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Geometry from coastal life: A grounded theory of primary students' 3D geometry understanding in Northern Coastal West Java

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Abstract

Background: Although three-dimensional (3D) geometry is an essential component of the elementary school mathematics curriculum, research exploring how students develop spatial understanding of 3D geometric objects in authentic learning contexts remains limited. Furthermore, the challenge of bridging visual, verbal, and manipulative representations persists as a major gap in the literature.
Aims: This study aims to address this gap by examining the process through which elementary students develop conceptual understanding of 3D geometry using a grounded theory approach.
Method: The study was conducted at a public elementary school in Indramayu Regency, West Java, Indonesia. A total of 26 students (20 female and 6 male, aged 11–12) voluntarily participated. Data were collected through 3D geometric visualization tests and in-depth interviews focusing on students' thought processes in imagining, comparing, and manipulating spatial forms. Data analysis followed the three stages of grounded theory methodology: open coding, axial coding, and selective coding, to construct a theory grounded in empirical data.
Results: The findings reveal that students' understanding of 3D volume is still in a transitional stage, moving from concrete experiences to formal mathematical representations. Familiar local contexts alone were found insufficient to bridge spatial understanding without adequate visual and pedagogical support. Major obstacles included conceptual misconceptions, procedural errors, limited visualization skills, and reliance on teacher assistance.
Conclusion: The core category, "multiple representations as a bridge to spatial understanding," underscores the importance of integrating concrete visualization, verbal description, and mathematical symbolism in geometry instruction. This study suggests that teachers should design instructional strategies that systematically combine visual media, concrete manipulatives, and verbal approaches. Such integration is crucial to ensure that local contexts effectively serve as a bridge between real-world experiences and abstract mathematical understanding.

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INTRODUCTION

Three-dimensional (3D) geometry is recognized as a core component of mathematical literacy because it equips students with the ability to visualize, analyze, and represent spatial structures. Despite its importance, many elementary school students still face significant difficulties in transitioning from concrete experiences to abstract reasoning, especially when dealing with concepts of volume and unit conversion (Tian et al. 2024; Ocal & Halmatov. 2021). This challenge becomes even more urgent in the context of today's education systems that emphasize higher-order thinking skills. A lack of conceptual understanding in geometry at early stages can hinder future achievement in mathematics and science-related fields. Thus, investigating how students develop spatial reasoning in authentic contexts is essential for improving both pedagogy and curriculum design.

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The urgency of this research is further highlighted by the prevalence of misconceptions and procedural errors when students solve geometry problems. For example, studies show that students often confuse area with volume, misapply formulas, or rely excessively on rote memorization instead of conceptual reasoning (Alzubi et al. 2025; Sudirman et al. 2023). These recurring difficulties suggest that conventional teaching strategies focusing only on textbook-based or symbolic instruction are insufficient. Instead, there is a pressing need to adopt approaches that integrate local contexts, visual aids, and manipulative tools. By situating geometry within students' cultural and environmental experiences, educators can potentially bridge the gap between informal knowledge and formal mathematics.

Moreover, the context of coastal life presents a compelling lens for studying 3D geometry learning. Coastal communities are rich in real-world structures such as boats, fish boxes, and observation towers that embody geometric principles. However, research reveals that familiar contexts do not always guarantee meaningful abstraction if not supported with scaffolding strategies (Rau, 2017; Widodo et al., 2017). This underscores the need for empirical studies that explore how contextual problems influence cognitive transitions in geometry learning. By focusing on students in northern coastal West Java, this research addresses both theoretical significance in cognitive development and practical relevance for ethnomathematics-based education.

This study is designed to explore the cognitive processes of elementary students in understanding 3D geometry through grounded theory. Unlike predetermined instructional models, grounded theory allows concepts to emerge directly from students' interactions with tasks and contexts. Such an approach provides a more authentic understanding of how learners engage with problems, apply strategies, and encounter obstacles. The rationale lies in generating a substantive theory that reflects the dynamics of cognitive transition (from concrete experiences to symbolic representation) within a specific cultural context. This contributes not only to mathematics education but also to broader discussions on contextual learning and ethnomathematics.

Recent studies have emphasized the role of multimodal and contextual strategies in improving students' geometric reasoning. For example, Alsanousi & Prabhu (2025) developed multimodal assessment models to track cognitive proficiency, highlighting the need to integrate behavioral and visual metrics in learning. Similarly, Rieder & Aschenbrenner (2024) showed how contextual information displays in learning environments foster spatial transitions in problem solving. Fiorentino et al. (2023) investigated interdisciplinary mathematics teacher training and found that multimodal approaches improve pre-service teachers' understanding. Ramos et al. (2021) highlighted how contextual predictors influence learning trajectories of high-ability students, reinforcing the importance of context in shaping mathematical reasoning. These studies collectively underscore that contextual and multimodal approaches are increasingly central to fostering geometry learning outcomes. Other relevant works have examined transitions in reasoning processes. Mendl et al. (2024) reported how students struggle with voluntary task switching without contextual cues. Kelber et al. (2024) explored how cognitive control adjustments transfer between learners, stressing the role of guided interaction. Halliburton et al. (2024) examined how self-regulation develops under stress and its implications for sustained learning. Yang et al. (2023) highlighted teacher agency as a mediator in implementing innovative pedagogies, while Khurshid et al. (2023) synthesized the effects of pedagogical interventions at university level. Taken together, these ten studies illustrate that the success of contextual and representational learning depends not only on the presence of local context but also on the cognitive, motivational, and instructional scaffolds that support abstraction.

Despite growing interest in contextual and multimodal strategies, few studies have examined how elementary students in developing countries cognitively transition from concrete to symbolic reasoning within authentic cultural contexts. Most prior works have focused on either advanced learners or pre-service teachers, leaving a gap in understanding how younger students engage with geometry in their local environments. Moreover, while ethnomathematics often assumes that local contexts automatically enhance learning, evidence suggests that without structured scaffolding, familiar contexts can even create confusion. Therefore, a research gap exists in exploring the intersection of grounded theory, cultural context, and elementary geometry learning.

The purpose of this study is to investigate how elementary students in coastal areas develop an understanding of 3D geometry concepts, particularly volume, when exposed to contextual problems drawn from their daily environment. Specifically, this research aims to identify students' cognitive processes, the obstacles they encounter, and the conditions under which contextual problems succeed or fail to support abstraction. By doing so, the study intends to formulate a grounded theory that explains the transition from concrete experiences to symbolic reasoning. Ultimately, the research contributes to the theoretical discourse on cognitive development while offering practical recommendations for teachers and curriculum designers seeking to implement culturally relevant yet cognitively effective geometry instruction.

