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Exploring psychological, conceptual, and instrumental ontogenetic learning obstacles in elementary geometry: Evidence from students' solutions to composite plane figure area tasks

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Abstract

Background: Geometry is a fundamental component of elementary mathematics that supports the development of logical reasoning, spatial visualization, and problem-solving skills. However, many students continue to experience persistent learning difficulties that extend beyond procedural errors and reflect deeper ontogenetic learning obstacles associated with cognitive readiness and conceptual development. Despite increasing attention to learning obstacles in mathematics education, empirical studies examining the psychological, conceptual, and instrumental dimensions of ontogenetic obstacles in elementary geometry remain limited.
Aims: This study aimed to explore students' psychological, conceptual, and instrumental ontogenetic learning obstacles when solving composite plane figure area tasks.
Methods: A qualitative descriptive approach was employed as the prospective analysis stage of Didactical Design Research (DDR). Twenty sixth-grade elementary school students participated in the study. Data were collected through a validated Learning Obstacle Diagnostic Test consisting of three open-ended tasks and analyzed descriptively based on the ontogenetic learning obstacle framework.
Results: The findings revealed that conceptual ontogenetic obstacles were the most dominant, followed by instrumental obstacles, while psychological obstacles emerged primarily as a consequence of unresolved conceptual and procedural difficulties.
Conclusion: The three types of ontogenetic learning obstacles were interconnected and significantly influenced students' understanding of composite plane figure area concepts. These findings provide an empirical foundation for designing adaptive instructional strategies that better accommodate students' cognitive development and learning needs.

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INTRODUCTION

Mathematics is a fundamental discipline that plays a significant role in developing logical reasoning, analytical thinking, systematic problem-solving, and critical decision-making skills. Beyond mastering numerical operations, mathematics enables learners to construct knowledge through reasoning, abstraction, communication, and mathematical representation (Torres-Peña et al., 2025) . These competencies have become increasingly important in the twenty-first century, where individuals are expected to solve complex problems, think critically, and adapt to rapidly changing environments. Consequently, mathematics has become a compulsory subject across all levels of formal education, beginning in elementary school and continuing through higher education

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(Aucejo & James, 2021; Büchele & Feudel, 2023; Szabo et al., 2020). At the elementary level, mathematics learning is designed to establish strong conceptual foundations that support students' future mathematical development. The elementary mathematics curriculum integrates various content domains with process-oriented competencies to promote meaningful learning experiences. These domains include numbers, algebra, measurement, geometry, and data analysis, while the associated process skills emphasize reasoning, problem-solving, communication, representation, and mathematical connections (Adeleke et al., 2025; Aljura et al., 2025; Ziatdinov & James R. Valles, 2022). The integration of mathematical content and processes is intended to foster students' ability to apply mathematical knowledge in both academic and real-life contexts. Meaningful mathematics learning therefore requires students to understand concepts rather than merely memorize formulas or procedures. Developing conceptual understanding from the early years of schooling is essential for preparing students to engage successfully with increasingly complex mathematical ideas throughout their educational journey.

Geometry constitutes one of the essential domains of elementary mathematics because it provides students with opportunities to develop spatial reasoning, visualization, measurement, and analytical thinking skills. Through geometry, students learn to recognize geometric relationships, interpret visual information, and connect abstract mathematical concepts with tangible objects encountered in everyday life (Abrahamson et al., 2020; Dorel, 2023; Hwang et al., 2020; Price et al., 2020). One of the important topics introduced at the elementary level is the area of composite plane figures, which requires students to combine multiple geometric concepts simultaneously. Unlike calculating the area of a single geometric shape, solving composite figure tasks requires students to decompose complex figures into simpler components, recognize relationships among constituent shapes, and apply appropriate area formulas systematically (C.-Y. Lee et al., 2023; Lehmann, 2023). These cognitive processes demand not only procedural competence but also strong conceptual understanding of measurement principles and geometric structures. Students are expected to identify relevant information, organize mathematical relationships, and justify their solution strategies logically. Such learning activities contribute to the development of higher-order thinking skills, including reasoning, creativity, problem-solving, and mathematical communication (Ceballos et al., 2026; Nilimaa, 2023; Sutarni et al., 2024). However, the complexity of composite plane figure tasks often exceeds students' existing conceptual understanding, making this topic one of the most challenging areas within elementary geometry. As a result, many students encounter persistent difficulties in interpreting geometric representations and selecting appropriate solution strategies. These recurring difficulties indicate that understanding composite plane figures involves considerably more than applying memorized formulas, requiring students to construct meaningful conceptual relationships among multiple mathematical ideas.

Despite the importance of geometry in elementary mathematics, many students continue to perceive mathematics as a difficult and intimidating subject, particularly when confronted with complex geometric problems. These negative perceptions frequently reduce students' confidence, learning motivation, and willingness to engage actively in mathematical reasoning (Aguilar, 2021; Shekhar et al., 2020; Skilling et al., 2020). Students' learning difficulties are not limited to computational mistakes but often reflect deeper cognitive barriers that hinder meaningful conceptual development. Within mathematics education, these barriers are commonly understood through the perspective of learning obstacles, which explain why students fail to construct appropriate mathematical understanding despite receiving classroom instruction. Learning obstacles emerge when students experience discrepancies between instructional demands and their cognitive readiness, prior knowledge, or conceptual maturity. Among the various categories of learning obstacles, ontogenetic learning obstacles are particularly important because they emphasize the relationship between students' developmental characteristics and the complexity of the learning material. Ontogenetic learning obstacles encompass psychological, conceptual, and instrumental dimensions that collectively influence students' learning experiences throughout the instructional process (Osei & Bjorklund, 2024; Semper & Iriso, 2026). Nevertheless, existing studies have predominantly emphasized epistemological and didactical learning obstacles, whereas investigations focusing specifically on ontogenetic learning obstacles remain relatively limited, particularly within the context of elementary geometry. Furthermore, only a few studies have comprehensively examined the interactions among psychological, conceptual, and instrumental ontogenetic learning obstacles when students solve composite plane figure area tasks. Therefore, a deeper investigation of these interconnected dimensions is necessary to provide a more comprehensive understanding of students' cognitive barriers and to establish a stronger foundation for developing instructional designs that better accommodate students' conceptual development and learning needs.

Despite the growing body of research on mathematics education, several important gaps remain regarding the understanding of students' learning obstacles in elementary geometry. Previous studies have primarily focused on improving geometry learning through instructional interventions, such as schematic chunking, virtual reality, multisensory learning environments, and digital technologies, with an emphasis on enhancing students' geometry performance and reducing learning difficulties rather than explaining the underlying cognitive barriers that hinder conceptual development (Galitskaya & Drigas, 2023; Liu et al., 2021; Price et al., 2020; D. Zhang, 2021). Other studies have extensively investigated students' misconceptions related to area and perimeter, demonstrating that learners frequently confuse these concepts, apply formulas procedurally without conceptual understanding, and experience persistent misconceptions that continue into teacher education (Durmaz & Işiksal Bostan, 2022; Harbison et al., 2026; Runnalls & Hong, 2020; Yunianto et al., 2021; Zhou et al., 2025). Meanwhile, research grounded in learning obstacle theory has increasingly examined epistemological and didactical obstacles across various mathematical topics and has highlighted the potential of Didactical Design Research (DDR) for identifying students' learning barriers and designing adaptive instruction (Wijaya et al., 2021). However, empirical studies that specifically investigate ontogenetic learning obstacles remain limited, particularly those that simultaneously examine the interaction among psychological, conceptual, and instrumental ontogenetic learning obstacles in elementary geometry. Furthermore, existing studies generally describe students' misconceptions, procedural errors, or learning difficulties as isolated phenomena, without explaining how conceptual limitations evolve into procedural difficulties and subsequently influence students' psychological readiness during mathematical learning. Therefore, this study addresses these gaps by providing a comprehensive analysis of the interrelationships among psychological, conceptual, and instrumental ontogenetic learning obstacles experienced by elementary school students when solving composite plane figure area tasks within the framework of Didactical Design Research, thereby contributing a more comprehensive theoretical understanding of ontogenetic learning obstacles in mathematics education.

This study aims to explore the psychological, conceptual, and instrumental ontogenetic learning obstacles experienced by elementary school students when solving composite plane figure area tasks. Specifically, the study seeks to identify the characteristics of each type of ontogenetic learning obstacle that emerges during students' mathematical reasoning and problem-solving processes. It also examines how conceptual understanding influences students' ability to apply appropriate mathematical procedures when solving geometry tasks. Furthermore, this study investigates the relationship between conceptual and instrumental obstacles and their contribution to the emergence of psychological obstacles during learning. By examining students' written responses and reasoning, this study provides empirical evidence regarding the multidimensional nature of ontogenetic learning obstacles in elementary geometry. The study further seeks to explain how these obstacles interact rather than exist as isolated learning difficulties. In addition, the findings are expected to enrich the theoretical understanding of ontogenetic learning obstacles within the framework of Didactical Design Research. From a practical perspective, the study intends to provide evidence that can assist teachers in identifying students' cognitive readiness before introducing more complex geometry concepts. The findings are also expected to support the development of instructional designs that are more responsive to students' conceptual development and learning needs. Ultimately, this study contributes to the advancement of mathematics education research by providing a comprehensive understanding of ontogenetic learning obstacles as a foundation for designing more effective geometry instruction in elementary schools.

