



Defragmenting Student's Thinking Structures with Logical Errors in Solving STEAM-Based Geometry Problems through the Scaffolding Building Blocks Strategy

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ABSTRACT: The purpose of this study was to investigate how Scaffolding Building Blocks facilitates the defragmentation of students' thinking structures characterized by logical errors in solving STEAM-based geometry problems. This study employed a qualitative descriptive design involving one ninth-grade student selected through purposive sampling. Data were collected through a STEAM-based geometry problem-solving test, task-based semi-structured interviews, and documentation of students' written work. Data analysis followed the Miles and Huberman model, consisting of data condensation, data display, and conclusion drawing. Data validity was ensured through methodological triangulation. The findings indicate that the student's logical errors did not stem from a lack of conceptual understanding, but from fragmented relationship among mathematical concept during problem solving. The student relied on intuitive selection of arithmetic operations, which resulted in incoherent reasoning chains across solution stages. The implementation of Scaffolding Building Blocks enabled the student to reconstruct conceptual relationships through concrete geometric representations and guided questioning. This process progressively shifted the student's thinking from fragmented and intuition-driven reasoning toward coherent, structured, and logically consistent problem-solving. The study concludes that Scaffolding Building Blocks is effective in facilitating the defragmentation of students' thinking structures by reorganizing conceptual relationships in STEAM-based geometry problem solving. Beyond improving solution accuracy, the strategy promotes the reconstruction of logical reasoning structures, offering a pedagogically meaningful approach to addressing students' logical errors in mathematics learning.

KEYWORDS: Defragmentation, Student's Thinking Structure, Logical Error, STEAM-Based Geometry, Building Blocks Scaffolding

INTRODUCTION

STEAM-based geometry learning requires students not only to master mathematical concept but also to integrate knowledge across disciplines to solve contextual problems. Within the STEAM framework, mathematics serves as a language that connects science, technology, engineering, and art, enabling students to establish logical relationships among concepts when interpreting and solving real-world problems (Yakman, 2010). Consequently, solving geometry problems extends beyond the application of mathematical formulas and procedures; it requires students to organize multiple concepts into coherent reasoning structures that support effective problem solving (NCTM, 2000; Nugraha et al., 2023).

Despite its importance, numerous studies have reported that students continue to experience difficulties in solving geometry problems. These difficulties are not limited to weaknesses in spatial visualization or insufficient procedural knowledge but also involve the inability to connect relevant mathematical concepts during the problem-solving process (Fajari, 2020; Fauzi & Arisetyawan, 2020; Susilo & Sutarto, 2023). As a result, students frequently produce illogical solution strategies even when they possess the conceptual knowledge required to solve the problems correctly.

These findings suggest that students' errors are not always caused by inadequate conceptual understanding. In many cases, students possess the necessary concepts but fail to establish logical relationships among them, resulting in fragmented reasoning. According to Subanji (2016), this condition is referred to as fragmented thinking structures, in which the relationships among concepts are not organized into a coherent cognitive structure. One manifestation of such fragmentation is logical error, which occurs when students apply relevant concepts separately but fail to connect them through appropriate mathematical reasoning, leading to invalid conclusions.



Addressing fragmented thinking structures requires a process of defragmentation, which reorganizes conceptual relationships into a more coherent cognitive structure (Subanji, 2016). One instructional approach that has been widely adopted for this purpose is scaffolding. Previous studies have demonstrated that scaffolding can enhance conceptual understanding, mathematical problem-solving ability, and learning motivation by providing instructional support that is gradually adjusted to students' needs (Damayanti et al., 2020; Kusmaryono, 2021; Kusmaryono & Wijayanti, 2020; Retnodari et al., 2020). However, existing scaffolding studies have primarily emphasized procedural support and learning outcomes, while the process of reorganizing students' fragmented thinking structures has received limited attention.