METHOD

Research Design

This study employed a qualitative approach with a grounded theory (GT) design. Grounded theory was chosen because it allows for the generation of substantive theories that emerge directly from participants' lived experiences rather than being imposed by pre-existing frameworks (Lim, 2025; Urcia, 2021). Such a design is well-suited to investigating the process through which elementary students transition from concrete experiences to formal reasoning in three-dimensional (3D) geometry. By focusing on students' verbal explanations, problem-solving strategies, and representational practices, this research captures the complexity of cognitive development. The GT framework was implemented in three systematic phases: open coding, axial coding, and selective coding. Open coding involved identifying initial concepts from raw interview and test data, axial coding organized these concepts into interrelated categories, and selective coding identified the core category representing the central phenomenon. This design ensures that theoretical insights remain closely grounded in empirical evidence (Makri & Neely, 2021). Moreover, adopting grounded theory aligns with the rationale of studying cognitive transition in authentic contexts, as it prioritizes inductive discovery of processes.

Participants

The participants of this study consisted of 26 elementary students from grades five and six in a coastal school in Indramayu Regency, West Java, Indonesia. The sample included 20 female students and 6 male students, with ages ranging between 11 and 12 years. The selection of participants was based on voluntary involvement, with informed consent obtained from parents and school administrators. Participants represented diverse academic backgrounds, ensuring a range of ability levels to capture heterogeneity in geometric understanding. Ethical approval was secured from the school authority, and all procedures complied with confidentiality and anonymity principles. Such diversity was critical to the grounded theory approach, which seeks to identify both common and divergent thinking patterns. This variation in participants allowed the research to highlight the challenges faced by both high-performing and low-performing students in solving contextual 3D geometry problems.

Table 1. Profile of Participants by Gender and Age

Gender	Age 11	Age 12	Total
Female	12	8	20
Male	4	2	6
Total	16	10	26

Table 1 shows the distribution of participants by gender and age. Of the 26 students, the majority were female (20 students) and the remainder were male (6 students). Participants were divided between 11 years old (16 students) and 12 years old (10 students). This distribution emphasizes sample diversity, which is important in grounded theory-based research. By varying age and gender, the study was able to capture the diversity of thinking processes and problem-solving strategies in three-dimensional geometry. This heterogeneity also strengthens the study's internal validity, as the results obtained do not only represent a specific, homogeneous group but also illustrate broader thinking patterns. Furthermore, differences in gender and age can be factors that influence students' learning styles, cognitive representations, and how they connect real-world contexts with mathematical symbols (Cui et al. 2024; Wei et al. 2025).

Instruments

Two instruments were used to collect data: an open-ended 3D geometry test and semi-structured interviews. The geometry test was designed to assess students' ability to calculate the volume of geometric solids such as rectangular prisms, cubes, triangular prisms, and square pyramids. Each test item was contextualized in coastal life settings, such as fish boxes, salt containers, and observation towers, to reflect authentic real-world problems. The test emphasized not only procedural skills but also conceptual reasoning and the ability to connect mathematical formulas with real-life scenarios. Semi-structured interviews were then conducted with selected students representing different achievement levels. Interview questions explored students' reasoning processes, strategies, and obstacles encountered when solving geometry tasks. Combining test and interview data ensured methodological triangulation, which enhanced the validity and trustworthiness of findings (Arias Valencia 2022; Khalil et al. 2024). The instruments were validated through expert review and pilot testing with a small group of students before the main study.

Data Analysis Plan

Data analysis followed the procedures of grounded theory methodology. First, open coding was conducted by carefully examining test responses and interview transcripts line by line, allowing emergent concepts to be identified without prior assumptions. These initial codes were then grouped into categories during axial coding, which established relationships between student errors, strategies, and conceptual understanding. In the final stage, selective coding identified a single core category that explained the central process of cognitive transition from concrete to abstract reasoning. The iterative process of coding involved constant comparison, memo writing, and theoretical sampling to refine categories. Throughout the analysis, peer debriefing and intercoder reliability checks were conducted to enhance credibility and minimize researcher bias. The GT process also integrated both qualitative insights and descriptive statistics, providing a comprehensive picture of students' performance. The framework of the GT analysis applied in this study is illustrated below.

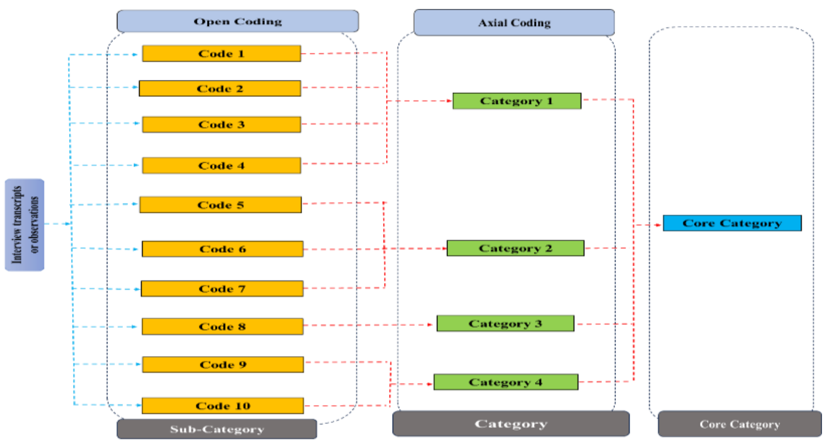

Figure 1. GT Analysis Framework

Figure 1 illustrates the grounded theory analysis framework used in this study. The process begins with open coding, where raw data from tests and interviews are analyzed line by line to generate initial codes. The next stage is axial coding, which groups initial codes into broader categories based on causal relationships, conditions, and consequences. Finally, selective coding is conducted to identify core categories that describe key patterns in students' cognitive processes. For example, the core category that emerged in this study is the transition from concrete experience to formal reasoning. This figure is important because it demonstrates that the analysis is not only descriptive but also theoretical, resulting in a model that can explain learning phenomena in depth. This visualization helps readers understand how complex qualitative data are processed into substantive theory grounded in students' real-life experiences (Lim, 2025; Urcia, 2021: Makri & Neely, 2021).

RESULTS AND DISCUSSION

Results

The implementation of geometry learning in a primary school located in a coastal area was carried out using a structured, active, and contextual learning approach. The instructional process was designed in three main phases: before class, in class, and after class. This approach aims to support student engagement and build conceptual understanding by connecting geometric concepts with real-life contexts drawn from the students' everyday environment.

Figure 2. Giving instructions

In the before class phase, students studied introductory geometry material independently at home using simple digital media provided by the teacher (See Figure 2). This media included short videos, illustrated explanations, and interactive visual materials introducing basic geometric shapes and properties. The content was contextualized to reflect local coastal life, such as fishing nets, stilt houses, and boat structures. This phase served as a preliminary exposure to help students grasp fundamental ideas before engaging in classroom activities.