LITERATURE REVIEW

Geometry is a fundamental domain of mathematics that enables students to understand shapes, spatial relationships, measurement, and visual representation. Learning geometry extends beyond recognizing geometric figures because it also requires students to develop reasoning skills that support mathematical abstraction and problem solving. Within elementary mathematics, composite plane figures represent one of the essential geometry topics because they integrate concepts of measurement, spatial visualization, and geometric decomposition (Flavin et al., 2025; Lehmann, 2023; Lowrie & Logan, 2023; Q. Zhang, 2021). A composite plane figure is formed by combining two or more simple geometric shapes into a single figure while preserving the properties of each constituent shape. Solving area problems involving composite plane figures requires students to recognize the component shapes before selecting appropriate mathematical strategies for calculating the total area (Flavin et al., 2025; Lehmann, 2023; Sari et al., 2023). This process involves decomposing complex figures into simpler regions and synthesizing multiple area calculations into a single solution. Consequently, students are expected to coordinate conceptual understanding with procedural knowledge throughout the solution process. Learning composite plane figure area therefore requires considerably more than recalling area formulas because students must understand the mathematical relationships among the constituent figures. Failure to establish these relationships frequently results in misconceptions, inappropriate strategy selection, and computational errors during geometry learning. Therefore, understanding the conceptual complexity of composite plane figures is essential for explaining why many elementary students continue to experience persistent difficulties in geometry learning.

Geometry learning has been widely explained through theories of students' cognitive development, particularly the hierarchical model proposed in geometry education. According to this perspective, students progressively develop geometric understanding through increasingly sophisticated levels of reasoning rather than acquiring concepts simultaneously (Adeniji & Baker, 2022; Jablonski & Ludwig, 2023; Seah & Horne, 2021). At the initial stage, students recognize geometric figures primarily through visual appearance without understanding their defining properties. As learning progresses, students begin to analyze the characteristics of geometric figures and identify relationships among their properties. More advanced stages require learners to establish logical connections among geometric concepts, formulate mathematical arguments, and construct deductive reasoning. These developmental stages indicate that meaningful geometry learning depends on the alignment between instructional complexity and students' cognitive readiness. When instructional materials exceed students' developmental levels, conceptual understanding becomes fragmented and mathematical reasoning is hindered. Conversely, learning activities that correspond to students' cognitive development facilitate deeper conceptual understanding and more flexible problem-solving strategies. Composite plane figure area tasks represent a suitable context for examining students' cognitive development because they require simultaneous integration of visualization, decomposition, measurement, and reasoning. Therefore, investigating students' responses to these tasks provides valuable insights into the cognitive processes that underlie successful geometry learning.

Area is one of the most fundamental measurement concepts introduced during elementary mathematics education, yet it remains among the most difficult concepts for students to understand meaningfully. A meaningful understanding of area extends beyond the ability to substitute numerical values into formulas because it requires students to recognize area as a quantitative attribute representing the extent of a two-dimensional region. Students are expected to understand the relationship between measurement units, geometric dimensions, and the structure of plane figures before applying area formulas appropriately (Caviedes Barrera et al., 2023; Hwang et al., 2020; Idrus et al., 2022; M. Y. Lee & Lee, 2021; Payadnya et al., 2023). However, many learners rely primarily on memorized procedures without developing an adequate conceptual understanding of area measurement. This procedural orientation frequently causes students to confuse the concepts of area and perimeter or to apply formulas incorrectly when solving unfamiliar geometry problems. Such misconceptions become increasingly evident when students encounter irregular or composite plane figures that cannot be solved through direct formula substitution. In these situations, students must first identify the constituent geometric figures, determine suitable decomposition strategies, and integrate several area calculations into a coherent mathematical solution (Hsu & Silver, 2026; C.-Y. Lee et al., 2023; Yunianto et al., 2025). Failure to construct these conceptual relationships often results in fragmented reasoning and unsuccessful problem-solving performance. Consequently, conceptual understanding of area serves as an essential prerequisite for successful learning of composite plane figure area tasks. Examining students' conceptual understanding therefore provides an important theoretical foundation for identifying learning obstacles that emerge during elementary geometry instruction.

The concept of learning obstacles has become one of the most influential theoretical perspectives for explaining why students experience persistent difficulties in mathematics learning. Rather than attributing learning failure solely to students' academic ability, learning obstacle theory emphasizes the interaction between learners' cognitive characteristics, instructional design, and the nature of mathematical knowledge. Within the Theory of Didactical Situations, learning obstacles are generally classified into epistemological, didactical, and ontogenetic obstacles, each representing different sources of barriers that hinder meaningful learning (Hendriyanto et al., 2024; Maifa et al., 2025; Prabowo et al., 2022; Sugiarni et al., 2025). Epistemological obstacles arise when previously acquired knowledge is applied beyond its appropriate context, causing students to construct incomplete or inaccurate mathematical understanding. Didactical obstacles originate from instructional decisions, learning resources, or teaching strategies that do not adequately support students' conceptual development. Ontogenetic obstacles, in contrast, emerge when the level of instruction is inconsistent with students' cognitive development, prerequisite knowledge, or psychological readiness to learn. Unlike epistemological and didactical obstacles, ontogenetic obstacles emphasize the learner's developmental condition as a determining factor in mathematical understanding. Previous studies have demonstrated that learning obstacles frequently coexist and influence one another throughout the learning process rather than occurring independently. Consequently, identifying learning obstacles before instructional intervention has become an essential component of Didactical Design Research because it enables educators to design learning experiences that correspond more closely with students' cognitive characteristics. Therefore, learning obstacle theory provides a comprehensive theoretical framework for interpreting students' errors as manifestations of deeper cognitive barriers rather than isolated procedural mistakes.

Among the three categories of learning obstacles, ontogenetic learning obstacles provide a particularly valuable perspective for understanding the relationship between students' developmental readiness and the complexity of mathematical learning. Ontogenetic learning obstacles are commonly classified into psychological, conceptual, and instrumental dimensions that collectively influence students' ability to construct meaningful mathematical understanding. Psychological ontogenetic obstacles are associated with students' emotional readiness, learning motivation, confidence, and willingness to engage in mathematical activities (Capone, 2022; Yang et al., 2024). Conceptual ontogenetic obstacles arise when students lack sufficient conceptual maturity to understand new mathematical ideas because prerequisite concepts have not yet been fully established. Instrumental ontogenetic obstacles occur when students experience difficulties in applying mathematical procedures, techniques, or representations despite possessing partial conceptual knowledge. These three dimensions should not be interpreted as independent learning difficulties because they frequently interact throughout the learning process and collectively influence students' mathematical performance. Conceptual deficiencies may lead to procedural failures, while repeated procedural failures may subsequently reduce students' confidence and motivation to participate actively in mathematics learning. Within the framework of Didactical Design Research, identifying these multidimensional obstacles constitutes the prospective analysis stage that precedes the development of instructional interventions. Understanding the interaction among psychological, conceptual, and instrumental ontogenetic learning obstacles enables teachers to design learning environments that better accommodate students' cognitive development and learning readiness. Therefore, investigating ontogenetic learning obstacles in composite plane figure area tasks provides both theoretical and practical contributions to mathematics education by supporting the development of more adaptive and cognitively responsive instructional designs.

METHOD

Research Design

This study used a qualitative approach. Qualitative research has several characteristics: (1) it is conducted in natural settings (without specific intervention); (2) the researcher serves as the primary instrument; (3) it is descriptive; (4) it emphasizes process; (5) analysis is inductive; and (6) the research emphasizes meaning. The method used was descriptive-analytical. The descriptive-analytical method is a research method that seeks to collect data in accordance with actual reality, without any special treatment, for subsequent analysis and interpretation in accordance with the research objectives. This study serves as a preliminary study within the framework of Didactical Design Research (DDR). It is situated in the first stage of DDR, namely prospective analysis. Prospective analysis involves examining a didactic situation before instruction is implemented. The activity carried out during prospective analysis is the analysis of learning obstacles, which serves as the basis for developing a didactic design. The data used in this study are the results of the learning obstacle test. These data were then analyzed qualitatively to identify students' ontogenetic obstacles in the combined area of plane figures. More specifically, the analysis focused on the three types of ontogenetic obstacles: psychological, instrumental, and conceptual.

Participants

The participants in this study were 20 sixth-grade elementary school students who had previously studied the topic of the combined area of two-dimensional shapes. Participants were selected using purposive sampling. These participants were selected because the combined area of two-dimensional shapes is taught in the fifth-grade curriculum; therefore, it can be confirmed that sixth-grade students have already covered this material. The participants in this study were all sixth-grade students at a public elementary school in South Sumedang Subdistrict, Sumedang Regency. This school is located in a semi-rural area. The school uses the Merdeka Curriculum, in accordance with applicable regulations in Indonesia. Based on the results of the initial diagnostic assessment, students' math skills are at the developing stage.

Instruments

The primary instrument used in this study was a learning obstacle test specifically developed to identify students' learning obstacles regarding the combined area of plane figures. The research instrument consisted of three open-ended questions. Each question was developed in accordance with an outline that referenced the pre-established learning objectives. The instrument was developed through several stages, namely: (1) analysis of CP and ATP; (2) development of the blueprint; (3) development of the question framework; and (4) validation by experts. Validation was conducted using the expert judgment method, specifically by two mathematics lecturer at the Indonesian University of Education.