One promising approach is the Scaffolding Building Blocks Strategy, which utilizes magnetic building blocks to support students in constructing concrete visual representations of geometric objects (Mardhiyatirahmah, 2022). These representations enable students to re-examine the relationships among geometric forms, measurements, and problem-solving strategies in a more systematic manner. Although studies on scaffolding and STEAM-based learning have increased in recent years, research investigating how the Scaffolding Building Blocks Strategy facilitates the defragmentation of students' thinking structures when logical errors occur during STEAM-based geometry problem solving remains scarce. Consequently, the mechanisms through which students' fragmented thinking structures are reorganized during scaffolding are still insufficiently understood.

Based on this research gap, the present study aims to investigate the process of defragmenting students' thinking structures with logical errors in solving STEAM-based geometry problems through the Scaffolding Building Blocks Strategy. The findings are expected to contribute to the theoretical understanding of thinking structure defragmentation and provide practical insights for designing scaffolding strategies that are responsive to students' fragmented thinking during mathematical problem solving

MATERIALS AND METHODS

Research Design and Participant

This study employed a qualitative descriptive approach to investigate the process of defragmenting students' thinking structures characterized by logical errors in solving STEAM-based geometry problems through the Scaffolding Building Blocks Strategy. A qualitative approach was selected because it enables an in-depth exploration of students' thinking processes before, during, and after the defragmentation process.

The study was conducted at MTs NU Al Badar, Jember, Indonesia, during the 2025/2026 academic year. The research participant was selected using purposeful sampling (Creswell & Guetterman, 2021). The selection process began by administering a STEAM-based geometry problem-solving task to ninth-grade students. Students' written responses were analyzed to identify fragmented thinking structures based on the classification proposed by Subanji (2016). One student who consistently demonstrated logical errors throughout the problem-solving process was selected as the research participant and assigned the pseudonym SSM.

Research Instruments

In qualitative research, the researcher served as the primary research instrument and was directly involved in all stages of the study, including planning, data collection, data analysis, interpretation, and reporting of the findings. To support the data collection process, several research instruments were employed. The first instrument was a STEAM-based geometry problem-solving task designed to identify students' fragmented thinking structures. The second instrument consisted of semi-structured interview guidelines developed based on Polya's stages of problem solving to explore students' thinking processes, identify the causes of logical errors, and examine changes in their thinking structures throughout the defragmentation process. The third instrument comprised documentation, including students' written work, interview transcripts, field notes, and photographs documenting the research activities.

Prior to data collection, the written test and interview guidelines were validated by three experts, consisting of two mathematics education lecturers and one mathematics teacher. The validation evaluated both content validity and construct validity to ensure the appropriateness of the research instruments.

Research Procedures

The study was conducted in four sequential stages. The first stage involved identifying fragmented thinking structures through a STEAM-based geometry problem-solving task. The task was administered to ninth-grade students, and their written responses were analyzed to determine the types of fragmented thinking structures. Based on the analysis, one student who met the research

criteria was selected as the research participant.

The second stage involved conducting an initial semi-structured interview with the participant. The interview aimed to explore the participant's thinking process in greater depth, confirm the type of fragmentation identified from the written task, and identify the causes of the logical errors.

The third stage involved implementing the Scaffolding Building Blocks Strategy. During this stage, the researcher provided scaffolding through guided questioning, the use of magnetic building blocks as concrete representations of three-dimensional geometric objects, and reflective discussions. Rather than providing direct answers, the researcher facilitated the participant in reconstructing conceptual relationships, reorganizing fragmented thinking structures, and independently developing an appropriate solution.

The fourth stage involved evaluating the defragmentation outcomes. After the scaffolding process was completed, the participant was asked to solve the same STEAM-based geometry problem independently. The participant's written responses and follow-up interview were then analyzed to identify changes in the thinking structure following the defragmentation process

Data Analysis

The data were analyzed using the interactive analysis model proposed by Miles and Huberman (2014), which consists of four interconnected components: data collection, data condensation, data display, and conclusion drawing and verification. Data obtained from the written task, interviews, and documentation were analyzed continuously to identify fragmented thinking structures, describe the defragmentation process, and evaluate changes in the participant's thinking structure following the implementation of the Scaffolding Building Blocks Strategy.

