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Geometric Thinking Levels in Learning Quadrilaterals: A Van Hiele-Based Case Study in a Papuan Junior High School

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Abstract

This study investigated the geometric thinking levels of eighth-grade students in a Papuan junior high school, using the van Hiele theoretical framework, with a focus on their understanding of quadrilaterals. The research addressed common misconceptions and limited conceptual understanding among students by exploring how they classified, identified, and described the properties of quadrilaterals. A qualitative descriptive design was employed, involving 25 students selected through purposive sampling. Data were collected using structured interviews, drawing tasks, and classification activities. The primary instrument included three tasks: drawing various quadrilaterals, identifying and defining their properties, and classifying them based on shared attributes. The results showed that 50% of students operated at van Hiele Level 0 (Visualization), 36% were transitioning between Level 0 and Level 1 (Analysis), and only 14% reached Level 1. Students frequently relied on visual appearance rather than formal geometric attributes, leading to persistent misconceptions about hierarchical relationships among shapes. No students demonstrated reasoning beyond Level 1. The findings emphasized the need for instructional approaches that integrate cultural context, use dynamic visual tools, and scaffold learning to support higher-order geometric reasoning. Further research is recommended to develop culturally responsive models and extend the study across different educational contexts.

Keywords: geometric thinking; Papuan students; quadrilaterals; Van Hiele theory

INTRODUCTION

Geometry occupies a central role in mathematics education, functioning not only as a fundamental component of mathematical curricula but also as a critical foundation for developing spatial visualization, logical reasoning, and problem-solving skills. Through geometric learning, students encounter abstract mathematical ideas that enhance their cognitive abilities and foster cross-disciplinary critical thinking competencies beyond mathematics itself. The essential role of geometry in supporting students' comprehension of mathematical structures and logical analysis has been well documented (Karpuz & Atasoy, 2020; Ramírez-Uclés & Ruiz-Hidalgo, 2022). Moreover, geometry enables learners to visualize, interpret, and manipulate spatial relationships, establishing the groundwork for advanced mathematical reasoning (Harris et al., 2021; Lowrie & Logan, 2023). However, the mastery of geometric concepts remains a major pedagogical challenge worldwide, especially when addressing the complex structures of quadrilaterals, which often demand more than procedural knowledge but require deep conceptual understanding and reasoning.

Despite its recognized importance, many students continue to face substantial difficulties in understanding geometric concepts, particularly in classifying and analyzing quadrilaterals. Numerous studies have consistently reported widespread misconceptions concerning the hierarchical relationships and properties of quadrilateral shapes. For instance, students often confuse rectangles, rhombuses, and parallelograms due to insufficient conceptual understanding and overlapping visual characteristics (Birgin & Özkan, 2024; Papadopoulos, 2024). These misconceptions are often rooted in limited exposure to conceptual learning experiences, insufficient use of visual aids, and overly procedural teaching methods that emphasize memorization rather than deep understanding (Karaca, 2023; Nursyahidah et al., 2023). In culturally diverse and remote regions such as Papua, Indonesia, these challenges may become more pronounced due to contextual factors such as limited learning resources, insufficient teacher professional development, and the lack of integration between students' local cultural backgrounds and formal mathematical instruction.

In response to these persistent challenges, adopting effective instructional approaches has become increasingly essential. The integration of interactive digital tools such as GeoGebra has demonstrated significant improvements in students' conceptual understanding by enabling dynamic and visual exploration of geometric properties (Birgin & Uzun Yazıcı, 2021; Gurmu et al., 2024; Zhang et al., 2025). In addition, contextual learning models that relate abstract geometric ideas to real-life experiences have been shown to foster deeper engagement and meaningful learning (Ayan-Civak et al., 2021; Utami et al., 2024; Žakelj et al., 2024). Pedagogical interventions that emphasize the hierarchical nature of quadrilateral classification systems have also been effective in reducing misconceptions (Akar & Işıksal-Bostan, 2024; Ekawati et al., 2023; Steffen & Winsor, 2021). Moreover, professional development programs aimed at enhancing teachers' pedagogical content knowledge are crucial to support effective classroom implementation (Kamaruddin et al., 2017; Leton et al., 2020). However, most of these studies have been conducted in well-resourced educational settings. Limited empirical research has investigated how these strategies can be effectively adapted and applied in remote, culturally diverse contexts such as Papua, where unique socio-cultural dynamics may influence students' cognitive processes in learning geometry.