The in-class phase served as the core learning session, where the teacher facilitated a series of active and collaborative activities. Students worked in groups to engage in discussions, explore geometric objects using concrete materials, and solve problems rooted in local contexts. These classroom tasks encouraged students to apply geometric reasoning in identifying shapes, measuring dimensions, and understanding spatial relationships found in their surroundings. The teacher functioned as a facilitator, guiding students through discovery-based learning that emphasized relevance and application.

Figure 3. Construction Process Through Training

In the after-class phase, students were assigned enrichment tasks to strengthen their conceptual understanding. These tasks encouraged students to apply geometry in real-life situations, such as measuring and classifying objects around their homes based on geometric properties, or creating simple sketches of traditional coastal structures. This phase served as both reinforcement and reflection, allowing students to internalize and extend what they had learned in class.

Throughout the implementation, the researcher conducted observations focusing on student interactions, engagement during group discussions, and their ability to apply geometric concepts in practical situations. The findings indicated that this structured, contextual approach fostered active participation, improved conceptual comprehension, and encouraged students to connect mathematics meaningfully with their daily lives in a coastal environment.

Tabel 2. Descriptive Statistics

Statistic	Value
Maximum Value	75.00
Minimum Value	25.00
Mean	50.67
Standard Deviation	12.40

The descriptive statistical analysis (See Table 2) of the dataset reveals a mean score of approximately 50.67, indicating that the average performance of the individuals in the dataset is slightly above the midpoint of the observed values. The maximum score is 75.00, while the minimum score is 25.00, suggesting a wide range of variability among the data. This spread implies the presence of both high and low-performing individuals within the group. A relatively high mean close to the center of the range shows that most data points are moderately distributed rather than being heavily skewed toward one end.

Furthermore, the standard deviation is 12.40, which signifies a moderate level of dispersion around the mean. This means that while the average performance is around 50.67, individual scores tend to deviate from the mean by about 12.40 points on average. Such a spread suggests a heterogeneous group, where performance levels vary considerably. This variation can be useful for identifying different learner needs or grouping individuals for targeted interventions based on their performance bands.

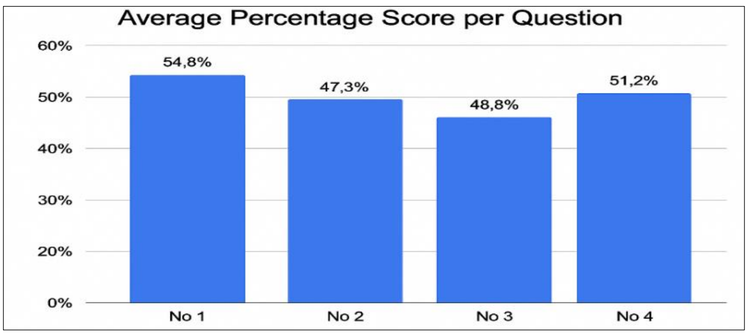

Figure 4. Average Percentage Score Per Question

The assessment results based on the average percentage scores for each question reveal that students performed most consistently on Question 1, with an average score of 54.6%. This indicates a relatively good understanding of the material covered in this question. Questions 3 and 4 follow with 48.8% and 51.2% respectively, suggesting a moderate level of comprehension. Meanwhile, Question 2 shows the lowest average score at 47.3%, indicating that students may have found this particular item more challenging or that it addressed a concept that requires further reinforcement.

The variation in percentage scores across the four questions reflects differing levels of student mastery. It may be beneficial for educators to review the instructional strategies or materials associated with Question 2 to identify possible gaps in understanding. Additionally, focusing on targeted interventions for questions with lower performance could help in achieving a more balanced and thorough comprehension of the content across all assessed areas.

Students' Thinking Process and Obstacles in Solving Question Number 1

Soal 1 Seorang nelayan memiliki kotak penyimpanan ikan berbentuk balok dengan ukuran panjang 120 cm, lebar 80 cm, dan tinggi 60 cm. Kotak ini digunakan untuk menyimpan hasil tangkapan ikan sebelum dijual ke pasar. Berapa liter volume maksimum kotak penyimpanan ikan tersebut? (Catatan: 1 liter = 1.000 cm³)	A fisherman has a fish storage box in the shape of a rectangular prism with a length of 120 cm, a width of 80 cm, and a height of 60 cm. This box is used to store the fish he catches before selling them at the market. What is the maximum capacity of the fish storage box in liters? (Note: 1 liter = 1,000 cm³)

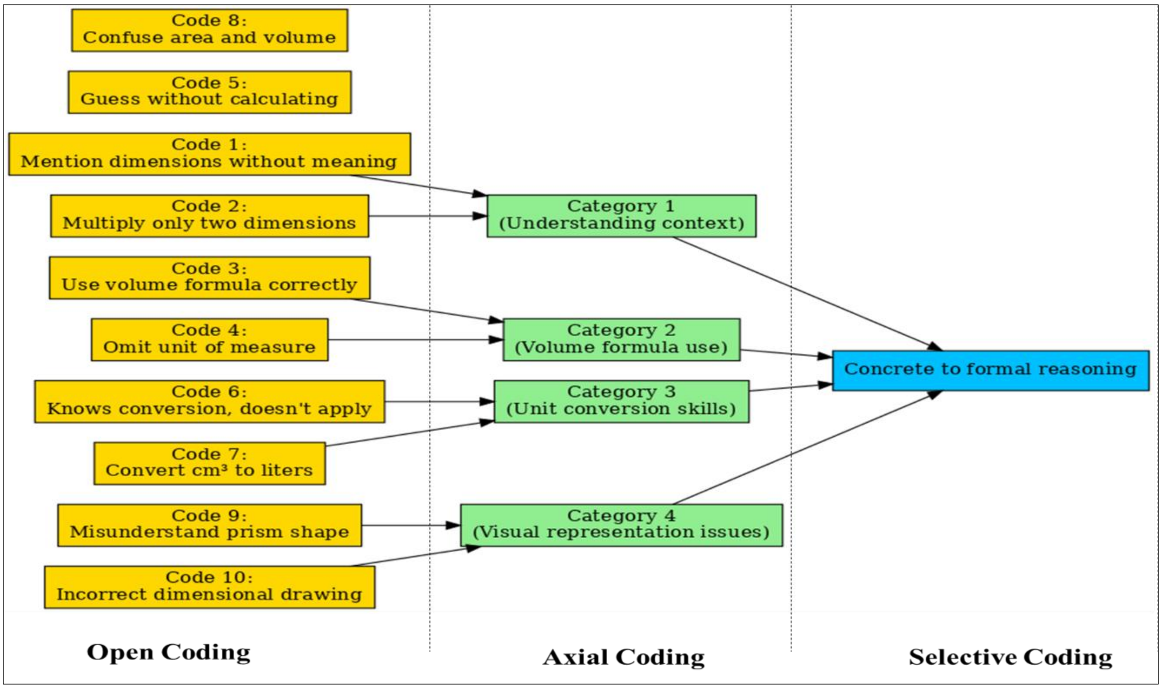

Figure 5. Students' Thinking Process in Solving Question Number 1

The Figure 5 illustrates the process of qualitative data analysis using the GT approach, specifically in the context of elementary students' understanding of 3D geometry in coastal areas. The diagram begins with interview transcripts, which are then broken down into several open codes. Each open code represents a specific student statement or behavior, such as *"Multiply only two dimensions"* or *"Convert cm^3 to liters."* This open coding process is conducted inductively without predefined categories, aiming to capture the diversity of student responses in a detailed and authentic manner.