The trustworthiness of the findings was established through technique triangulation by comparing data obtained from interviews with the participant's written work. These two sources of evidence were continuously examined throughout the analysis to ensure the consistency, credibility, and trustworthiness of the research findings.

RESULTS

Analysis of the Fragmentation of the Thinking Structure: Logical Errors

Based on the results of the STEAM-based geometry problem-solving test and follow-up interviews, SSM was identified as a participant exhibiting logical errors, a type of fragmentation in thinking structure. This fragmentation was characterized by the inability to establish logical relationships among relevant mathematical concepts throughout the problem-solving process. Although SSM possessed most of the required mathematical concepts, including the concepts of plane area, the Pythagorean theorem, roof area, solar panel area, electrical power, and electrical energy, these concepts were not organized into a coherent thinking structure. Consequently, each decision made during problem solving was driven more by intuition and familiar procedures than by logical mathematical relationships among quantities.



Figure 1. SSM's initial solution to the STEAM-based geometry problem

As shown in Figure 1, SSM demonstrated an adequate understanding of the problem context. The participant successfully sketched the building, identified its components as a combination of a rectangular prism and a triangular prism, labeled the given dimensions, indicated the total building height, and represented the 0.5 m roof overhang. These findings suggest that the difficulty



did not arise from comprehending the problem or interpreting the given information. Instead, the fragmentation emerged when SSM attempted to connect the available information into a logically structured mathematical solution.

The first indication of fragmentation appeared in item (b), where SSM was asked to determine the area of one sloping roof surface. SSM correctly selected the area formula, length \times width, but immediately substituted the building length (12 m) and the building width (8 m), obtaining an area of 96 m². This procedure indicates that SSM understood the concept of plane area but failed to identify the appropriate dimensions required by the formula. The horizontal width of the building was incorrectly treated as the sloping length of the roof. However, determining the roof area first requires calculating the sloping side using the Pythagorean theorem by considering both the roof height and the roof overhang. Thus, although SSM possessed both the area concept and the Pythagorean theorem, these concepts were not logically connected. The conceptual sequence linking roof height, effective building width including the overhang, the Pythagorean theorem, the sloping roof length, and the roof area was absent from the participant's thinking structure. This marked the initial occurrence of the logical error.

The fragmentation became more evident in item (c), where SSM calculated the roof area available for solar panel installation. Instead of considering only the two sloping roof surfaces, SSM also included the triangular faces of the roof and summed all calculated areas, resulting in a total area of 696 m². Furthermore, the participant completely ignored the information stating that only 80% of each sloping roof surface could be used for panel installation. These findings indicate that SSM processed the information presented in the problem independently rather than integrating it according to the purpose of each calculation. As a result, the relationships among the building geometry, the installation area, and the effective roof coverage were not logically established.

The logical fragmentation became even more apparent in item (d), which required determining the maximum number of solar panels. After obtaining the total area of 696 m², SSM did not relate this area to the dimensions of a single solar panel. Instead, the participant multiplied two previously calculated area values. This operation demonstrates a failure to recognize the mathematical relationship between the available installation area and the area of one solar panel. Conceptually, the number of panels should be obtained by dividing the effective roof area by the area of a single panel. However, this relationship was absent from SSM's thinking structure, leading to the selection of an inappropriate operation based on procedural intuition rather than mathematical reasoning.

The logical errors generated in the previous steps subsequently affected the calculation of electrical power and daily energy production. In item (e), SSM directly multiplied the total roof area (696 m²) by the power rating of a single solar panel (300 Wp), implicitly treating the roof area as if it represented the number of installed panels. This procedure omitted the essential step of converting the effective roof area into the number of panels. Consequently, the logical relationship among roof area, number of panels, and total electrical power was not established. In item (f), SSM multiplied the previously calculated power by five hours of effective sunlight to determine daily energy production. Although the energy formula itself was appropriate, the resulting value remained incorrect because it was derived from an invalid representation of electrical power.

