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# Computational Thinking Skills in Exponential Functions using GeoGebra-assisted Problem-Based Learning

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***Abstract:*** *This study aims to describe senior high school students' Computational Thinking (CT) skills in exponential function material through GeoGebra-assisted Problem-Based Learning (PBL). Computational thinking is an essential 21st-century skill, yet Indonesian students' mathematical literacy remains low. This research employed a descriptive qualitative method, involving 33 students of class XII IPA 2 at MAN 1 Banyuasin as subjects. Data were collected through CT skill tests, observations, and semi-structured interviews. The CT indicators analyzed included decomposition, pattern recognition, abstraction, and algorithmic thinking. The results showed that the majority of students (25 students) were in the "moderate" category, while 3 students reached the "high" category, and 5 students were in the "low" category. Students in the high category successfully fulfilled all four CT indicators. In contrast, students in the moderate and low categories faced significant difficulties in the abstraction and algorithmic thinking stages. GeoGebra played a crucial role as a dynamic visualization tool that helped students bridge abstract exponential concepts to concrete visual forms and served as a self-verification tool for their algorithmic solutions. The integration of GeoGebra in PBL provides a structured environment for students to develop systematic problem-solving strategies.*

***Keywords:*** *Computational Thinking, Mathematical Problem Solving, GeoGebra, Exponential Functions*

## 1. INTRODUCTION

Computational Thinking (CT) has emerged as a fundamental 21st-century skill involving a systematic approach to formulating problems and expressing their solutions [1]. According to Wing [2], CT is not merely about programming but encompasses four main pillars: decomposition, pattern recognition, abstraction, and algorithmic thinking. In mathematics education, these skills are crucial as they train students to think logically, efficiently, and systematically when facing complex mathematical problems [3]. Furthermore, CT plays a vital role in forming a generation capable of solving problems with precise and efficient algorithms [4]. Through CT, students are encouraged to break down large problems into smaller, more manageable parts [5]. This process is essential as it serves as a foundation for developing higher-order thinking skills in the digital era [5].

However, reality shows that mathematical literacy and systematic thinking skills among students in Indonesia remain relatively low. This is reflected in the Programme for International Student Assessment (PISA) results, which consistently place Indonesia in the lower ranks regarding logical reasoning abilities [6]. While there was a slight improvement in the 2022 PISA rankings, the average score for Indonesian mathematical literacy remains significantly below the international average, indicating that fundamental challenges in CT skills persist [7]. These challenges are particularly evident in topics with high levels of abstraction, such as exponential functions [8]. Many students find this material difficult due to its complex nature, often leading to obstacles in connecting theoretical concepts with real-world applications [9]. Previous studies confirm that students' difficulties in exponential functions are closely related to a lack of structured thinking skills and challenges in understanding the correlation between exponent changes and growth patterns [9].

Based on preliminary discussions with mathematics teachers at MAN 1 Banyuasin conducted on June 26, 2025, it was identified that students still struggle to decompose complex problems into simple steps. Specifically, in exponential material, students often fail to recognize basic patterns and frequently make errors in calculations involving exponential properties. This difficulty becomes even more apparent in contextual problems that require logical stages of resolution, where students tend to give up before finding the correct solution algorithm. The conventional learning methods used in the school are considered suboptimal in stimulating students' computational thinking power. Integrating modern approaches that combine mathematical problem-solving with CT frameworks is considered an effective solution to help students understand the underlying structure of exponential material [10].

As a solution, integrating Problem-Based Learning (PBL) with the assistance of technology is considered capable of providing a positive impact. PBL frameworks integrated with CT can train students to be more logical, creative, and structured when facing complex issues [11]. Although the use of technology in education has become widespread, recent research by Wijayanti et al. (2025) indicates that integrating CT into subjects like exponential functions still reveals a significant “gap” in students' abstraction skills. This suggests that mere exposure to technology is insufficient; the pedagogical framework must specifically target how students filter complex information [10]. The use of interactive software such as GeoGebra has proven effective in supporting the implementation of CT in mathematics classrooms [12]. GeoGebra allows students to perform dynamic explorations of exponential function graphs, thereby facilitating the process of pattern recognition and abstraction [13]. Accurate and interactive visualization through GeoGebra significantly enhances conceptual understanding compared to static media [14]. Furthermore, this software assists students in verifying the solution algorithms they have constructed independently [15]. Recent interventions suggest that students' CT skills in exponential topics are diverse, highlighting the urgent need for appropriate technological support to bridge these gaps [16].