Research Procedure

This study was conducted in a single session, with no experimental treatments. The research procedures included preparation, implementation, and analysis. The preparation process involved a literature review, instrument development, and instrument validation. Once the preparation process was completed, the study proceeded to the implementation phase. During this phase, data were collected using the prepared instruments. In addition, direct observation was also used as a supplementary method to enrich the data obtained. After the data were collected, the analysis process began.

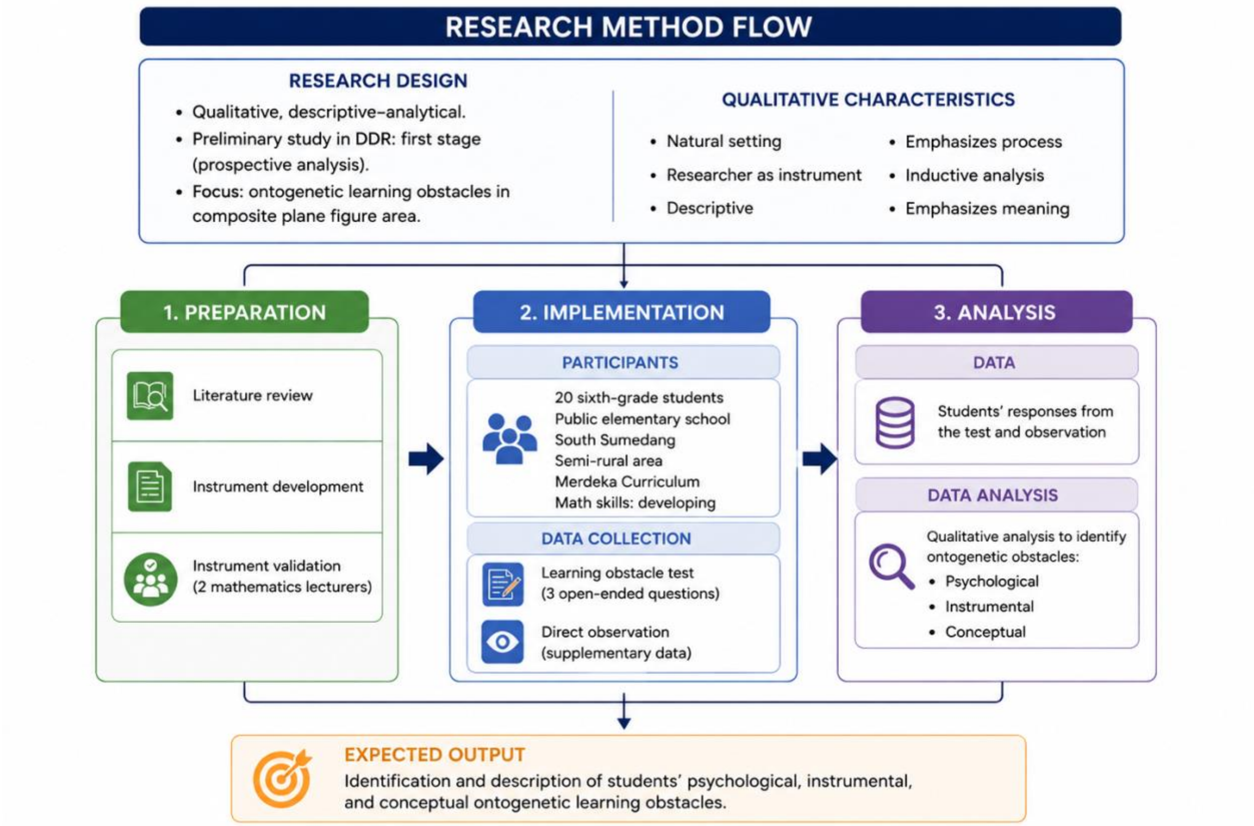
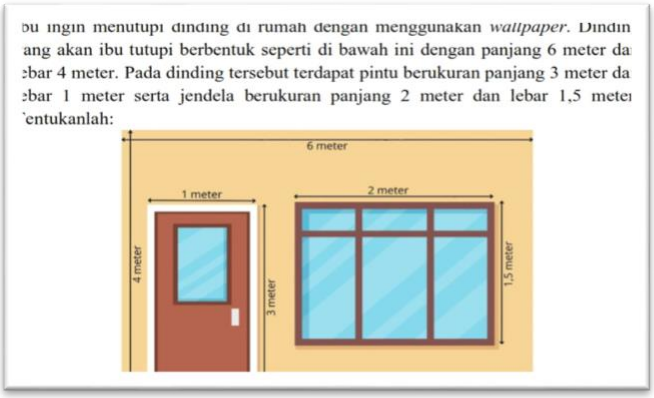


Figure 1. Research Method Flow

RESULTS AND DISCUSSION

Results

The research instruments used were derived from a single problem. The problem presented to the students is shown in Figure 1 below.



The figure presents an authentic geometry task requiring students to determine the wallpaper area needed to cover a rectangular wall after excluding the areas of a door and a window. The task was designed to assess students' conceptual understanding of area, geometric decomposition, and procedural reasoning when solving composite plane figure problems. Students' responses were analyzed to identify psychological, conceptual, and instrumental ontogenetic learning obstacles within the framework of Didactical Design Research.

Figure 2. Problems presented in the learning obstacle test instrument

This problem was developed into three essay questions presented in the learning obstacle test. The first question asked students to identify the area of the wall covered with wallpaper. Among all participants in this study, there were four types of student responses. These four types of responses are shown in the following figure.

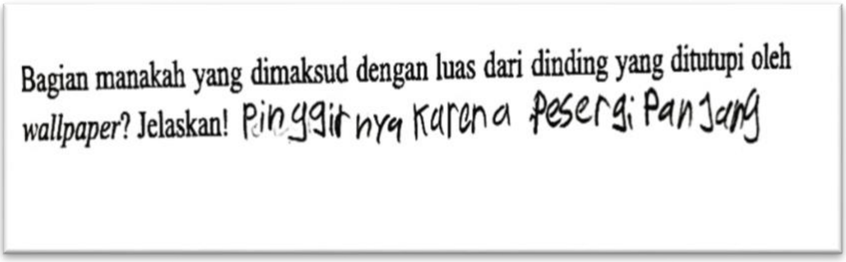


Figure 3. Answer type 1 for question number 1

Figure 3 presents a representative student response to the first Learning Obstacle Diagnostic Test item. The response, "The edges because it is a rectangle," indicates a misconception in distinguishing area from perimeter. This finding reflects a conceptual ontogenetic learning obstacle, showing that the student had not yet developed a meaningful understanding of the concept of area. Answer type 1 for question number 1 indicates the presence of a conceptual ontogenetic obstacle. These students conflated the concepts of area and perimeter in two-dimensional shapes. There was a conceptual error that prevented them from distinguishing between the concepts of area and perimeter in two-dimensional shapes.

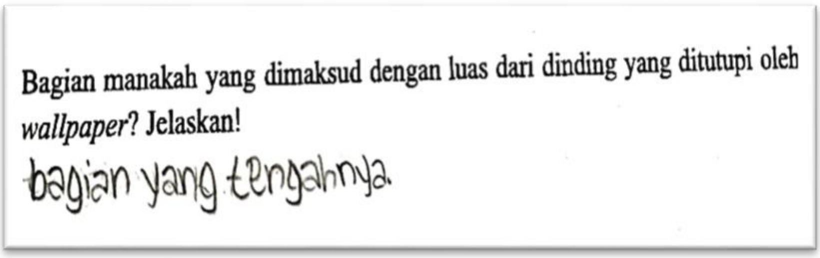


Figure 4. Answer type 2 for question number 1

Figure 4 presents a representative student response indicating a conceptual ontogenetic learning obstacle. The student identified area as “the middle part,” demonstrating an intuitive understanding that area refers to the interior of a shape but without a complete mathematical conceptualization of area. Answer type 2 to question number 1 indicates a psychological ontogenetic obstacles. The student was able to present a visual argument but did not yet have a correct conceptual understanding of the area of a two-dimensional shape. This response can be categorized as correct, although some aspects remain unclear from a mathematical conceptual standpoint.

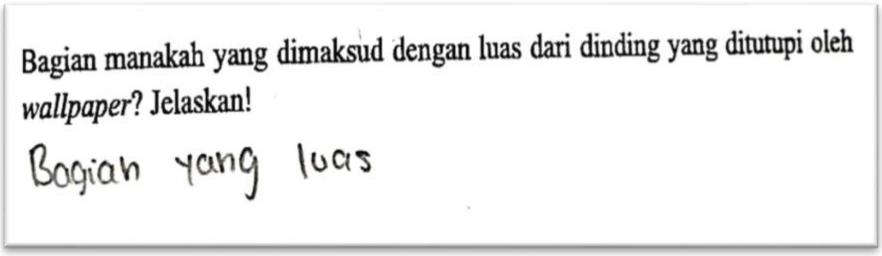


Figure 5. Answer type 3 for question number 1

Figure 5. presents a representative student response indicating a conceptual ontogenetic learning obstacle. The student answered “the wide part,” which reflects a tautological response that merely repeats the keyword in the question without demonstrating a meaningful conceptual understanding of area. Answer type 3 for question number 1 indicates a conceptual ontogenetic obstacles. This type of answer shows that the student does not understand the concept of area in two-dimensional shapes. The student merely repeats the question in their answer in a tautological manner. The student’s response does not address the question.