The next stage is axial coding, where related open codes are grouped into broader categories based on emerging patterns, causal relationships, conditions, or consequences. For instance, codes like *"Knows conversion, doesn't apply"* and *"Convert cm^3 to liters"* are associated with the category "Unit conversion skills." This step serves to construct a conceptual structure from dispersed data, allowing a deeper understanding of the difficulties students encounter to emerge systematically.

The final phase is selective coding**,** which involves identifying a core category that encapsulates the central patterns of students' thinking in understanding the concept of 3D volume. In the diagram, all axial categories converge toward a single core idea: "Concrete to formal reasoning." This core category indicates that students are undergoing a process of transforming concrete experiences (e.g., observing a fisherman's storage box) into formal mathematical representations (e.g., calculating volume using formulas and unit conversions). This process reflects students' cognitive dynamics in developing spatial understanding through contextual and visual experiences.

The core category "Concrete to formal reasoning" encapsulates the essential transition in students' cognitive development, wherein they move from tangible, everyday experiences to abstract mathematical thinking. This transformation is crucial in learning geometry, particularly in understanding three-dimensional concepts such as volume. In the context of the study, students begin by relating to real-life objects—like a fisherman's fish box—through sensory or experiential knowledge, which then gradually evolves into the application of formal procedures, including the use of geometric formulas and unit conversions. This shift highlights not only the integration of contextual understanding with mathematical reasoning but also underscores the importance of instructional approaches that scaffold learners from familiar, concrete representations to more symbolic, formal abstractions.

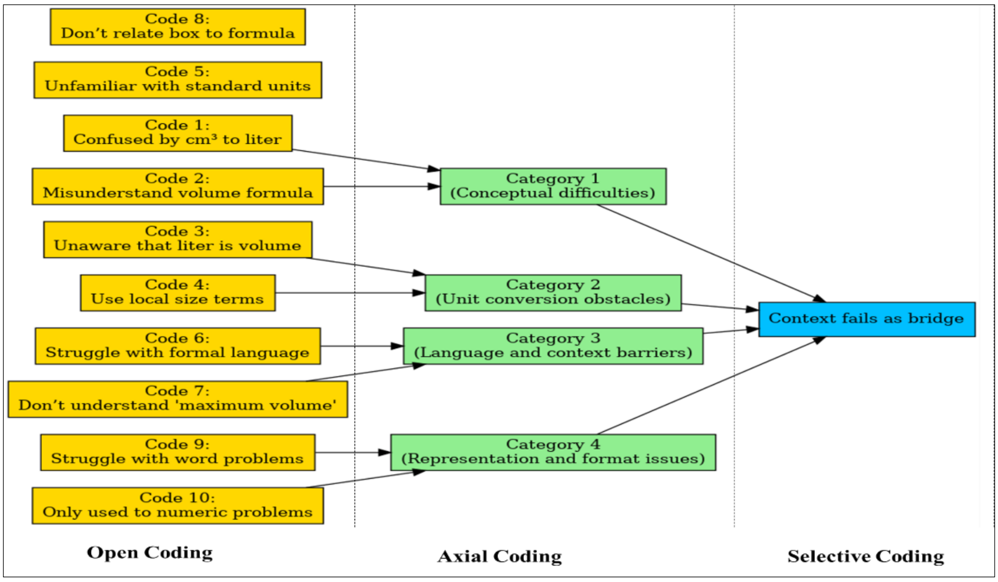

Figure 6. Obstacles in Solving Question Number 1

The axial coding section in the figure illustrates how students' difficulties in understanding 3D geometry are conceptually organized into four major categories. Category 1: Conceptual difficulties captures students' misunderstandings about the concept of volume, such as misapplying the formula or failing to recognize that a liter is a unit of volume. This reveals a disconnect between students' everyday experiences with physical objects and their formal mathematical knowledge. Meanwhile, Category 2: Unit conversion obstacles reflects challenges students face when dealing with standard units, especially converting between cubic centimetres and liters. The use of local, non-standard size references—like "a bucket" or "a basin"—further emphasizes the lack of familiarity with metric units in daily discourse.

Category 3: Language and context barriers highlights students' struggles with the linguistic complexity of math problems. Phrases such as "maximum volume" or formal question structures can obscure meaning for learners who are more accustomed to informal or local expressions, making it harder to access the mathematical task embedded in the context. Lastly, Category 4: Representation and format issues addresses students' difficulties in interpreting and solving word problems, particularly when they are more familiar with numerical drills than with verbal problem scenarios. Altogether, these axial categories point to a core issue "Context fails as bridge" suggesting that, despite being drawn from students' real-life environments, the contextualization of problems often does not effectively support their transition from everyday experiences to formal mathematical reasoning.

The core category "Context fails as bridge" signifies a critical disconnect between students' real-life experiences and their ability to engage with formal mathematical reasoning. Although the problem scenario is drawn from a familiar coastal context (such as a fisherman's fish storage box) the formal presentation of the task, including symbolic language, unit conversions, and abstract representations, often prevents students from recognizing the mathematical relevance of that context. Instead of facilitating understanding, the context becomes a barrier when it is not meaningfully connected to students' prior knowledge or everyday practices. This finding underscores the importance of designing instructional strategies that not only embed real-world contexts but also scaffold students' transition from informal, intuitive understanding to structured mathematical thinking.