Exploring exponential functions using GeoGebra is essential to bridge students' theoretical and practical understanding [17]. The integration of mathematical problem-solving and technological visualization is expected to be an effective means to measure and improve students' CT skills. Therefore, this study aims to describe senior high school students' Computational Thinking skills in exponential function material through GeoGebra-assisted mathematical problem-based learning, focusing on the four main indicators: decomposition, pattern recognition, abstraction, and algorithms.

## 2. THEORETICAL BASIS

### 2.1 Computational Thinking (CT) Framework

Computational Thinking is a multifaceted cognitive process that involves formulating problems and their solutions in a way that can be effectively processed by an information-processing agent [1]. Wing (2017) emphasizes that CT is a fundamental skill for everyone, not just computer scientists, as it fosters analytical reasoning [18]. In the digital era, CT is considered a crucial instrument for solving complex challenges through organized and logical thinking [4].

Beyond basic problem-solving, CT implementation in the classroom is often associated with “strategic thinking,” where students must understand the underlying structure of a problem before determining a solution path [10]. This involves several iterative phases, such as tinkering (exploring), creating (developing solutions), and debugging (correcting errors), all of which contribute to stronger problem-solving capacities [11]. In this study, the four pillars of CT are operationalized as follows:

- **Decomposition**: The ability to break down complex exponential equations or contextual growth problems into smaller, identifiable variables and constraints.
- **Pattern Recognition**: Identifying trends in exponential data, such as doubling periods or half-life patterns, and recognizing similarities across different types of exponential functions.
- **Abstraction**: Filtering out irrelevant narrative details in word problems to focus on the core mathematical model and exponential properties.
- **Algorithms**: Designing a systematic, step-by-step procedure to solve for variables or to construct an accurate visual representation in a digital environment [3].

### 2.2 Mathematical Problem-Based Learning and Polya’s Strategy

Problem-Based Learning (PBL) is a student-centered instructional model that presents contextual problems as a trigger for the learning process. This model provides a conceptual framework that guides students to engage actively in both independent and collaborative exploration [19]. In mathematics education, PBL is considered an ideal learning environment because it conditions students to think logically and systematically when facing challenges they have never encountered before [20].

The effectiveness of PBL in improving students' cognitive abilities heavily depends on how students navigate the stages of problem-solving. One of the most relevant strategies is Polya's problem-solving steps, which include four main phases: understanding the problem, devising a plan, carrying out the plan, and looking back [8]. Each phase demands analytical sharpness; for instance, in the problem-understanding stage, students must be able to identify key information and the goal of the question with precision [21].

The synergy between the PBL model and Computational Thinking (CT) is inherent, as the PBL syntax naturally stimulates the pillars of computational thinking. Yasmin and Negara (2024) state that the PBL model significantly influences the improvement of CT because it requires students to analyze, organize, and solve problems in a structured manner [22]. By integrating CT within PBL, students are trained to formulate problems such that solutions can be represented through effective computational steps [7].

Ultimately, the application of PBL combined with the CT framework aims to develop Higher Order Thinking Skills (HOTS). This aligns with modern curriculum demands that require students to have cognitive flexibility and persistence in processing complex information [23]. Through this integration, students do not only focus on finding the correct answer but also understand the logical structure behind every solution they construct [6].

### 2.3 GeoGebra as a Dynamic Tol for Exponential Functions

GeoGebra is a dynamic mathematics software that integrates algebra, geometry, and calculus features into an intuitive interactive platform. As a cognitive tool, GeoGebra allows students to explore mathematical concepts more deeply through dynamic visualization [24]. Empirical evidence has shown that using this application can enhance students' conceptual understanding of topics with high levels of abstraction, such as functions and geometry [25].

In the context of exponential function material, GeoGebra plays a crucial role in bridging symbolic and visual representations. Students can use the “slider” feature to manipulate parameters within exponential equations and observe real-time graph changes [13]. This facilitates students in identifying critical characteristics, such as curve asymptotes, exponential growth, and decay, which are often difficult to visualize statically on paper [17].