Fragmentation also appeared in the final stage, where SSM evaluated whether the generated electricity could satisfy the laboratory's monthly energy demand. Rather than comparing the total monthly energy produced by the solar panels with the required 1200 kWh, SSM performed another multiplication involving the available numerical values. This procedure indicates that the participant treated the quantities in the problem as isolated numerical values instead of recognizing their conceptual relationships. Consequently, the logical sequence linking daily energy production, monthly energy generation, and laboratory energy demand was not constructed.

Overall, SSM's solution demonstrates a pattern of error propagation, in which the initial logical error influenced every subsequent stage of the solution process. Each intermediate result was accepted without evaluating whether the underlying conceptual relationships were mathematically valid. Consequently, although the solution appeared procedurally sequential, the entire reasoning process was built upon incorrect conceptual connections, leading to an invalid conclusion.

Overall, the findings indicate that SSM's fragmented thinking structure is characterized by logical errors rather than a lack of conceptual knowledge. The participant possessed the mathematical concepts required to solve the problem but failed to organize and connect these concepts into a coherent sequence of mathematical reasoning. This fragmented thinking structure provided the basis for implementing the Scaffolding Building Blocks Strategy during the subsequent defragmentation process.

Defragmentation of the thinking structure through the Scaffolding Building Blocks Strategy



Figure 2. A building constructed by SSM using magnetic building blocks.

The defragmentation process was implemented through the Scaffolding Building Blocks Strategy, which was designed to facilitate the gradual reorganization of SSM's fragmented thinking structure. Rather than providing procedural guidance or directly supplying formulas, the scaffolding focused on reconstructing the logical relationships among fragmented mathematical concepts through concrete representations, guided questioning, and reflective reasoning at each stage of problem solving.

The initial stage emphasized reconstructing the problem representation. SSM was asked to build a three-dimensional model of the laboratory using magnetic building blocks based on the information provided in the problem. This activity enabled the participant to reexamine the building as a composite of a rectangular prism and a triangular prism from both visual and spatial perspectives. Through this concrete representation, SSM successfully distinguished the sloping roof surfaces, the triangular faces, and the roof overhang according to their respective geometric characteristics. As a result, the participant reconstructed a more accurate geometric representation, providing the foundation for subsequent conceptual reasoning.

After the problem representation had been reconstructed, the scaffolding shifted toward rebuilding the logical relationships among mathematical concepts. Instead of introducing formulas directly, the researcher guided SSM to identify the information that had to be determined before any calculation could be performed. Through guided questioning, SSM recognized that the roof height should first be obtained by subtracting the height of the rectangular prism from the total building height. The participant also realized that the sloping roof length could not be taken directly from the given dimensions but had to be determined using the Pythagorean theorem while considering the roof overhang. Consequently, the previously fragmented conceptual sequence gradually became integrated into a coherent chain of reasoning, enabling SSM to determine the roof area using the appropriate geometric dimensions.

The subsequent stage focused on reorganizing the sequence of mathematical reasoning throughout the solution process. Before the intervention, SSM treated each question independently and selected mathematical operations primarily through intuition whenever uncertainty arose. Following the scaffolding process, however, the participant began to recognize the causal relationships among successive solution steps. The area of the sloping roof was first used to determine the effective installation area, the effective area was then used to calculate the maximum number of solar panels, the number of panels became the basis for determining the total electrical power, and the total power was subsequently used to calculate daily electrical energy production. This progression indicates that mathematical decisions were no longer based on isolated procedures but on logically connected relationships among quantities.

Overall, the defragmentation process demonstrates that the Scaffolding Building Blocks Strategy facilitated more than the correction of procedural errors. The strategy supported the reorganization of SSM's thinking structure through three complementary mechanisms: reconstructing the problem representation, rebuilding logical relationships among mathematical concepts, and reorganizing the sequence of mathematical reasoning. These interconnected processes enabled the fragmented thinking structure

to develop into a more coherent and logically organized framework for solving STEAM-based geometry problems.