Students' Thinking Process and Obstacles in Solving Question Number 2

Soal 2 Di desa nelayan, para petani garam menyimpan garam hasil panennya dalam wadah berbentuk **kubus** dengan ukuran panjang rusuk **1 meter**. Jika seorang petani memiliki 5 **wadah garam** yang semuanya terisi penuh, **berapa total volume garam yang dapat disimpan dalam semua wadah tersebut?** (*Catatan: 1 m³ = 1.000 liter*)	In a fishing village, salt farmers store their harvested salt in containers shaped like cubes, each with an edge length of 1 meter. If a farmer has 5 containers, all of which are completely filled, what is the total volume of salt that can be stored in all the containers? (Note: 1 m³ = 1,000 liters)

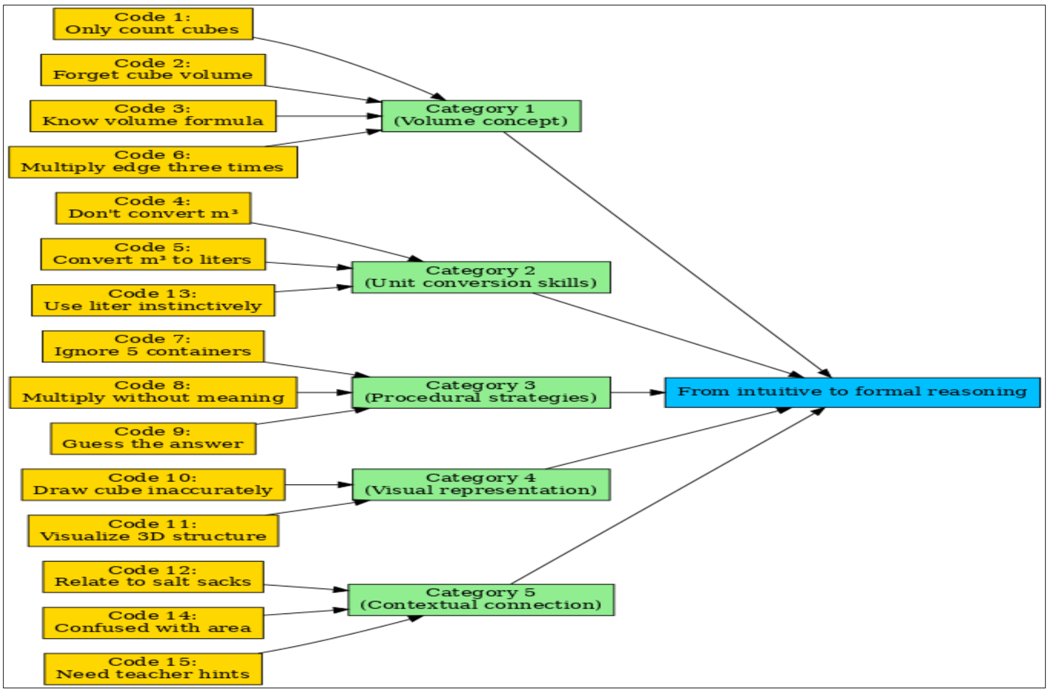

Figure 7. Students' Thinking Process in Solving Question Number 2

The figure illustrates a qualitative data analysis process based on the GT approach, focusing on elementary students' responses from a coastal area in Indramayu when solving a 3D geometry problem involving the volume of a cube in the context of salt farming. Fifteen open codes were identified from student interview transcripts, reflecting diverse behaviors and thought patterns during problem-solving. For instance, codes such as *"Multiply edge three times"* and *"Only count cubes"* indicate students' basic understanding of shape and volume, while *"Don't convert m^3"* and *"Use liter instinctively"* reveal challenges in understanding and applying unit conversions. Some students also exhibited conceptual confusion like *"Confused with area"* or required teacher assistance (*"Need teacher hints"*), signalling that their thinking processes remain largely concrete and have yet to fully transition to abstract reasoning.

Through axial coding, these open codes were grouped into five broader categories: volume concept understanding, unit conversion skills, procedural strategies, visual representation, and contextual connection. These categories offer a comprehensive view of the types of difficulties and strategies students employed. Ultimately, all axial categories converge on one core category: "From intuitive to formal reasoning." This core concept highlights that students' understanding develops from intuitive approaches grounded in real-life experiences toward formal reasoning based on mathematical concepts and procedures. The diagram emphasizes that contextual learning can serve as a crucial bridge for helping students build spatial reasoning and abstract thinking in mathematics, provided it is supported by appropriate scaffolding and the integration of multiple representations.

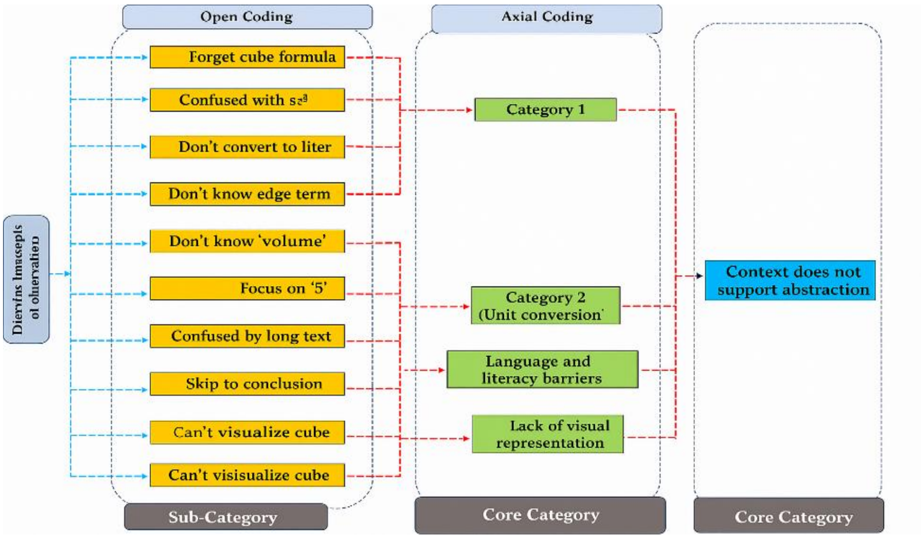

Figure 8. Students' Obstacles in Solving Question Number 2

The diagram visualizes the qualitative data analysis of elementary students' 3D geometry thinking barriers through the lens of grounded theory, specifically when solving a problem involving volume of cube containers used by salt farmers in a coastal village. The open coding phase yielded fifteen distinct student responses and behaviors, such as "Forget cube formula," "Ignore 'liter' unit," and "No cube image in mind." These responses reflect fragmented or partial understanding, indicating how students often rely on informal knowledge, struggle with formal mathematical expressions, or are disconnected from the expected geometric reasoning. These open codes are clustered into five axial categories that represent broader themes of difficulty: conceptual misunderstanding, unit conversion issues, language and literacy barriers, lack of visual representation, and weak connections to real-world experience.

Each axial category contributes to the emergence of a core category: "Context does not support abstraction." This central theme captures the insight that, although the question is set in a familiar real-life setting, such as salt farming, the formal structure and mathematical demands of the task fail to bridge the gap between students' daily experiences and abstract geometric reasoning. Students may recognize the context but do not intuitively translate it into formal operations like using the volume formula or converting cubic meters to liters. The figure highlights the urgent need to redesign word problems to be more culturally and cognitively accessible, incorporating contextual visuals, everyday language, and ethnomathematical approaches that truly link students' lived environments with formal mathematics learning.