The link between GeoGebra and Computational Thinking lies in its ability to facilitate computational experiments. When students enter commands into the input bar, they are practicing algorithmic thinking by translating their logical steps into a sequence of instructions executable by the software [15]. This process helps students build accurate mathematical models while validating their hypotheses through interactive simulations [26].

Beyond cognitive aspects, the use of GeoGebra in CT-based learning also positively impacts student motivation and attitudes toward mathematics. By providing space for experimentation and instant feedback, this technology builds an exploratory and independent learning environment [12]. The synergy between accurate visualization and systematic thinking processes ensures that students can achieve a more comprehensive understanding of the structure of exponential function material [16].

## 3. METHOD

This research employed a descriptive qualitative method to describe the *Computational Thinking* (CT) skills of senior high school students. The study was conducted at MAN 1 Banyuasin from October to December 2025. The subjects were 33 students from class XII IPA 2, selected because they had previously studied exponential functions and possessed the cognitive maturity required for *Problem-Based Learning* (PBL). A purposive sampling technique was applied to select five primary subjects for in-depth interviews based on their academic diversity and CT test results.

The research was carried out in three systematic stages: preparation, implementation, and analysis. In the preparation stage, the researcher developed and validated instruments, including lesson plans, GeoGebra user guides, and Student Worksheets (LKPD) integrated with PBL. To ensure the validity of the research instruments, all materials—including the CT skill test—were validated by three experts: two lecturers from the Undergraduate Program of Mathematics Education, namely Mrs. Elsa Susanti, M.Pd. and Mrs. Rahma Siska Utari, M.Pd., as well as a mathematics teacher from MAN 1 Banyuasin, Mr. Alfarisi, S.Pd. These experts evaluated the instruments based on material accuracy and CT indicators. The instruments were subsequently revised and improved following the suggestions and feedback provided by these experts to ensure they were suitable for data collection.

The implementation stage spanned four meetings: (1) GeoGebra orientation, (2) PBL sessions on exponential growth, (3) PBL sessions on exponential decay, and (4) a CT skill test followed by interviews. The students' CT skills were evaluated based on the indicators and descriptors presented in Table 1.

Table 1. Indicators and Descriptors of Computational Thinking

| No. | Indicators | Descriptors |
|---|---|---|
| 1. | Decomposition | Students are able to break down complex problems into smaller, more manageable parts |
| 2. | Pattern Recognition | Students are able to identify patterns, similarities, or trends from data to understand the problem more deeply. |
| 3. | Abstraction | Students are able to ignore irrelevant details and focus on essential information to formulate concepts or models |
| 4. | Algorithm | Students are able to develop solution steps logically, structurally, and systematically. |

Data collection involved triangulation of three techniques: observation, written tests, and semi-structured interviews. Observations focused on five randomly selected students to monitor their interaction with GeoGebra during the PBL process. The written test consisted of three open-ended problems related to climate change, designed to measure CT pillars. Following the test, interviews were conducted to explore students' reasoning processes and their strategies in utilizing GeoGebra for verification. The scoring system for the CT test is detailed in Table 2, covering the indicators of *decomposition, abstraction, pattern recognition,* and *algorithms*.

Table 2. Scoring Rubrics for Computational Thinking

| Skor | ***Problem Decomposition*** | ***Abstraction & Pattern Recognition*** |
|---|---|---|
| 0 | No answer provided or the answer is completely irrelevant to the problem. | |
| 1 | Students only identify a small part of the information known from the problem, without a clear goal. Information is inaccurate or incomplete. | Students can only recognize patterns verbally but are unable to formulate them into mathematical models or general concepts |
| 2 | Students identify most of the information, but some details are missed. The final goal is stated but lacks detail or clarity. | Students recognize patterns and attempt to formulate them into a mathematical model, but the formula or model is not entirely accurate. |
| 3 | Students accurately and completely identify all important information and state the final goal clearly and in detail. | Students identify patterns and relationships, successfully formulating them into a precise mathematical model or general formula. |

| Skor | ***Algorithm*** |
|---|---|
| 0 | No answer provided or the answer is completely irrelevant. |
| 2 | Students write solution steps, but they are illogical and unsystematic. GeoGebra steps are missing or incorrect. |
| 4 | Students arrange fairly logical solution steps, but some stages are missed or disorganized. GeoGebra steps are included but incomplete. |
| 6 | Students arrange solution steps logically, structurally, and systematically from start to finish. GeoGebra steps are included correctly and in detail. |

The data analysis followed the interactive model by Miles and Huberman, consisting of *data reduction, data display*, and *conclusion drawing/verification* [12]. The written test results were categorized into three levels of CT ability: High, Moderate, and Low, as shown in Table 3. To ensure data reliability, the researcher involved peer observers and conducted technical triangulation by comparing test scores, observation notes, and interview transcripts to form a comprehensive profile of the students' *Computational Thinking* skills.