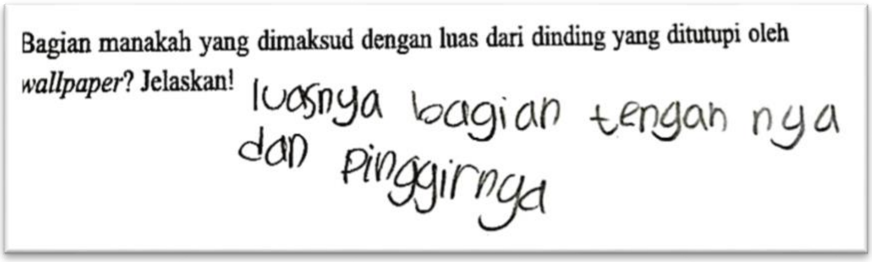
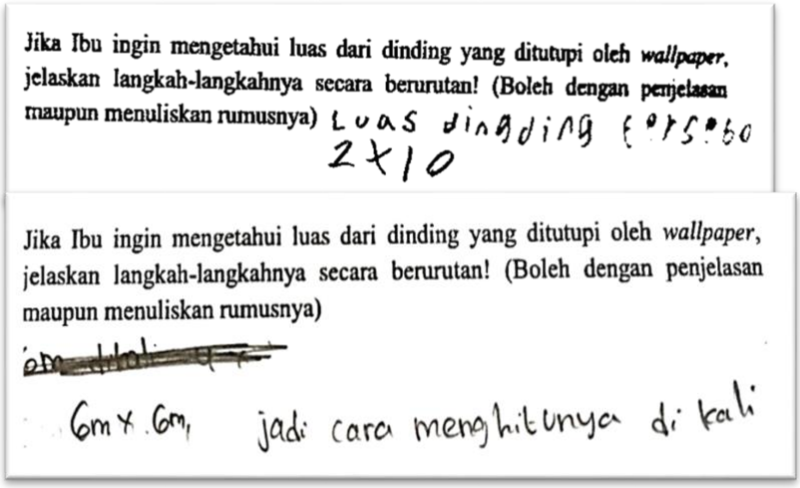


Figure 6. Answer type 4 for question number 1

Figure 6. presents a representative student response indicating a conceptual ontogenetic learning obstacle. The student described the area as “the middle part and the edges,” revealing a misconception that combines the concepts of area and perimeter rather than distinguishing them as separate geometric attributes. Answer type 4 to question number 1 indicates the presence of a conceptual ontogenetic obstacles. This is demonstrated by the student’s inability to fully understand the concept of the area of a two-dimensional shape. The terms the student uses still mix up perimeter and area.

Question 2 asks students to explain, in a procedural, systematic manner, the steps for calculating the area of a wall covered with wallpaper. Students’ answers to Question 2 can be categorized into three types. These three types of answers are as follows.



Jika Ibu ingin mengetahui luas dari dinding yang ditutupi oleh *wallpaper*, jelaskan langkah-langkahnya secara berurutan! (Boleh dengan penjelasan maupun menuliskan rumusnya) Luas dingding

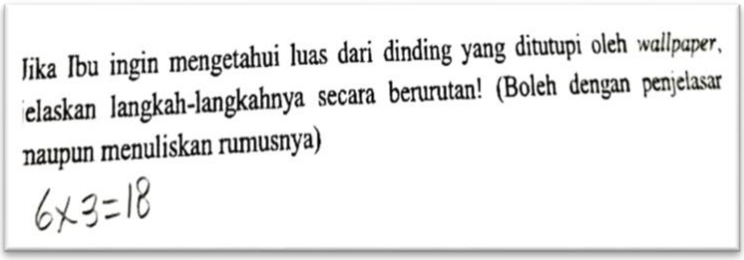
2x10

Jika Ibu ingin mengetahui luas dari dinding yang ditutupi oleh *wallpaper*, jelaskan langkah-langkahnya secara berurutan! (Boleh dengan penjelasan maupun menuliskan rumusnya)

6m x 6m, jadi cara menghitunya di kali

Figure 7. Answer type 1 for question number 2

Figure 7. presents representative student responses illustrating an instrumental ontogenetic learning obstacle. Although the students recognized that the area should be calculated using multiplication, they selected inappropriate dimensions and failed to apply the correct procedure for determining the wallpaper-covered area of the composite figure. These responses indicate that students possessed partial procedural knowledge but were unable to transfer it effectively to a more complex problem context. Answers type 1 for question number 2 indicate the presence of ontogenetic conceptual difficulties. These students' answers deviate from the question's context. This type of obstacle was the most common among students' answers. It may have occurred because students did not understand the correct concept for calculating the area of a composite plane figure. It may also have occurred because students had not yet mastered the prerequisite material, leading them to answer haphazardly by simply multiplying the numbers visible in the figure.



Jika Ibu ingin mengetahui luas dari dinding yang ditutupi oleh *wallpaper*, jelaskan langkah-langkahnya secara berurutan! (Boleh dengan penjelasan maupun menuliskan rumusnya)

6x3=18

Figure 8. Answer type 2 for question number 2

Figure 8. presents a representative student response illustrating an instrumental ontogenetic learning obstacle. The student directly calculated the wall area using 6 × 3 = 18 without considering the areas of the door and window that should be excluded. This response indicates that the student relied on a familiar procedure but failed to adapt it to the composite geometry context. Answer type 2 for question number 2 indicates an instrumental ontogenetic obstacle. The answer consists solely of the arithmetic operation of multiplying two numbers, without any operational steps. This answer does not meet the requirements of the question. The student was unable to use the appropriate techniques and procedures to answer the question.

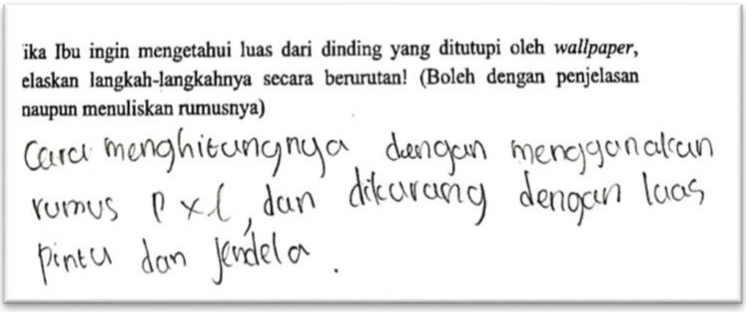

ika Ibu ingin mengetahui luas dari dinding yang ditutupi oleh *wallpaper*,
elaskan langkah-langkahnya secara berurutan! (Boleh dengan penjelasan
naupun menuliskan rumusnya)
Cara menghitungnya dengan menggunakan rumus p x l, dan dikurang dengan luas pintu dan jendela .

Figure 9. Answer type 3 for question number 2

Figure 9 presents a representative student response demonstrating an appropriate understanding of the procedure for determining the wallpaper-covered area. The student correctly explained that the wall area should be calculated using the rectangle area formula and then reduced by the areas of the door and window, indicating successful integration of conceptual understanding and procedural reasoning. Answer type 3 for question number 2 is a correct and complete answer. This type of answer contains a complete and systematic procedure. The student answered the question correctly. This indicates that the student no longer has any ontogenetic obstacles.

Question 3 asks students to calculate the area of a wall covered with wallpaper using the method explained in the previous question. There are three types of student responses to Question 3. These three types of responses are as follows.

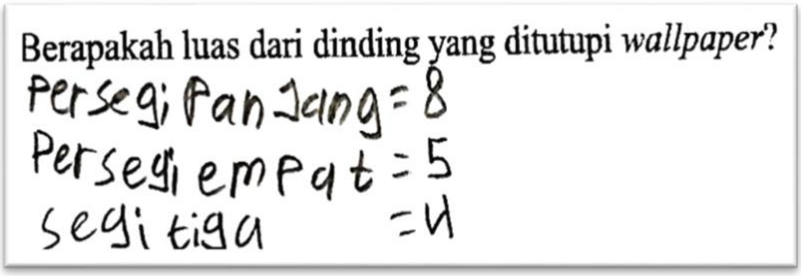

Berapakah luas dari dinding yang ditutupi *wallpaper*?
Persegi Panjang = 8
Persegi empat = 5
Segitiga = 4

Figure 10. Answer type 1 for question number 3

Figure 10. presents a representative student response illustrating a conceptual ontogenetic learning obstacle. Instead of determining the wallpaper-covered area, the student listed several geometric shapes with unrelated numerical values, indicating difficulty in identifying relevant information and decomposing the composite figure into appropriate components for area calculation. Type 1 student responses to question 3 indicate the presence of conceptual and psychological ontogenetic obstacles. Conceptual ontogenetic obstacles are evident in students' errors in interpreting the question. Students do not yet understand how to calculate area, so their answers are out of context with the question. Psychological ontogenetic obstacles are evident when students are asked to explain the meaning of their answers; they repeatedly say "I don't know" and "I'm confused," indicating that psychological obstacles prevent them from answering the question.