Students' Thinking Process and Obstacles in Solving Question Number 3

Soal 3 Untuk melindungi alat tangkapannya dari panas matahari, seorang nelayan membuat tenda berbentuk prisma segitiga di atas perahunya. Alas segitiga tenda memiliki panjang 1.5 meter dan tinggi 1 meter, sedangkan panjang tenda (bagian memanjang perahu) adalah 2 meter. Berapa volume ruang yang ada di dalam tenda tersebut?	To protect his fishing gear from the sun, a fisherman builds a tent in the shape of a triangular prism on top of his boat. The triangular base of the tent has a base length of 1.5 meters and a height of 1 meter, while the length of the tent (aligned with the boat) is 2 meters. What is the volume of the space inside the tent?

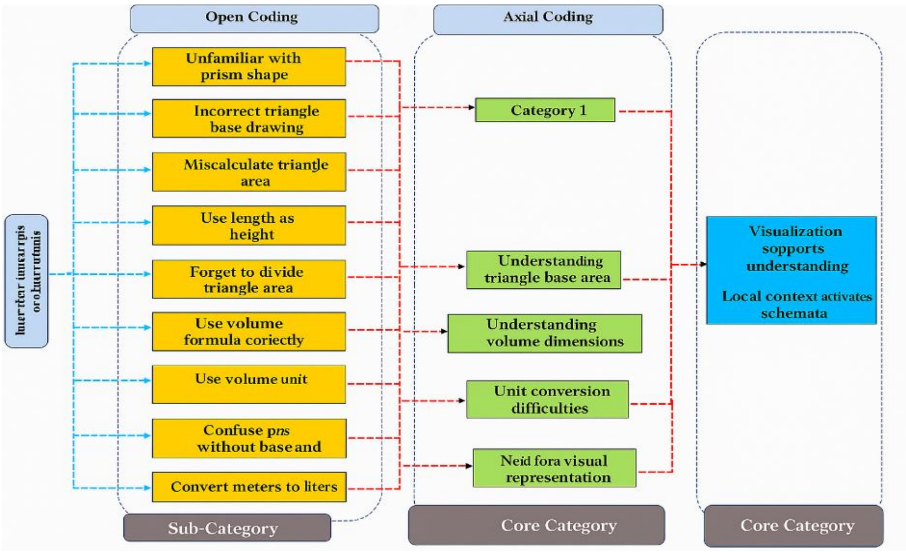

Figure 9. Thinking Process in Solving Question Number 3

The diagram illustrates the grounded theory coding process applied to understand elementary students' thinking in solving a 3D geometry problem involving the volume of a triangular prism. It begins with open coding, which identifies specific observable student responses and behaviors from interview transcripts, such as "Confuses base and height" or "Multiplies all dimensions." These codes represent the initial breakdown of qualitative data into meaningful units. From these, patterns and themes begin to emerge, capturing both conceptual misunderstandings and procedural errors related to geometric volume calculation, especially within the context of real-life, culturally relevant problems like a fisherman's tent.

Through axial coding, the open codes are organized into broader conceptual categories such as "Conceptual Misunderstanding," "Procedural Challenges," "Contextual Integration," and "Visual Reasoning Barriers." These categories reflect the interconnected challenges students' face, such as distinguishing between surface and volume or correctly identifying the base and height of a triangle. All axial categories are eventually synthesized into a single core category—"Shifting from Concrete to Symbolic Reasoning"—which encapsulates the overarching cognitive transformation needed for students to translate tangible, everyday experiences into formal mathematical understanding. This model emphasizes the importance of instructional strategies that bridge concrete experiences with abstract representations to enhance spatial reasoning.

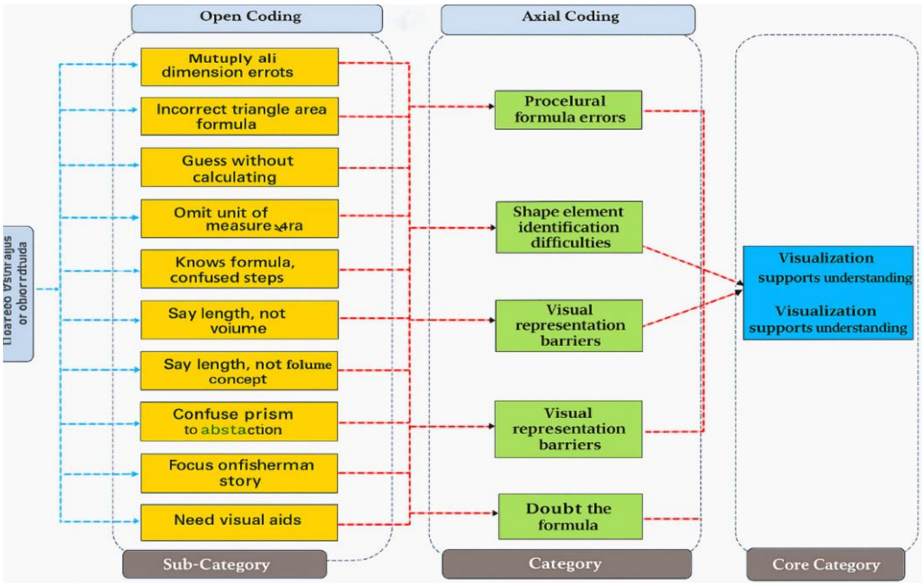

Figure 10. Obstacles in Solving Question Number 3

The diagram illustrates the grounded theory coding process used to explore elementary students' thinking when solving a 3D geometry problem involving the volume of a triangular prism. The open coding stage identified specific student responses and difficulties, such as "Ignore triangle base," "Use rectangle formula," and "Forget to halve base area." These individual codes represent the students' initial interpretations and reasoning patterns. During axial coding, these open codes were grouped into broader thematic categories such as "Understanding triangle properties," "Volume formula misconceptions," and "Procedural application errors." This stage helped reveal how different cognitive obstacles are interrelated and form consistent categories of difficulty in spatial reasoning.

In the final selective coding phase, these axial categories were synthesized into a core category: "Misalignment of shape and formula." This core category represents the central challenge many students face—bridging their understanding of the triangular prism's structure with the appropriate mathematical operations needed to calculate its volume. Despite contextual cues from the problem (e.g., "tent" on a "boat"), students often defaulted to familiar formulas unrelated to the triangular prism, indicating a gap between visual-spatial interpretation and symbolic mathematical reasoning. The diagram emphasizes how grounded theory helps reveal layered thinking processes and cognitive transitions in geometry learning.

Students' Thinking Process and Obstacles in Solving Question Number 4

Soal 4

Di pesisir pantai, terdapat menara pantau nelayan berbentuk **limas segi empat** yang digunakan untuk mengawasi kondisi laut. Alas menara berbentuk persegi, dengan panjang sisi **4 meter**, dan tinggi menara **9 meter**.

Berapa volume ruang dalam menara pantau tersebut?

On the coast, there is a fisherman's observation tower in the shape of a square pyramid, which is used to monitor sea conditions. The base of the tower is a square with side lengths of 4 meters, and the height of the tower is 9 meters. What is the volume of the space inside the observation tower?