Reconstruction of the Thinking Structure after Defragmentation

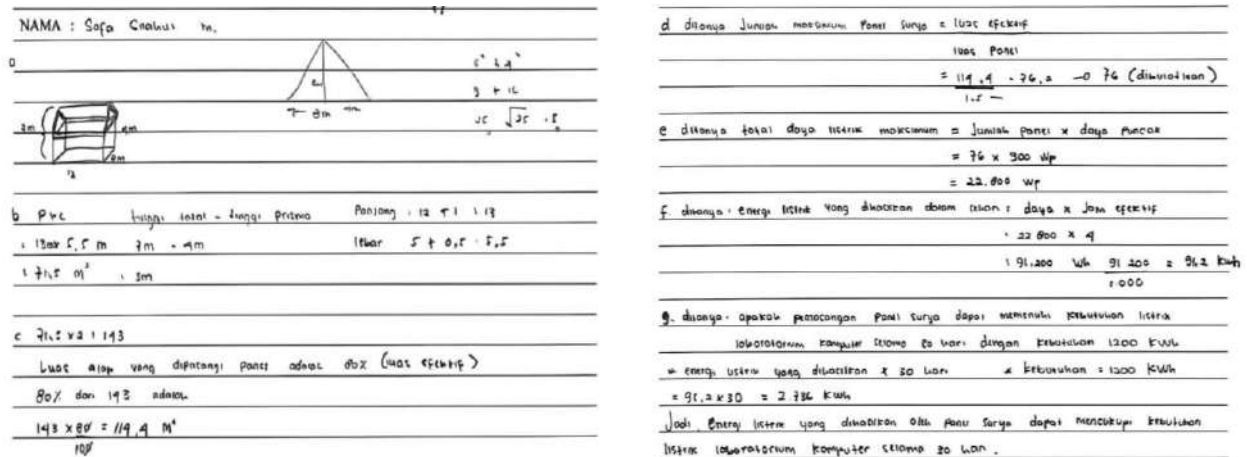


Figure 3. SSM's solution after the defragmentation process through the Scaffolding Building Blocks Strategy

Figure 3 illustrates SSM's solution after completing the defragmentation process through the Scaffolding Building Blocks Strategy. Compared with the initial solution, substantial changes were observed in the organization of the participant's thinking structure. Rather than solving each question independently, SSM constructed the solution through a coherent sequence of logically connected mathematical relationships. This finding indicates that the participant's thinking structure had been successfully reorganized following the defragmentation process.

The first reconstruction was evident in the identification of prerequisite information before performing any calculations. SSM recognized that the sloping roof length had to be determined before calculating the roof area. The participant correctly established the relationship between the total building height and the height of the rectangular prism to obtain the roof height and subsequently applied the Pythagorean theorem to determine the sloping roof length. Unlike the initial solution, the relevant concepts were no longer treated as isolated pieces of knowledge but were integrated into a coherent conceptual sequence.

Further reconstruction was observed in determining the effective roof area available for solar panel installation. SSM correctly excluded the triangular faces from the installation area and incorporated the condition that only 80% of the sloping roof surface could be used for panel installation. After obtaining the effective roof area, the participant determined the maximum number of solar panels by dividing the effective installation area by the area of a single panel. Each calculation was supported by appropriate mathematical relationships, and no intuitive or arbitrary selection of mathematical operations was observed.

The reconstructed thinking structure also became evident in the subsequent calculations of electrical power, daily energy production, and the evaluation of the laboratory's monthly energy demand. SSM consistently used the result of each step as the prerequisite for the next, forming a continuous chain of mathematical reasoning. In addition to obtaining correct numerical results, the participant was able to justify each procedure using appropriate mathematical arguments. This finding indicates that mathematical decisions were no longer based on intuition or habitual procedures but on an integrated understanding of the conceptual relationships underlying the problem.

Overall, the findings demonstrate that the defragmentation process resulted in the successful reconstruction of SSM's thinking structure. Previously fragmented conceptual relationships were reorganized into a coherent network in which each concept functioned as a prerequisite for subsequent reasoning. Consequently, the improvement was reflected not only in the correctness of the final solution but also in the development of a coherent and logically connected thinking structure for solving STEAM-based geometry problems.