A widely recognized and extensively utilized theoretical framework for analyzing students' geometric thinking is the van Hiele theory, developed by Dina and Pierre van Hiele (Arnal-Bailera & Manero, 2024; Fuys, 1984; Razak & Sutrisno, 2017). This model describes how students progress through a sequence of qualitatively distinct levels of understanding, beginning with recognition of shapes based on their visual appearance, followed by the ability to identify specific properties of geometric figures. As students advance, they develop informal reasoning to establish relationships among properties and categories of shapes. Further progression allows students to engage in formal deductive reasoning, constructing logical proofs based on geometric theorems, and eventually to operate at a highly abstract level where reasoning occurs within formal mathematical systems. Each level builds upon mastery of the preceding stage, requiring carefully designed instructional support to facilitate students' cognitive transitions. The sequential and hierarchical nature of this framework makes the van

Hiele model especially valuable for diagnosing students' thinking processes and guiding effective geometry instruction (Nahdi et al., 2024; Uyen et al., 2021; Vieira & Cyrino, 2023).

The global application of the van Hiele model has demonstrated consistent success in improving students' geometric thinking across diverse educational contexts. In Turkey, its implementation has effectively enhanced middle school students' abilities to classify and reason geometrically (Deringöl, 2020). Similarly, research in Malaysia has shown that structured van Hiele-based instruction positively influences students' spatial reasoning and problem-solving capabilities (Naufal et al., 2020). These cross-national findings strongly affirm the flexibility, adaptability, and effectiveness of the van Hiele model as an instructional and diagnostic framework for developing geometric thinking in diverse educational systems. However, despite these encouraging outcomes, very limited empirical studies have examined its application within indigenous, multicultural, and geographically isolated educational environments such as Papua, Indonesia.

However, a significant research gap remains in culturally diverse and geographically remote regions such as Papua, Indonesia, where the implementation of the van Hiele model has received limited empirical attention. While numerous international studies have validated the model's effectiveness, few investigations have explored how students' cultural backgrounds, indigenous knowledge systems, and unique socio-educational contexts influence their geometric thinking processes. Hermansyah & Aqil (2024) emphasize that educational challenges in Papua are often exacerbated by the absence of culturally responsive pedagogies that meaningfully integrate local experiences into mathematical instruction. Yalley et al. (2021) underscore that applying the van Hiele model effectively in such regions requires thoughtful adaptation to the cultural and cognitive characteristics of indigenous learners. Therefore, examining Papuan students' geometric thinking levels through the lens of the van Hiele framework can provide new insights into how cultural context shapes students' reasoning, offering both theoretical contributions to the literature and practical implications for localized instructional design.

In response to the identified research gap, this study aims to investigate the geometric thinking levels of junior high school students in Papua, Indonesia, in the context of quadrilateral concepts by applying the van Hiele theoretical framework. Specifically, the study seeks to: (1) identify the distribution of students across the van Hiele levels and (2) analyze the misconceptions and reasoning patterns exhibited by the students in understanding quadrilaterals. Theoretically, this study contributes to the literature by expanding the application of the van Hiele model to indigenous educational contexts, while practically offering insights for designing culturally responsive geometry instruction in underrepresented regions.

METHOD

This study employed a qualitative descriptive research design to examine junior high school students' levels of geometric thinking related to quadrilateral concepts using the van Hiele theoretical framework. The qualitative descriptive design was chosen to facilitate an in-depth exploration of students' cognitive developmental stages and the misconceptions encountered in classifying and analyzing quadrilaterals. This research design allowed the researcher to capture rich data from multiple sources, including written tests, interviews, and classroom observations.