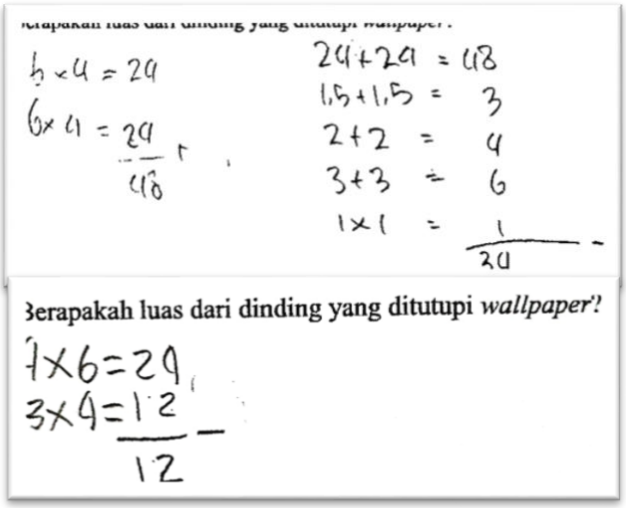


Figure 11. Answer type 2 for question number 3

Figure 11. presents representative student responses illustrating an instrumental ontogenetic learning obstacle. Although the students attempted to calculate the wallpaper-covered area using arithmetic operations, they applied inappropriate procedures and selected irrelevant numerical values. These responses indicate that the students possessed partial procedural knowledge but were unable to transfer it effectively to the composite plane figure context. Answer type 2 for question number 3 indicates the presence of psychological and instrumental obstacles. The student believed that a certain part needed to be calculated by subtraction, but still applied the procedure incorrectly. The student appeared to have difficulty following the given procedure. The psychological obstacle was evident in the student's response, which conveyed the impression that "the important thing is just to do it," indicating that the student's motivation to solve this problem correctly was low.

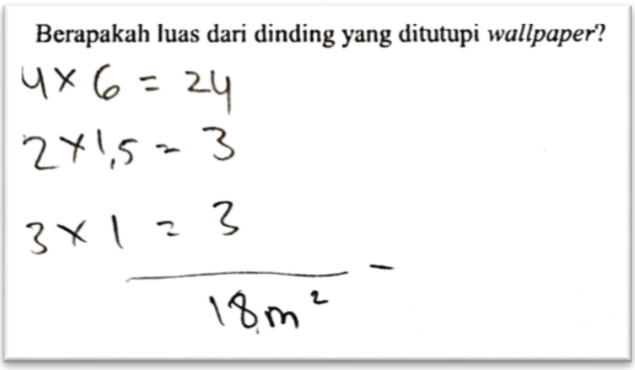


Figure 12. Answer type 3 for question number 3

Figure 12. presents a representative student response illustrating an instrumental ontogenetic learning obstacle. The student correctly identified the required area calculations for the wall, door, and window but produced an incorrect final result due to an error in integrating the intermediate calculations. This response indicates that the student possessed appropriate conceptual understanding but experienced difficulty applying the complete calculation procedure accurately. The type 3 student's response to question number 3 is the most correct, complete, and systematic. This indicates that students who provided this type of answer no longer face learning obstacles, particularly ontogenetic learning obstacles. This response aligns with the question's requirements.

Discussion

The findings demonstrate that ontogenetic learning obstacles emerged consistently across all learning obstacle tasks, indicating that students' difficulties in learning composite plane figure area cannot be explained solely by procedural mistakes but instead reflect broader cognitive and developmental barriers. Among the three identified dimensions, conceptual ontogenetic obstacles were the most dominant, followed by instrumental obstacles, while psychological obstacles appeared as a consequence of unresolved conceptual and procedural difficulties. This pattern suggests that students' learning difficulties develop progressively rather than independently, where deficiencies in conceptual understanding gradually influence procedural performance and eventually affect students' psychological readiness to engage in mathematical learning. Such findings support the theoretical assumption that mathematical understanding develops through the interaction between cognitive readiness, prior knowledge, and instructional experiences. Previous studies have similarly reported that learning obstacles in mathematics rarely originate from a single source but instead emerge through the interaction of multiple cognitive and instructional factors (Hendriyanto et al., 2024; Kokkonen & Schalk, 2021; Saha et al., 2024; Wu, 2025; X. Zhang et al., 2020). However, most previous investigations have concentrated primarily on epistemological and didactical learning obstacles, whereas relatively few studies have examined the multidimensional nature of ontogenetic learning obstacles in elementary geometry. The present findings therefore extend existing knowledge by demonstrating that psychological, conceptual, and instrumental ontogenetic obstacles should be interpreted as interconnected components of students' mathematical learning rather than isolated categories. This multidimensional interpretation provides a more comprehensive explanation of why students who possess partial procedural knowledge may still fail to solve geometry problems successfully. It also explains why repeated conceptual failure frequently develops into procedural confusion and reduced learning confidence over time. Consequently, identifying ontogenetic learning obstacles before instructional intervention becomes an essential prerequisite for designing learning environments that are responsive to students' cognitive development and learning readiness.

Conceptual ontogenetic obstacles constituted the most prominent finding of this study, particularly in students' misconceptions regarding the concepts of area, perimeter, and the decomposition of composite plane figures. Students frequently interpreted area as a specific location within a figure rather than as a measurable attribute representing the extent of a two-dimensional region, indicating that meaningful conceptual schemas had not yet been established. Similar misconceptions have been widely reported in elementary mathematics, where students often confuse area with perimeter or apply formulas without understanding the underlying measurement concepts (Chiphambo & Mtsi, 2021; Idrus et al., 2022; Runnalls & Hong, 2020). Previous studies have also shown that misconceptions related to area measurement persist because students develop fragmented concept images that differ substantially from formal mathematical definitions (Ding, 2024; Sánchez et al., 2024; Thurn et al., 2020). From the perspective of geometry learning, these findings are consistent with cognitive development theories suggesting that students who remain at early visualization levels tend to classify geometric concepts based on perceptual appearance rather than on defining properties. Consequently, students experience difficulty recognizing that composite plane figures can be decomposed into simpler geometric components without altering their total area. This inability to perform geometric decomposition limits students' capacity to establish relationships among constituent figures and prevents them from selecting appropriate mathematical strategies. Furthermore, the persistence of conceptual misconceptions indicates that classroom instruction may have emphasized procedural calculation more strongly than conceptual reasoning, thereby limiting opportunities for students to construct meaningful mathematical understanding.

These findings reinforce previous arguments that conceptual understanding should precede procedural fluency because meaningful knowledge construction enables students to transfer mathematical ideas more effectively to unfamiliar situations. Therefore, strengthening conceptual understanding of area measurement and geometric decomposition should become a primary instructional priority for reducing conceptual ontogenetic learning obstacles in elementary geometry.

Instrumental ontogenetic obstacles emerged when students were unable to transfer previously learned mathematical procedures to unfamiliar composite geometry tasks despite demonstrating partial procedural knowledge. Students generally recognized that calculating area required multiplication and subtraction procedures, yet they failed to determine appropriate geometric components or apply these procedures systematically within the given problem context. This finding indicates that procedural knowledge alone is insufficient for solving composite geometry problems unless it is supported by adequate conceptual understanding. Similar conclusions have been reported in previous studies showing that procedural fluency without conceptual comprehension often results in rigid algorithmic behavior that cannot be adapted to novel mathematical situations (Bojorque et al., 2025; Mogan et al., 2026; Schulz, 2024). The present findings also support the proposition of Cognitive Load Theory, which explains that students experiencing excessive cognitive demands allocate much of their working memory capacity to basic calculations, leaving insufficient cognitive resources for higher-order reasoning and problem representation (Pyke et al., 2025; Sortwell et al., 2026; van Nooijen et al., 2024). Consequently, students become more likely to perform arbitrary calculations, repeat familiar procedures, or ignore important geometric information contained within the problem. Previous research concerning area measurement has likewise demonstrated that students frequently memorize formulas without understanding when and why particular procedures should be applied, resulting in procedural errors during complex geometry tasks. The results of this study further indicate that instrumental ontogenetic obstacles frequently originate from unresolved conceptual weaknesses rather than from procedural incompetence alone. This relationship explains why students who correctly remembered mathematical formulas nevertheless failed to produce accurate solutions when confronted with composite plane figure area tasks. Therefore, instructional practices should integrate conceptual explanation, visual reasoning, and procedural application simultaneously so that students develop flexible mathematical knowledge capable of supporting successful problem solving across diverse geometry contexts.

Psychological ontogenetic obstacles represented the final dimension identified in this study and were primarily manifested through students' hesitation, uncertainty, low confidence, and limited willingness to engage in solving geometry problems. Unlike conceptual and instrumental obstacles, psychological obstacles did not emerge independently but developed after students repeatedly encountered conceptual misunderstandings and procedural failures during the learning process. This finding suggests that students' emotional readiness to learn mathematics is strongly influenced by their previous learning experiences and perceptions of competence rather than by affective factors alone (Di Martino et al., 2023; Gao, 2020; Hofer et al., 2023; Skilling et al., 2020). Similar findings have been reported in studies on mathematics anxiety, which indicate that repeated failure in solving mathematical problems gradually reduces students' confidence, increases avoidance behavior, and limits their willingness to employ effective problem-solving strategies (Jiang et al., 2021; Wang et al., 2025; Zhu et al., 2024). Students who perceive themselves as unsuccessful learners frequently adopt superficial approaches, provide incomplete responses, or attempt to finish mathematical tasks without carefully evaluating the correctness of their answers. Such behaviors were evident in this study, where several students demonstrated partial conceptual understanding but failed to elaborate their reasoning because they lacked confidence in their own responses. This condition indicates that psychological readiness functions as both a consequence and a reinforcing factor of conceptual and procedural learning difficulties. From a cognitive perspective, negative emotional responses may further increase cognitive load by diverting students' attention away from mathematical reasoning toward managing feelings of uncertainty and failure. Consequently, reducing psychological ontogenetic obstacles requires instructional environments that encourage students to express ideas freely, learn from mistakes, and gradually develop confidence through appropriately scaffolded learning experiences. Therefore, teachers should consider psychological readiness as an integral component of mathematics instruction because strengthening students' confidence may contribute to improved conceptual understanding and procedural performance simultaneously.