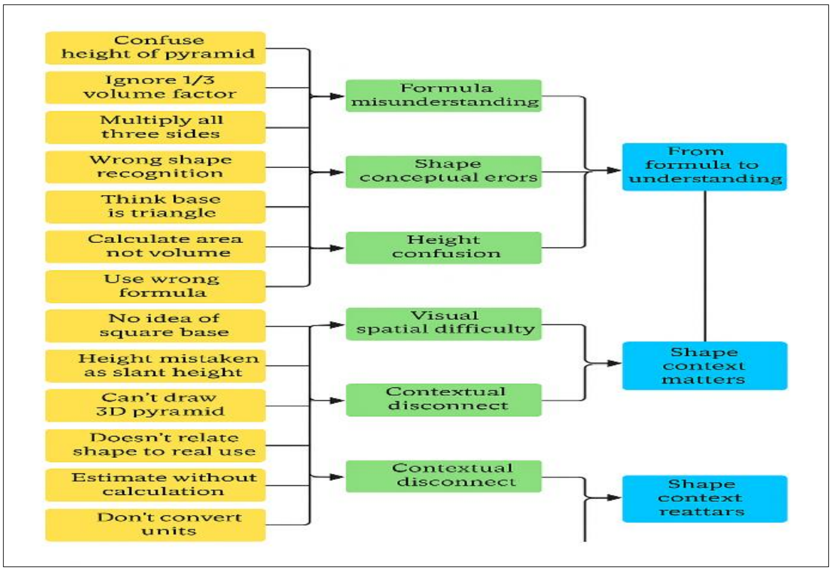

Figure 11. Students' Thinking Process in Solving Question Number 4

The diagram visualizes the process of qualitative data analysis using a Grounded Theory approach, specifically applied to the ways elementary students in coastal Indramayu reason through a geometry problem involving a square pyramid. The process begins with 15 open codes, which represent direct student responses or observable thinking patterns—for example, "Only square visible," "Don't write formula," and "Guess base area." These codes are distilled from students' verbal explanations or written work as they attempt to solve a volume problem involving a square pyramid. The open codes are grouped into five axial codes, such as Formula application errors, Misconception of base area, and Contextual visualization issues. These categories reflect shared difficulties across multiple student responses, capturing both procedural and conceptual obstacles.

These axial codes converge into two selective (core) codes: From object to formula and Contextual shape abstraction. The first selective code highlights the cognitive transition from perceiving a real-world object (a watchtower) to applying an abstract geometric formula. The second captures the struggle some students face in mentally reconstructing a 3D pyramid structure from verbal descriptions alone. Together, the categories point to a critical insight: while students may be familiar with the physical context (the tower), they often fail to connect that familiarity to formal geometric understanding. This suggests that real-world contexts do not automatically support abstraction unless guided by instruction that bridges visual familiarity with mathematical reasoning.

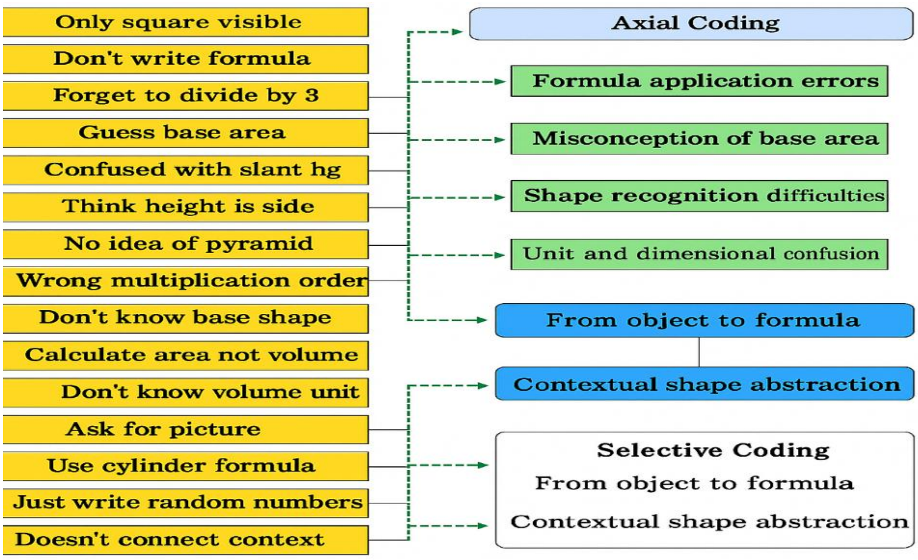

Figure 12. Obstacles in Solving Question Number 4

The diagram visually presents the qualitative coding process derived from elementary students' responses in solving a 3D geometry problem involving a square pyramid structure. The open coding phase reveals 15 distinct cognitive and conceptual obstacles, such as forgetting to divide by 3, misidentifying the base shape, and assuming the height is a side of the pyramid. These codes are then systematically grouped into five axial categories: *Formula application errors*, *Misconception of base area*, *Shape recognition difficulties*, *Unit and dimensional confusion*, and *need for contextual support*. Each category consolidates recurring errors, providing a clearer picture of the patterns in student thinking and the specific sources of difficulty.

These axial categories are then connected to two overarching selective codes: *From object to formula* and *Contextual shape abstraction*. The first selective code underscores the central cognitive transition required—students must move from perceiving the real-world object (a square pyramid) to formulating a mathematical representation using the volume formula. The second highlights the challenge of abstracting geometrical shapes from familiar contexts like an observation tower. Together, they reveal that while students are exposed to real-world structures, transforming these into formal mathematical reasoning is still a major hurdle, especially without sufficient visual or instructional scaffolds.

Discussion

The findings of this study indicate that elementary students' thinking processes in understanding 3D geometry in coastal areas are marked by an incomplete cognitive transition from concrete experiences to formal mathematical representations. Although the problems were presented using familiar local contexts—such as a fisherman's fish box, salt containers, tents on boats, and observation towers—students frequently failed to associate these real-world objects with the symbolic concept of volume. Many students demonstrated intuitive understanding of these objects but made errors or showed uncertainty in applying mathematical formulas, performing unit conversions, and identifying geometric structures. This cognitive transition was hindered by conceptual misconceptions, procedural mistakes, and an overreliance on teacher assistance or practical experience alone. Core categories such as *"Concrete to formal reasoning"* and *"From intuitive to formal reasoning"* highlight the urgent need for instructional strategies that can systematically bridge real-world experience with abstract mathematical reasoning.

Furthermore, although local contexts were used as pedagogical tools, they were not always effective as cognitive bridges, as reflected in the core categories *"Context fails as bridge"* and *"Context does not support abstraction."* Students often struggled to benefit from contextual references due to linguistic misinterpretations, lack of visual support, and failure to link everyday experiences with formal geometric concepts and formulas. These barriers were consistently evident across different tasks—for example, misidentifying the base of a triangular prism, mistaking a slant edge as the height of a pyramid, or using non-standard measurement units such as "bucket" or "basin." These findings underscore the necessity of designing culturally contextualized problems accompanied by explicit visualizations, scaffolded instruction, and an ethnomathematical approach that meaningfully integrates students' local experiences into formal mathematical understanding.