Table 3. Categorization of Computational Thinking Abillity

| Score Range | Category |
|---|---|
| $N \geq (\bar{x} + \sigma)$ | High |
| $(\bar{x} - \sigma) < N < (\bar{x} + \sigma)$ | Moderate |
| $N \leq (\bar{x} + \sigma)$ | Small |

## 4. RESULTS AND DISCUSSION

### 4.1 Analysis Of Students' Computational Thinking Skills

The *Computational Thinking* (CT) skills of the students were assessed using a written test consisting of contextual problems regarding exponential functions. Based on the data analysis of 33 students in class XII IPA 2, the distribution of students' CT abilities is categorized into three levels: High, Moderate, and Low. The summary of these results is presented in Table 4.

Table 4. Frequency Distribution of Students' Computational Thinking Skill Categories

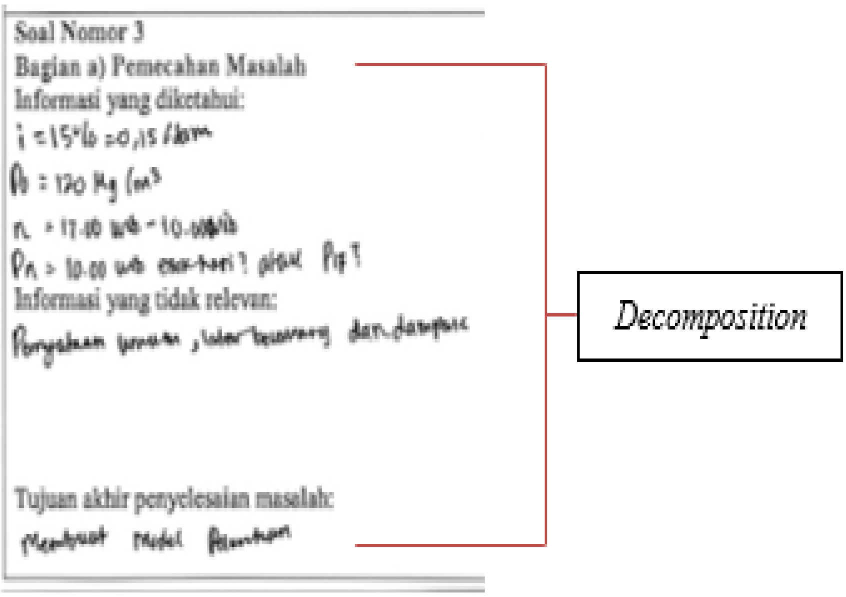
| Category | Frequency |
|---|---|
| High | 3 |
| Moderate | 25 |
| Low | 5 |

As shown in Table 4, the majority of students (25 students) fall into the "Moderate" category. Only a small fraction of the class reached the "High" category (3 students), while 5 students were in the "Low" category. This distribution indicates that while most students have a foundational understanding of CT, they still face challenges when integrated with complex mathematical concepts like exponential functions.

To provide a deeper insight into how students process each CT pillar, an analysis was conducted based on the four indicators: *decomposition, pattern recognition, abstraction,* and *algorithmic thinking*

### 1) Decomposition

In this indicator, almost all students in the high and moderate categories were able to identify the "known" and "asked" aspects of the problem. They could break down the climate change context into mathematical variables such as the initial population $(P_0)$ and the growth rate $(i)$. However, students in the low category often failed to distinguish between the constant growth rate and the time variables. This occurs because students are accustomed to procedural problems where all provided numbers must be used, leading to confusion when faced with complex narratives containing irrelevant data.



