. The distribution of students' computational thinking abilities according to score categories is presented in [Table 1](#). These findings suggest that although some students demonstrate strong computational thinking skills, a substantial proportion still encounter difficulties, particularly in higher-order thinking processes. The imbalance across indicators further indicates that the development of students' computational thinking abilities remains suboptimal. Therefore, targeted instructional strategies are required to improve students' overall computational thinking performance.

Table 1. Distribution of Students' Computational Thinking Abilities

No	Category	Grade Interval	Number of Students	Percentage (%)
1	Tinggi	80-100	5	13.9
2	Sedang	60-79	17	47.2
3	Rendah	0-59	14	38.9
	Total		36	100

With significant variations across all indicators, the study's findings demonstrate that students' computational thinking abilities remain at a moderate level. In particular, abstraction and generalization were identified as the most challenging components, whereas pattern recognition demonstrated relatively stronger performance. This finding suggests that students tend to rely more on recognizing familiar patterns than on engaging in deeper conceptual and analytical processing. Such tendencies indicate that students' mathematical understanding remains largely procedural and has not yet fully developed into higher-order reasoning skills.

The difficulties in abstraction and generalization may be attributed to students' limited ability to transform contextual problems into formal mathematical representations. Many students were unable to identify essential elements of a problem and distinguish them from irrelevant information, resulting in incomplete or inaccurate conclusions. This finding is consistent with previous research that emphasizes abstraction as one of the most challenging aspects of computational thinking in mathematics education (Lockwood et al., 2016). These studies highlight that abstraction requires not only conceptual understanding but also the ability to generalize mathematical relationships across different problem contexts.

Furthermore, the low performance in algorithm construction indicates that students still lack structured and systematic reasoning skills. Many students were unable to organize solution procedures logically, which led to procedural errors and incomplete solutions. This finding aligns with the perspective that computational thinking involves the ability to design and implement effective step-by-step procedures

(Fagerlund et al., 2021; Grover & Pea, 2018). Without strong algorithmic thinking skills, students may conceptually understand the problem but still fail to produce mathematically accurate solutions.

Interestingly, students demonstrated relatively better performance in pattern recognition compared to other indicators. This finding suggests that students are more familiar with identifying similarities among problems, possibly due to repeated exposure to analogous question types in classroom practice. However, this competence often remains at a surface-processing level, where students are capable of recognizing recurring patterns without comprehending the underlying mathematical structures and relationships. Similar findings have been reported in previous studies, which indicate that students tend to rely on intuitive pattern matching rather than deeper analytical and deductive reasoning processes.

Another significant finding of this study is that students' errors were influenced by multiple factors, including limited conceptual understanding, difficulties in interpreting problem statements, and a lack of experience in developing solution strategies. These findings are consistent by previous studies indicating that conceptual understanding and cognitive processing play a critical role in students' ability to formulate accurate mathematical representations and derive valid solutions (Sweller et al., 2019). Furthermore, difficulties in understanding problem contexts have been identified as a major obstacle that interferes with students' progression through subsequent stages of mathematical problem solving (Darling-Hammond et al., 2020). These factors interact dynamically and contribute to inconsistencies in students' computational thinking processes. In particular, students who encounter difficulties in interpreting problem contexts are more likely to experience challenges across all computational thinking stages, ranging from problem decomposition to abstraction and generalization.

The principal contribution of this study lies in its comprehensive identification of error patterns at each stage of computational thinking. In contrast to previous studies that predominantly focused on measuring students' computational thinking performance, this study provides a more in-depth analysis of the nature, locations, and underlying causes of students' errors. This contribution is particularly important for the development of more effective instructional strategies that specifically address weaknesses in students' mathematical reasoning and computational thinking processes. By understanding these patterns of errors, educators can design instructional interventions and learning activities that more effectively facilitate the development of students' computational thinking skills.

These findings imply that the development of abstraction and algorithmic thinking skills should become a primary focus in mathematics education. Instructional approaches such as problem-based learning, collaborative learning, and the integration of educational technology may support students in developing logical, systematic, and procedural reasoning skills. Additionally, educators need to provide students with greater opportunities to engage in higher-order thinking tasks that require reasoning, mathematical generalization, reflection, and justification. Through these approaches, students are expected to strengthen their computational thinking skills and achieve improved mathematical problem-solving performance.

Conclusion

The findings of the study indicate that students' computational thinking abilities in solving systems of linear inequalities in two variables are generally categorized at a moderate level, with substantial variation across computational thinking indicators. The findings reveal that students demonstrate relatively stronger performance in problem decomposition and pattern recognition, indicating their ability to identify relevant information and recognize relationships within mathematical problems. However, considerable difficulties were identified in the stages of abstraction and generalization, where students struggled to transform contextual problems into appropriate mathematical representations, simplify essential information, and formulate accurate and mathematically meaningful conclusions. By systematically identifying and characterizing patterns of errors occurring at each stage of computational thinking, including problem decomposition, pattern recognition, abstraction, and algorithm construction, these results directly address the research objective.

This study contributes to the field of mathematics education by providing a more comprehensive and process-oriented analysis of students' computational thinking errors, rather than focusing exclusively on learning outcomes or achievement scores. The findings extend previous research by demonstrating that students' difficulties are not merely associated with procedural inaccuracies but are also deeply rooted in conceptual understanding and higher-order thinking processes, particularly abstraction and mathematical generalization. These findings reinforce the theoretical perspective that computational thinking in mathematics requires the integration of conceptual knowledge, procedural fluency, and metacognitive regulation in order to effectively solve complex problems.

From a practical perspective, the findings imply that teaching mathematics instruction should focus more on enhancing students' abilities in abstraction and generalization through pedagogical approaches that promote higher-order thinking skills.

Instructional strategies such as problem-based learning, structured cognitive scaffolding, and the integration of technology-enhanced learning environments may support students in developing more systematic, logical, and meaningful problem-solving strategies. These pedagogical implications are particularly important for educators and curriculum developers in designing instructional practices that foster comprehensive computational thinking skills aligned with the demands of twenty-first-century education.

Despite its contributions, this study has several limitations. First, the study was conducted in one class consisting of 36 students, which may limit the generalizability of the findings to a broader educational context. Second, the study focused exclusively on a specific mathematical topic, namely systems of linear inequalities in two variables, which may not fully represent students' computational thinking abilities across other areas of mathematics. Therefore, future studies are recommended to involve larger and more diverse samples, investigate computational thinking across various mathematical domains, and evaluate the effectiveness of specific instructional interventions designed to enhance computational thinking skills. Overall, this study offers insights into students' computational thinking processes and error patterns, thereby contributing both theoretically and practically to the advancement of mathematics education.

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Author's Declaration

Author Contribution : Author 1: Conceptualization, Methodology, Data Collection, Writing – Original Draft Preparation.
Author 2: Writing – Review & Editing, Data Analysis
Author 3: Validation, Supervision, Data Analysis
Author 4 : Review & Editing, Validation

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