These findings align with the work of Downton & Livy (2022), Sudirman et al. (2022), and Tan-sisman and Aksu (2016), who reported that many students struggle to understand volume concepts due to limitations in spatial representation and their comprehension of geometric structures. In this study, students tended to rely on intuitive approaches grounded in real-life experience but encountered difficulties when required to apply formal formulas or perform unit conversions. Their intuitive familiarity with the physical object did not necessarily translate into accurate symbolic or procedural responses, especially in solving volume problems.

Moreover, Desai et al. (2021) emphasized the importance of representational support in helping students develop deeper geometric understanding. When students lack sufficient visual or concrete models to comprehend the structure of shapes such as triangular prisms or square pyramids, they often apply incorrect formulas, forget to divide the base area, or confuse critical attributes such as height and base. This aligns with the findings of Sudirman et al. (2022; 2023), who noted that in the absence of visual aids and systematic teacher intervention, students tend to rely on trial-and-error strategies or everyday intuition, which do not always align with formal geometric principles. Consequently, these findings reinforce the necessity of a learning approach that integrates real-world contexts, visual representation, and mathematical reasoning in a coherent and synergistic manner.

This is consistent with van Hiele's (2002) theory, which posits that students progress through distinct levels of geometric thinking, and that many elementary school students remain in the visual or descriptive stage, lacking the deductive reasoning skills needed to analyze 3D shapes (Alex & Mammen, 2018). As demonstrated in the core categories *"Concrete to formal reasoning"* and *"From intuitive to formal reasoning"* (Widodo et al. 2017), students in this study had not yet reached the level of formal mastery, as they were unable to translate real-world shapes into symbolic mathematical operations.

Theoretically, these findings are supported by Piaget's cognitive development theory, particularly the concrete operational stage, in which children understand mathematical concepts through manipulation of tangible objects but still struggle with abstract reasoning in the absence of visual or symbolic support. In this sense, real-world contexts are important, but must be accompanied by visual or concrete media that help children construct accurate spatial imagery. The findings also align with Vygotsky's theory of the Zone of Proximal Development (ZPD), which emphasizes that learners require scaffolding from teachers to move from intuitive knowledge toward formal understanding (Margolis, 2020; Rahman, 2024). In this study, many students were only able to solve problems after receiving prompts from the teacher, underscoring the critical role of active instructional support in bridging their cognitive development.

In other words, this study enriches the literature on contextual geometry education by demonstrating that the success of context-based approaches is not automatic. Context must be pedagogically structured to match students' cognitive developmental levels, supported by appropriate visual representations, and delivered using accessible language. This research cautions that without explicit connections between context and formal mathematical structure, students may become even more confused. Therefore, the findings advocate for an instructional design that integrates local context, multimodal representations, and the geometric thinking stages as described by van Hiele, ensuring that learning is both effective and meaningful.

Implications

The findings of this study carry important implications for mathematics education, particularly in designing geometry instruction that bridges real-world contexts and abstract reasoning. For curriculum developers, the study emphasizes that contextualization must be complemented with scaffolding strategies that explicitly guide students from intuitive knowledge toward symbolic understanding. Teachers should not only rely on students' familiarity with objects such as fish boxes or salt containers but also integrate visual representations and manipulatives to make the connection to formal formulas more explicit. Furthermore, the results support theoretical perspectives of Piaget and Vygotsky, highlighting the necessity of developmentally appropriate tasks and scaffolding in the Zone of Proximal Development (Margolis, 2020; Rahman, 2024). These implications also extend to the development of ethnomathematics-based teaching materials, which must be carefully structured to ensure cultural contexts enhance rather than hinder abstraction.

Limitations

Despite its contributions, this study has several limitations that must be acknowledged. First, the research was conducted with a relatively small sample of 26 students from a single coastal school, which may limit the generalizability of the findings. Second, the study focused exclusively on elementary school students aged 11–12, leaving open the question of whether similar cognitive processes occur at other age levels. Third, while grounded theory provided rich insights, the reliance on qualitative data means that quantitative validation of the emergent categories remains to be explored. Fourth, the cultural context of coastal life may not fully represent other local or urban contexts where different experiences shape students' reasoning. Finally, the interviews and observations were limited to a short time frame, which may not capture longitudinal changes in students' cognitive development. These limitations suggest caution in overgeneralizing the results, while still recognizing their value as exploratory contributions.

Suggestions

Future research should expand the scope by including larger and more diverse samples across multiple regions and cultural settings to test the robustness of the emergent theory. Longitudinal studies are recommended to capture how students' transitions from concrete to formal reasoning evolve over time and with increasing instructional support. Additionally, integrating mixed-method designs would allow triangulation between qualitative findings and quantitative measures of spatial reasoning, providing stronger evidence for theory building. The use of technology such as augmented reality or digital manipulatives could also be investigated as tools to enhance the transition from context to abstraction, aligning with current trends in digital education. Collaboration with teachers is essential to co-design culturally relevant yet cognitively effective learning materials that address the obstacles identified in this study. By pursuing these directions, future research can build on the foundation established here to develop more comprehensive models of geometry learning that are both contextually meaningful and pedagogically sound.

CONCLUSION

This study shows that elementary students' understanding of volume in three-dimensional geometry is still transitional, with persistent misconceptions, procedural errors, and limited spatial visualization. Although tasks were presented in familiar local contexts, many students could not connect real-life objects with symbolic mathematical concepts, indicating that context alone is insufficient without systematic scaffolding. The findings emphasize the need for intentional pedagogy: contextual problems should align with students' developmental stages, supported by visual aids, manipulatives, and guided instruction. Theoretically, the results affirm Piaget's and Vygotsky's perspectives while critiquing the assumption in ethnomathematics that local context automatically enhances formal understanding. Practically, this study encourages teachers and curriculum designers to develop culturally relevant yet cognitively structured learning materials that strengthen students' spatial and symbolic literacy.

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AUTHOR CONTRIBUTIONS STATEMENT

This study was collaboratively conducted by three authors. Author 1 was responsible for conceptualizing the research design, coordinating data collection in primary schools along the northern coastal area of West Java, and conducting the initial open coding and theory development using grounded theory methodology. Author 2 contributed to the axial and selective coding processes, engaged in memo writing, and played a key role in synthesizing emerging categories into a coherent theoretical model. Author 3 supported the validation of the coding process, provided critical input during data interpretation, and revised the manuscript to improve its clarity, structure, and scholarly quality. All authors contributed to the manuscript writing, approved the final version, and agreed to be accountable for all aspects of the research.

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