DISCUSSION

The findings of this study indicate that the logical errors experienced by SSM in solving STEAM-based geometry problems were not caused by difficulties in performing mathematical calculations, but rather by the inability to establish logical relationships among relevant concepts during the problem-solving process. In the initial solution, the student tended to apply multiplication as a default operation when encountering uncertainty, without considering the mathematical meaning of the quantities involved. As a result, an initial error triggered a chain of subsequent errors across later stages of the solution. This condition suggests that the student's thinking structure was not yet systematically organized, even though the required information had already been available.

These findings are consistent with Subanji's (2016) theory of fragmented thinking structures, which states that learning errors do not necessarily stem from the absence of concepts, but rather from the failure to construct coherent relationships among cognitive schemes. In SSM's case, concepts such as area, percentage, solar panel coverage, electrical power, and energy were already possessed. However, these concepts remained isolated and were not integrated into a coherent reasoning structure. Consequently, the student was unable to determine solution procedures based on logical relationships among quantities and instead relied on intuition or habitual use of arithmetic operations. This characteristic strongly supports the classification of the observed error as a logical error, in which reasoning processes are not aligned with the underlying mathematical relationships.

A noticeable change in the student's thinking structure emerged after the implementation of the Scaffolding Building Blocks Strategy. The use of magnetic building blocks provided a concrete representation of the geometric structure, enabling the student to directly observe the relationships among the prism, roof surfaces, overhang, and the placement of solar panels. This concrete representation helped reconnect visual information with previously fragmented geometric concepts. Through a sequence of guided questions, the student was not only directed toward obtaining correct answers but also encouraged to reconstruct the mathematical reasoning underlying each step of the solution. Thus, the defragmentation process did not merely correct the final answer but reorganized the relationships among concepts into a more coherent structure.

These findings support Kusmaryono (2021), who stated that scaffolding facilitates gradual conceptual understanding through instructional support tailored to students' learning needs. They are also in line with Mardhiyatirahmah (2022), who emphasized that building blocks support the visualization of geometric objects, making abstract concepts more comprehensible. However, this study extends previous findings by demonstrating that the Scaffolding Building Blocks Strategy not only enhances conceptual understanding in geometry but also facilitates the defragmentation of thinking structures in students experiencing logical errors. In this sense, the concrete media functioned not merely as a visual aid, but as a cognitive bridge that supports the reconstruction of logical relationships among mathematical concepts through systematic scaffolding.

The implications of this study suggest that teachers should not focus solely on whether students arrive at correct answers, but also on the structure of reasoning underlying their problem-solving processes. Errors that appear procedural in nature may actually originate from fragmented conceptual relationships rather than a lack of conceptual knowledge. Therefore, the Scaffolding Building Blocks Strategy can be considered an alternative instructional approach that helps students build concrete representations, reconnect fragmented concepts, and reconstruct problem-solving procedures based on valid mathematical relationships, particularly in STEAM-based geometry learning.

This study has limitations, as it involved only a single participant exhibiting logical error characteristics; therefore, the findings are not intended for generalization. In addition, the defragmentation process was conducted within a task-based interview setting, meaning that the effectiveness of the strategy in full classroom implementation was not examined. Future research is recommended to investigate this strategy across different types of fragmented thinking structures or to apply it in broader STEAM-based geometry instruction involving a larger and more diverse sample of students.

CONCLUSION

This study reveals that logical errors in STEAM-based geometry problem solving arise not from a lack of conceptual knowledge, but from students' inability to establish logical relationships among already acquired concepts. This condition leads students to rely on intuitive or habitual use of arithmetic operations without considering the underlying mathematical relationships among quantities. The implementation of the Scaffolding Building Blocks Strategy facilitated the defragmentation of students' thinking structures through concrete geometric representations and gradual scaffolding. As a result, students were able to reconnect fragmented concepts, reorganize their reasoning sequences, and construct more systematic and logically coherent solution



procedures. These findings suggest that the Scaffolding Building Blocks Strategy not only supports the attainment of correct solutions but also contributes to the reconstruction of thinking structures affected by logical errors. Therefore, this strategy may be considered a promising pedagogical alternative for supporting the defragmentation of students' thinking structures in STEAM-based geometry learning.

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