Taken together, the findings indicate that psychological, conceptual, and instrumental ontogenetic learning obstacles should be understood as interconnected dimensions rather than as isolated categories of learning difficulties. The results demonstrate that conceptual weaknesses constitute the initial source of learning obstacles, which subsequently influence students' procedural performance and eventually contribute to the emergence of psychological barriers during mathematical learning. This sequential relationship extends existing theoretical perspectives by illustrating how ontogenetic learning obstacles evolve dynamically throughout students' learning experiences rather than appearing independently at different stages of instruction. Unlike previous studies that primarily described students' misconceptions, procedural errors, or learning difficulties separately, the present study provides empirical evidence that these phenomena are closely interconnected through the framework of ontogenetic learning obstacles. The findings therefore contribute to mathematics education by enriching the theoretical understanding of how students' cognitive development, conceptual maturity, and psychological readiness collectively influence geometry learning (Jablonski & Ludwig, 2023). Within the framework of Didactical Design Research, these findings reinforce the importance of conducting prospective analyses before designing instructional interventions because identifying students' ontogenetic learning obstacles enables teachers to anticipate potential learning barriers more effectively. The study also suggests that instructional improvement should not focus exclusively on procedural accuracy but should prioritize conceptual development, cognitive readiness, and psychological support as complementary components of meaningful mathematics learning. Integrating visual representations, decomposition activities, guided questioning, and reflective discussion may facilitate stronger conceptual construction while simultaneously reducing students' procedural and psychological difficulties. Such instructional strategies are expected to create learning environments that are more responsive to students' developmental characteristics and better aligned with the principles of learner-centered mathematics education. Consequently, this study provides both theoretical and practical evidence that understanding the interaction among psychological, conceptual, and instrumental ontogenetic learning obstacles is fundamental for designing adaptive geometry instruction that supports meaningful conceptual learning in elementary schools.

Implications

The findings of this study have important theoretical and practical implications for the advancement of mathematics education, particularly in understanding students' ontogenetic learning obstacles in elementary geometry. From a theoretical perspective, the study extends the existing framework of learning obstacle theory by demonstrating that psychological, conceptual, and instrumental ontogenetic obstacles are not independent phenomena but rather interconnected dimensions that develop dynamically throughout students' learning experiences. This multidimensional perspective provides a more comprehensive explanation of students' cognitive barriers than approaches that examine conceptual misconceptions or procedural errors separately. The findings also reinforce the importance of considering students' cognitive readiness as a central factor in designing effective mathematics instruction, especially when introducing conceptually demanding topics such as composite plane figure area. From a pedagogical perspective, the results suggest that geometry instruction should prioritize conceptual understanding before procedural fluency by engaging students in activities that strengthen geometric visualization, spatial reasoning, and the decomposition of composite figures. Teachers should also implement diagnostic assessments prior to instruction to identify students' ontogenetic learning obstacles and use the results to provide appropriate scaffolding based on students' developmental characteristics. Furthermore, instructional practices should create psychologically supportive learning environments that encourage students to express mathematical ideas, learn from errors, and develop confidence without fear of failure. The findings also imply that instructional materials should incorporate multiple visual representations, guided exploration, and reflective discussions to facilitate meaningful conceptual construction rather than emphasizing formula memorization alone. Within the framework of Didactical Design Research, the identification of ontogenetic learning obstacles provides an essential foundation for conducting prospective analyses and developing instructional designs that are responsive to students' learning needs. These findings further suggest that curriculum developers should integrate diagnostic learning activities and conceptual progression into elementary geometry curricula to better accommodate students' cognitive development. For researchers, the study provides empirical evidence that can support the development of more comprehensive models explaining the interaction among cognitive, procedural, and psychological dimensions of mathematics learning. Ultimately, these implications contribute to the development of adaptive, learner-centered geometry instruction that promotes meaningful conceptual understanding while reducing persistent learning obstacles among elementary school students.

Limitations and Suggestions for Future Research

This study has several limitations that should be considered when interpreting its findings and planning subsequent investigations. First, the study involved a relatively small number of participants from a single public elementary school, which may limit the transferability of the findings to students from different educational contexts, grade levels, or cultural backgrounds. Second, the investigation focused exclusively on composite plane figure area tasks, meaning that the identified ontogenetic learning obstacles may not fully represent students' learning characteristics in other geometry topics or mathematical domains. Third, the qualitative nature of the study emphasized an in-depth interpretation of students' written responses and observations rather than examining the prevalence of ontogenetic learning obstacles across larger populations. In addition, students' psychological ontogenetic obstacles were inferred primarily from observable behaviors and response patterns rather than from standardized psychological or motivational measurements. The study also examined learning obstacles during the prospective analysis stage of Didactical Design Research without evaluating the effectiveness of instructional interventions designed to overcome the identified obstacles. Furthermore, the analysis was limited to the three dimensions of ontogenetic learning obstacles and did not investigate their interactions with epistemological and didactical learning obstacles that may simultaneously influence students' mathematical learning. Future studies are therefore encouraged to involve larger and more diverse samples from different educational settings to improve the generalizability of the findings. Subsequent research should also investigate ontogenetic learning obstacles across a wider range of mathematical topics, including three-dimensional geometry, algebra, measurement, and proportional reasoning. In addition, mixed-methods or longitudinal research designs may provide deeper insights into how psychological, conceptual, and instrumental ontogenetic learning obstacles develop and change throughout students' learning trajectories. Future investigations are further recommended to design, implement, and evaluate instructional interventions within the complete Didactical Design Research cycle to determine the effectiveness of adaptive learning designs in reducing ontogenetic learning obstacles. Finally, integrating cognitive, affective, and instructional perspectives into future research may contribute to a more comprehensive understanding of students' mathematical learning processes and support the development of evidence-based instructional practices that promote meaningful conceptual learning in elementary mathematics.

CONCLUSION

This study explored psychological, conceptual, and instrumental ontogenetic learning obstacles experienced by elementary school students when solving composite plane figure area tasks within the framework of Didactical Design Research. The findings demonstrate that all three dimensions of ontogenetic learning obstacles were evident throughout students' responses, indicating that difficulties in elementary geometry extend beyond procedural errors and involve broader cognitive and developmental factors. Conceptual ontogenetic obstacles emerged as the most dominant form of learning obstacle, reflecting students' incomplete understanding of area concepts, geometric decomposition, and the distinction between area and perimeter. Instrumental ontogenetic obstacles were identified when students were unable to transfer previously learned mathematical procedures to unfamiliar problem situations despite possessing partial procedural knowledge. Psychological ontogenetic obstacles appeared primarily as a consequence of repeated conceptual misunderstandings and procedural failures, resulting in reduced confidence, uncertainty, and limited engagement in mathematical reasoning. These findings suggest that the three dimensions of ontogenetic learning obstacles are dynamically interconnected rather than functioning as isolated learning difficulties. The study therefore provides empirical evidence that meaningful geometry learning requires the simultaneous development of conceptual understanding, procedural competence, and psychological readiness. From a theoretical perspective, the findings extend the understanding of ontogenetic learning obstacles by demonstrating how cognitive, procedural, and affective dimensions interact during elementary mathematics learning. From a practical perspective, the study highlights the importance of identifying students' ontogenetic learning obstacles before instructional implementation as a foundation for designing adaptive learning experiences. The findings also reinforce the role of Didactical Design Research in supporting evidence-based instructional planning that aligns learning activities with students' cognitive development and learning needs. Furthermore, this study contributes to mathematics education by providing a comprehensive framework for interpreting students' learning difficulties beyond conventional analyses of misconceptions and procedural errors. Overall, the findings emphasize that recognizing and addressing the interaction among psychological, conceptual, and instrumental ontogenetic learning obstacles is essential for developing more effective, learner-centered geometry instruction that promotes meaningful conceptual understanding in elementary mathematics.

AUTHOR CONTRIBUTIONS STATEMENT

Annisa Febrianti Syamsudin contributed to conceptualization, methodology, investigation, data curation, formal analysis, validation, visualization, writing, original draft preparation, and project administration. Mubiar Agustin contributed to conceptualization, methodology, supervision, validation, formal analysis, writing, review and editing, and funding acquisition. Andhin Dyas Fitriani contributed to investigation, data curation, formal analysis, validation, visualization, writing, review and editing, and proofreading. All authors contributed substantially to the conception and design of

the study, critically reviewed the manuscript for important intellectual content, approved the final version of the manuscript, and agreed to be accountable for all aspects of the work.