Soal Nomor 3

Bagian a) Pemecahan Masalah

Informasi yang diketahui:

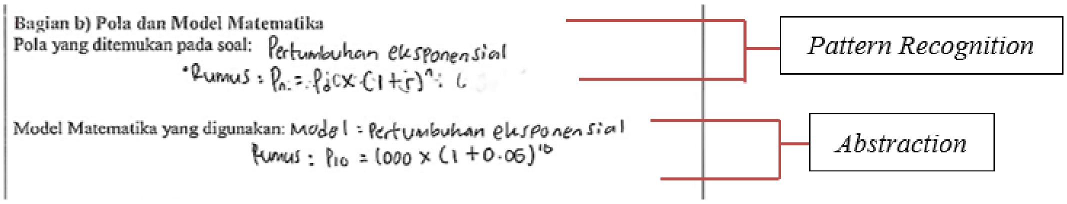
Informasi yang tidak relevan:

Tujuan akhir penyelesaian masalah:

Figure 1. Student's Work on the Decomposition Indicator

### 2) Pattern Recognition and Abstraction

The ability to recognize patterns varied significantly. High-ability students could easily see the doubling or tripling pattern in the exponential growth tables. However, many students in the moderate category struggled with *abstraction*. While they could see the pattern, they had difficulty transforming that pattern into a generalized exponential formula $(P_n = P_0(1 \pm i)^n$ .



**Bagian b) Pola dan Model Matematika**

Pola yang ditemukan pada soal: Pertumbuhan eksponensial

•Rumus : $P_n := P_0 \times (1+r)^n$ : (

Model Matematika yang digunakan: Model = Pertumbuhan eksponensial

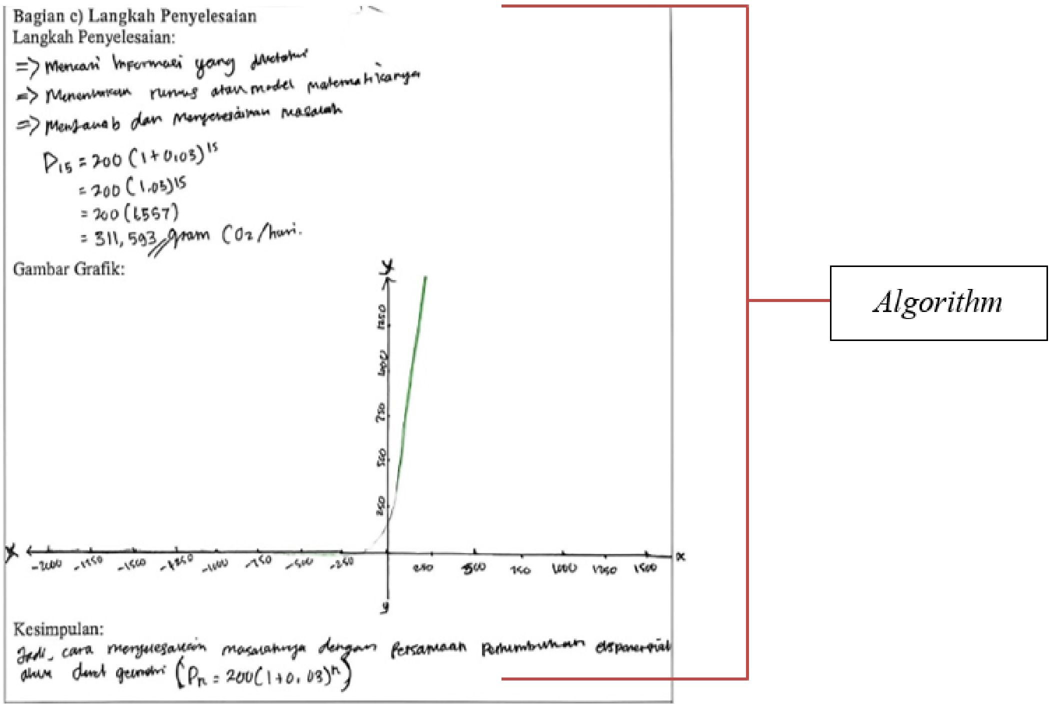
Rumus : $P_{10} = 1000 \times (1+0.06)^{10}$

Figure 2. Student's Work on Abstraction and Pattern Recognition Indicator

This difficulty stems from an "abstraction block," where students can identify numerical changes but fail to recognize the underlying exponential structure. For instance, in the climate change problem, moderate-category students identified that the CO2 concentration increased, but they could not formalize the relationship into an algebraic model because they were distracted by the socio-scientific narrative of the problem. This student struggle with abstraction is consistent with findings by Fauzi et al. (2024), which state that students tend to focus on superficial numerical data without comprehending the underlying mathematical model [3]. However, this research finds that GeoGebra's visual assistance can effectively minimize such cognitive barriers compared to traditional static methods by providing a concrete representation of abstract variables.