REFERENCES

Abrahamson, D., Nathan, M. J., Williams-Pierce, C., Walkington, C., Ottmar, E. R., Soto, H., & Alibali, M. W. (2020). The future of embodied design for mathematics teaching and learning. Frontiers in Education, 5. https://doi.org/10.3389/feduc.2020.00147

Adeleke, J. O., Balogun, H. A., & Ayanwale, M. A. (2025). Assessment of content and cognitive dimensions of learners' mathematics performance. STEM Education, 5(3), 383–400. https://doi.org/10.3934/steme.2025019

Adeniji, S. M., & Baker, P. (2022). Worked-examples instruction versus Van Hiele teaching phases: A demonstration of students' procedural and conceptual understanding. Journal on Mathematics Education, 13(2), 337–356. https://doi.org/10.22342/jme.v13i2.pp337-356

Aguilar, J. J. (2021). High school students' reasons for disliking mathematics: The intersection between teacher's role and student's emotions, belief and self-efficacy. International Electronic Journal of Mathematics Education, 16(3), em0658. https://doi.org/10.29333/iejme/11294

Aljura, A. N., Retnawati, H., Dewanti, S. R., Kassymova, G. K., Sotlikova, R., & Septiana, A. R. (2025). Mathematical reasoning and communication word problems with mathematical problem-solving orientation: A relation between the skills. Journal on Mathematics Education, 16(2), 529–558. https://doi.org/10.22342/jme.v16i2.pp529-558

Aucejo, E., & James, J. (2021). The path to college education: The role of math and verbal skills. Journal of Political Economy, 129(10), 2905–2946. https://doi.org/10.1086/715417

Bojorque, R., Moscoso, F., Arcos-Argudo, M., & Pesántez, F. (2025). A data-driven analysis of cognitive learning and illusion effects in university mathematics. Data, 10(11). https://doi.org/10.3390/data10110192

Büchele, S., & Feudel, F. (2023). Changes in students' mathematical competencies at the beginning of higher education within the last decade at a German university. International Journal of Science and Mathematics Education, 21(8), 2325–2347. https://doi.org/10.1007/s10763-022-10350-x

Capone, R. (2022). Blended learning and student-centered active learning environment: A case study with STEM undergraduate students. Canadian Journal of Science, Mathematics and Technology Education, 22(1), 210–236. https://doi.org/10.1007/s42330-022-00195-5

Caviedes Barrera, S., de Gamboa, G., & Badillo Jiménez, E. R. (2023). Mathematical objects that configure the partial area meanings mobilized in task-solving. International Journal of Mathematical Education in Science and Technology, 54(6), 1092–1111. https://doi.org/10.1080/0020739X.2021.1991019

Ceballos, H., van den Bogaart, T., van Ginkel, S., Spandaw, J., & Drijvers, P. (2026). How collaborative problem solving promotes higher-order thinking skills: A systematic review of design features and processes. Thinking Skills and Creativity, 59, 102001. https://doi.org/10.1016/j.tsc.2025.102001

Chiphambo, S. M., & Mtsi, N. (2021). Exploring grade 8 students' errors when learning about the surface area of prisms. Eurasia Journal of Mathematics, Science and Technology Education, 17(8), em1985. https://doi.org/10.29333/ejmste/10994

Di Martino, P., Gregorio, F., & Iannone, P. (2023). The transition from school to university mathematics in different contexts: Affective and sociocultural issues in students' crisis. Educational Studies in Mathematics, 113(1), 79–106. https://doi.org/10.1007/s10649-022-10179-9

Ding, Y. (2024). Analysis of students' conceptual change in learning Newton's third law with an integrated framework of model analysis and knowledge integration. Physical Review Physics Education Research, 20(2). https://doi.org/10.1103/PhysRevPhysEducRes.20.020141

Dorel, L. (2023). The relationship between visual and abstract comprehension in spatial geometry, and its importance to developing spatial perception and vision. International Journal for Technology in Mathematics Education, 30(4), 219–226. https://doi.org/10.1564/tme_v30.4.3

Durmaz, A., & Işiksal Bostan, M. (2022). Pre-service teachers' knowledge regarding the area of triangle. European Journal of Science and Mathematics Education, 10(2). https://doi.org/10.30935/scimath/11716

Flavin, E., Chung, M., Hwang, S., & Flavin, M. T. (2025). Augmented reality for area measurement reasoning of elementary students. Educational Technology Research and Development, 73(4), 2663–2697. https://doi.org/10.1007/s11423-025-10502-0

Galitskaya, V., & Drigas, A. S. (2023). Mobiles and ICT based interventions for learning difficulties in geometry. International Journal of Engineering Pedagogy, 13(4), 21. https://doi.org/10.3991/ijep.v13i4.36309

Gao, J. (2020). Sources of mathematics self-efficacy in Chinese students: A mixed-method study with Q-sorting procedure. International Journal of Science and Mathematics Education, 18(4), 713–732. https://doi.org/10.1007/s10763-019-09984-1

Harbison, L., Nic Fhinn, T., Scully, C., Nic Con Ultaigh, N., & Wyndham, B.-T. (2026). Exploring concept images and misconceptions in geometry through creative mathematical story writing. Investigations in Mathematics Learning, 0(0), 1–22. https://doi.org/10.1080/19477503.2026.2692318

Hendriyanto, A., Suryadi, D., Juandi, D., Dahlan, J. A., Hidayat, R., Wardat, Y., Sahara, S., & Muhaimin, L. H. (2024). The didactic phenomenon: Deciphering students' learning obstacles in set theory. Journal on Mathematics Education, 15(2), 517–544. https://doi.org/10.22342/jme.v15i2.pp517-544

Hofer, S. I., Reinhold, F., & Koch, M. (2023). Students home alone: Profiles of internal and external conditions associated with mathematics learning from home. European Journal of Psychology of Education, 38(1), 333–366. https://doi.org/10.1007/s10212-021-00590-w

Hsu, H.-Y., & Silver, E. A. (2026). Cognitive complexity of geometric proof and geometric calculation: A problem-solving perspective. Educational Studies in Mathematics, 121(1), 29–50. https://doi.org/10.1007/s10649-025-10434-9

Hwang, W.-Y., Zhao, L., Shadiev, R., Lin, L.-K., Shih, T. K., & Chen, H.-R. (2020). Exploring the effects of ubiquitous geometry learning in real situations. Educational Technology Research and Development, 68(3), 1121–1147. https://doi.org/10.1007/s11423-019-09730-y

Idrus, H., Rahim, S. S. A., & Zulnaidi, H. (2022). Conceptual knowledge in area measurement for primary school students: A systematic review. STEM Education, 2(1), 47. https://doi.org/10.3934/steme.2022003

Jablonski, S., & Ludwig, M. (2023). Teaching and learning of geometry: A literature review on current developments in theory and practice. Education Sciences, 13(7). https://doi.org/10.3390/educsci13070682

Jiang, R., Liu, R., Star, J., Zhen, R., Wang, J., Hong, W., Jiang, S., Sun, Y., & Fu, X. (2021). How mathematics anxiety affects students' inflexible perseverance in mathematics problem-solving: Examining the mediating role of cognitive reflection. British Journal of Educational Psychology, 91(1), e12364. https://doi.org/10.1111/bjep.12364

Kokkonen, T., & Schalk, L. (2021). One instructional sequence fits all? A conceptual analysis of the applicability of concreteness fading in mathematics, physics, chemistry, and biology education.

Educational Psychology Review, 33(3), 797–821. https://doi.org/10.1007/s10648-020-09581-7

Lee, C.-Y., Lei, K. H., Chen, M.-J., Lee, C.-R., & Chen, C.-C. (2023). Helping low-achieving students to comprehend the area of basic geometric shapes using an enclosing-rectangle scaffold via computer-assisted instruction. Cogent Education, 10(2), 2277576. https://doi.org/10.1080/2331186X.2023.2277576

Lee, M. Y., & Lee, J.-E. (2021). Spotlight on area models: Pre-service teachers' ability to link fractions and geometric measurement. International Journal of Science and Mathematics Education, 19(5), 1079. https://doi.org/10.1007/s10763-020-10098-2

Lehmann, T. H. (2023). Learning to measure the area of composite shapes. Educational Studies in Mathematics, 112(3), 531–565. https://doi.org/10.1007/s10649-022-10191-z

Liu, M., Bryant, D. P., Kiru, E., & Nozari, M. (2021). Geometry interventions for students with learning disabilities: A research synthesis. Learning Disability Quarterly, 44(1), 23–34. https://doi.org/10.1177/0731948719892021

Lowrie, T., & Logan, T. (2023). Spatial visualization supports students' math: Mechanisms for spatial transfer. Journal of Intelligence, 11(6). https://doi.org/10.3390/jintelligence11060127

Maifa, T. S., Suryadi, D., & Fatimah, S. (2025). Identifying learning obstacles in proof construction for geometric transformations: Conceptual, procedural, and visualization errors. Infinity Journal, 14(3), 673–694. https://doi.org/10.22460/infinity.v14i3.p673-694

Mogan, A. D., Guang, C., Bishop, C., Zajas, M., Alvarez, S., Whitsitt, C., Wilkey, E. D., & McNeil, N. M. (2026). Bridging the divide: Comparing the efficiency and transparency of two division algorithms. Journal of Educational Psychology. https://doi.org/10.1037/edu0001046

Nilimaa, J. (2023). New examination approach for real-world creativity and problem-solving skills in mathematics. Trends in Higher Education, 2(3), 477–495. https://doi.org/10.3390/higheredu2030028

Osei, P. C., & Bjorklund, D. F. (2024). Motivating the learning process: Integrating self-determination theory into a dynamical systems framework. Educational Psychology Review, 36(3), 89. https://doi.org/10.1007/s10648-024-09934-6

Payadnya, I. P. A. A., Prahmana, R. C. I., Lo, J.-J., Noviyanti, P. L., & Atmaja, I. M. D. (2023). Designing area of circle learning trajectory based on "what-if" questions to support students' higher-order thinking skills. Journal on Mathematics Education, 14(4), 757–780. https://doi.org/10.22342/jme.v14i4.pp757-780

Prabowo, A., Suryadi, D., Dasari, D., Juandi, D., & Junaedi, I. (2022). Learning obstacles in the making of lesson plans by prospective mathematics teacher students. Education Research International, 2022(1), 2896860. https://doi.org/10.1155/2022/2896860

Price, S., Yiannoutsou, N., & Vezzoli, Y. (2020). Making the body tangible: Elementary geometry learning through VR. Digital Experiences in Mathematics Education, 6(2), 213–232. https://doi.org/10.1007/s40751-020-00071-7

Pyke, W., Lunau, J., & Javadi, A.-H. (2025). Does difficulty moderate learning? A comparative analysis of the desirable difficulties framework and cognitive load theory. Quarterly Journal of Experimental Psychology, 78(10), 2181–2195. https://doi.org/10.1177/17470218241308143

Runnalls, C., & Hong, D. S. (2020). "Well, they understand the concept of area": Pre-service teachers' responses to student area misconceptions. Mathematics Education Research Journal, 32(4), 629–651. https://doi.org/10.1007/s13394-019-00274-1

Saha, M., Islam, S., Akhi, A. A., & Saha, G. (2024). Factors affecting success and failure in higher education mathematics: Students' and teachers' perspectives. Heliyon, 10(7). https://doi.org/10.1016/j.heliyon.2024.e29173

Sánchez, E., García-Ríos, V. N., & Sepúlveda, F. (2024). Development of high school students' conceptions of sampling distribution in the context of learning significance tests with technology. Educational Studies in Mathematics, 117(2), 215–238. https://doi.org/10.1007/s10649-024-10330-8

Sari, Y. M., Fiangga, S., El Milla, Y. I., & Puspaningtyas, N. D. (2023). Exploring students' proportional reasoning in solving guided-unguided area conservation problem: A case of Indonesian students. Journal on Mathematics Education, 14(2), 375–394. https://doi.org/10.22342/jme.v14i2.pp375-394

Schulz, A. (2024). Assessing student teachers' procedural fluency and strategic competence in operating and mathematizing with natural and rational numbers. Journal of Mathematics Teacher Education, 27(6), 981–1008. https://doi.org/10.1007/s10857-023-09590-7

Seah, R., & Horne, M. (2021). Developing reasoning within a geometric learning progression: Implications for curriculum development and classroom practices. Australian Journal of Education, 65(3), 248–264. https://doi.org/10.1177/00049441211036532

Semper, J. V. O., & Iriso, I. L. (2026). Learning model based on early psychological development and the constitutive role of relationship. Education Sciences, 16(1). https://doi.org/10.3390/educsci16010116

Shekhar, P., Borrego, M., DeMonbrun, M., Finelli, C., Crockett, C., & Nguyen, K. (2020). Negative student response to active learning in STEM classrooms: A systematic review of underlying reasons. Journal of College Science Teaching, 49(6), 45–54. https://doi.org/10.1080/0047231X.2020.12290664

Skilling, K., Bobis, J., & Martin, A. J. (2020). The "ins and outs" of student engagement in mathematics: Shifts in engagement factors among high and low achievers. Mathematics Education Research Journal, 33. https://ora.ox.ac.uk/objects/uuid:a86cafb5-ec71-4bd1-a40e-fc9a5bdb11ce

Sortwell, A., Gkintoni, E., Díaz-García, J., Ellerton, P., Ferraz, R., & Hine, G. (2026). Beyond cognitive load theory: Why learning needs more than memory management. Brain Sciences, 16(1). https://doi.org/10.3390/brainsci16010109

Sugiarni, R., Herman, T., Suryadi, D., Prabawanto, S., & Maskar, S. (2025). Digital didactical design alternatif based on learning obstacles in topic of proportion: A study of pre-service mathematics teachers. Acta Scientiae, 27(3). https://doi.org/10.17648/acta.scientiae.8155

Sutarni, S., Sutama, S., Prayitno, H. J., Sutopo, A., & Laksmiwati, P. A. (2024). The development of realistic mathematics education-based student worksheets to enhance higher-order thinking skills and mathematical ability. Infinity Journal, 13(2), 285–300. https://doi.org/10.22460/infinity.v13i2.p285-300

Szabo, Z. K., Körtesi, P., Guncaga, J., Szabo, D., & Neag, R. (2020). Examples of problem-solving strategies in mathematics education supporting the sustainability of 21st-century skills. Sustainability, 12(23). https://doi.org/10.3390/su122310113

Thurn, C. M., Hänger, B., & Kokkonen, T. (2020). Concept mapping in magnetism and electrostatics: Core concepts and development over time. Education Sciences, 10(5). https://doi.org/10.3390/educsci10050129

Torres-Peña, R. C., Peña-González, D., Lara-Orozco, J. L., Ariza, E. A., & Vergara, D. (2025). Enhancing numerical thinking through problem solving: A teaching experience for third-grade mathematics. Education Sciences, 15(6). https://doi.org/10.3390/educsci15060667

van Nooijen, C. C. A., de Koning, B. B., Bramer, W. M., Isahakyan, A., Asoodar, M., Kok, E., van Merrienboer, J. J. G., & Paas, F. (2024). A cognitive load theory approach to understanding expert scaffolding of visual problem-solving tasks: A scoping review. Educational Psychology Review, 36(1), 12. https://doi.org/10.1007/s10648-024-09848-3

Wang, Y., Zhang, J., & Pellicioni, M. S. (2025). Math anxiety is associated with skipping problems and less help-seeking behavior after error commission. Learning and Individual Differences, 120, 102681. https://doi.org/10.1016/j.lindif.2025.102681

Wijaya, A., Elmaini, & Doorman, M. (2021). A learning trajectory for probability: A case of game-based learning. Journal on Mathematics Education, 12(1), 1–16. https://doi.org/10.22342/jme.12.1.12836.1-16

Wu, Y. (2025). Unlocking mathematics success: Global lessons on student achievement, teacher satisfaction, and school environments. International Electronic Journal of Mathematics Education, 20(2). https://doi.org/10.29333/iejme/15900

Yang, K.-L., Krawitz, J., Schukajlow, S., Yang, C.-C., & Chang, Y.-P. (2024). German and Taiwanese secondary students' mathematical modelling task value profiles and their relation to mathematical knowledge and modelling performance. European Journal of Psychology of Education, 39(3), 2969–2989. https://doi.org/10.1007/s10212-024-00866-x

Yunianto, W., Jarvis, D., Lavicza, Z., Putra, Z. H., & El-Bedewy, S. (2025). Primary school students' problem-solving strategies in creating artworks with GeoGebra: Integrating computational thinking skills into mathematics and visual arts lessons. LUMAT: International Journal on Math, Science and Technology Education, 13(2), 1–1. https://doi.org/10.31129/LUMAT.13.2.2547

Yunianto, W., Rully Charitas Indra, P., & Crisan, C. (2021). Indonesian mathematics teachers' knowledge of content of area and perimeter of rectangle. Journal on Mathematics Education, 12(2), 223–238. https://doi.org/10.22342/jme.12.2.13537.223-238

Zhang, D. (2021). Teaching geometry to students with learning disabilities: Introduction to the special series. Learning Disability Quarterly, 44(1), 4–10. https://doi.org/10.1177/0731948720959769

Zhang, Q. (2021). Opportunities to learn three-dimensional shapes in primary mathematics: The case of content analysis of primary mathematics textbooks in Hong Kong. Eurasia Journal of Mathematics, Science and Technology Education, 17(6). https://doi.org/10.29333/ejmste/10884

Zhang, X., Räsänen, P., Koponen, T., Aunola, K., Lerkkanen, M.-K., & Nurmi, J.-E. (2020). Early cognitive precursors of children's mathematics learning disability and persistent low achievement: A 5-year longitudinal study. Child Development, 91(1), 7–27. https://doi.org/10.1111/cdev.13123

Zhou, Y.-J., Wang, X.-T., Chen, J., Xu, D., Cui, Y., & Wang, T. (2025). Estimation of lateral drifts of RC wall structural system by monitored coupling beams. Earthquake Engineering & Structural Dynamics, 54(9), 2325–2338. https://doi.org/10.1002/eqe.4364

Zhu, Y., Liu, X., Xiao, Y., & Sindakis, S. (2024). Mathematics anxiety and problem-solving proficiency among high school students: Unraveling the complex interplay in the knowledge economy. Journal of the Knowledge Economy, 15(4), 20516–20546. https://doi.org/10.1007/s13132-023-01688-w

Ziatdinov, R., & James R. Valles, J. (2022). Synthesis of modeling, visualization, and programming in GeoGebra as an effective approach for teaching and learning STEM topics. Mathematics, 10(3). https://doi.org/10.3390/math10030398