**3) Algorithmic Thinking**

This stage was the most complex for the students. Algorithmic thinking required students to arrange a step-by-step logical solution to find the final answer. Students in the low category often skipped steps or failed to apply the correct properties of exponents in their calculations, leading to illogical final results. Analysis of their work suggests that this is due to a lack of systematic checking habits; students often rush to the final calculation without validating the logical flow of their solution algorithm. The self-correction process observed when students utilized GeoGebra (as seen in Figure 4) supports the theory proposed by Utami (2025) that instant feedback from dynamic software is a critical catalyst in strengthening students' algorithmic logic and debugging skills [20].



**Bagian c) Langkah Penyelesaian**

Langkah Penyelesaian:

=> Mencari informasi yang diketahui

=> Menentukan rumus atau model matematikanya

=> Menjawab dan menyelesaikan masalah

$P_{15} = 200\,(1+0{,}05)^{15}$

$= 200\,(1{,}05)^{15}$

$= 200\,(1{,}557)$

$= 311{,}593$ gram $CO_2$/hari.

Gambar Grafik:

Kesimpulan:

Jadi, cara menyelesaikan masalahnya dengan persamaan pertumbuhan eksponensial atau deret geometri ($P_n = 200(1+0{,}03)^n$)

Figure 3. Student's Work on the Algorithm Indicator

## 4.2 The Role of GeoGebra in Supporting CT

During the observation of the *Problem-Based Learning* (PBL) process, GeoGebra played a vital role in bridging the gap between students' manual calculations and their conceptual understanding.

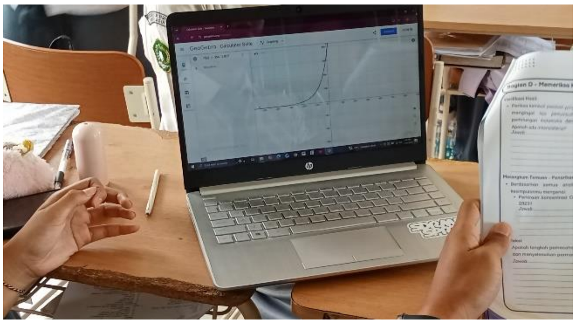


Figure 4. Student's Activity using GeoGebra

The dynamic nature of GeoGebra allowed students to manipulate sliders to see how the curve changes, which directly supported their abstraction skills. Specifically, for students in the moderate category, the use of sliders acted as a cognitive bridge to move toward high-category skills. By observing the immediate impact of changing the growth rate $(i)$ on the steepness of the exponential curve, students could visualize the connection between abstract algebraic variables and their graphical behavior.

Students also used the software to verify their manual algorithmic results. When a discrepancy occurred between their manual graph and the GeoGebra visualization, it prompted a self-correction process, which is a key element of computational reasoning. This "debugging" process strengthened their algorithmic thinking, as it forced students to re-examine their logical steps and refine their mathematical models until they achieved consistency between their manual work and the digital output. This iterative feedback loop provided by GeoGebra is essential for transitioning students from procedural understanding to structural computational thinking

## 5. CONCLUSION

This qualitative study concludes that senior high school students' *Computational Thinking* (CT) skills in solving exponential function problems are primarily characterized by a strong mastery of *decomposition* but significant fragility in *abstraction* and *algorithmic thinking*. Students in the high-ability category demonstrated a holistic integration of the four CT pillars, moving fluidly from identifying variables to constructing generalized mathematical models. However, the majority of students (the moderate group) showed a "conceptual gap," where they could recognize patterns visually but struggled to translate them into formal algebraic structures without external prompts.

The findings also highlight that the integration of GeoGebra as a cognitive scaffold in the *Problem-Based Learning* (PBL) model serves two critical functions: as a visual bridge for *abstraction* and as a verification tool for *algorithmic* accuracy. The dynamic feedback provided by GeoGebra allowed students to engage in a self-reflective "trial-and-error" process, which is essential for developing computational logic. Consequently, this study suggests that enhancing CT skills in mathematics requires not only technology but also instructional designs that explicitly emphasize the transition from concrete visual patterns to abstract mathematical generalizations.

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