The participants consisted of eighth-grade students from a junior high school located in Papua, Indonesia. A purposive sampling technique was used to select 25 students, representing diverse academic performance levels and learning backgrounds. The selected school reflects the socio-cultural diversity typical of the Papuan educational context, thereby allowing the study to examine how cultural and contextual variables influence geometric reasoning.

Data Collection Instruments

The primary research instrument used in this study was the researcher himself as the key instrument, in line with the qualitative research paradigm. In addition, a structured interview guide was developed to systematically collect data from the participants. The structured interview guide was designed to assess the students' levels of geometric thinking on quadrilateral topics according to van

Hiele's theory (Senk et al., 2022). The instrument contained three main tasks, each aiming to evaluate specific aspects of geometric understanding:

Task 1: Drawing Quadrilaterals

In this activity, students were asked to draw as many different quadrilaterals as possible. The purpose of this task was to explore students' ability to recognize, differentiate, and generate various quadrilateral shapes based on their visual and conceptual understanding. Students were then interviewed about the reasons for the differences among the shapes they had drawn.

Task 2: Identifying and Defining Quadrilaterals

In this stage, students were provided with various quadrilateral figures (shown as figures in the research instrument). Students were asked to identify each figure, name it, and explain the properties that characterize each quadrilateral. This task assessed the students' ability to recall, recognize, and articulate the formal properties of squares, rectangles, parallelograms, rhombuses, trapezoids, and kites.

Task 3: Classifying Quadrilaterals

In this final stage, students were required to classify the quadrilaterals based on shared properties or similarities. Students were also interviewed to explain the rationale behind their classification choices. This task aimed to assess students' ability to understand class inclusion, hierarchical relationships, and grouping based on geometric attributes.

Throughout these tasks, the interview questions were designed to probe deeply into students' thinking processes. Interviewers asked follow-up questions such as:

1. "Why do you say these shapes are different?"
2. "Can you explain the properties of this shape?"
3. "Why did you place these shapes into the same group?"

The data collected from these three tasks allowed the researcher to analyze students' levels of geometric thinking, identify misconceptions, and determine their placement within van Hiele's levels.

RESULTS

The study was conducted at SMP YPPK Santu Paulus Abepura with twenty-five seventh-grade students serving as research participants. Data were collected through structured interviews, drawing tasks, and classification tasks, and subsequently analyzed using van Hiele's levels of geometric thinking. Below are some examples of students' thinking level analysis.

1. Analysis of Subject S-1

Drawing Quadrilaterals

S-1 was able to draw seven quadrilaterals by focusing on differences in sides, angles, area, and perimeter. She explained:

"*Because the sides are different and the sizes are different*."

"*If you calculate them using formulas, the results will be different too*."

Although S-1 could distinguish between quadrilaterals, she did not recognize that the number of quadrilaterals is infinite. Her thinking level was identified as between Level 0 (Visualization) and Level 1 (Analysis).

Identifying and Defining Quadrilaterals

S-1 successfully identified squares, rectangles, parallelograms, rhombuses, trapezoids, and kites, but often relied on limited attributes and made classification errors. For instance, she incorrectly stated that a rhombus is not a parallelogram:

"*A parallelogram has different lengths and widths, but all sides of a rhombus are equal*."

This response reflects misconceptions regarding class inclusion. Her thinking level remained between Level 0 and Level 1.

Classifying Quadrilaterals

When classifying quadrilaterals, S-1 grouped them based on shape similarity without utilizing formal properties:

"*Because their characteristics are the same and their shapes are almost identical*."

This indicates reasoning consistent with Level 0 thinking.

2. Analysis of Subject S-5

Drawing Quadrilaterals

S-5 drew seven quadrilaterals, taking into account sides, angles, formulas, and occasionally irrelevant properties. He explained:

"*Because when observed from the properties, shape, side lengths, and angle measures, they are all different*."

His thinking level was assessed as between Level 0 and Level 1.

Identifying and Defining Quadrilaterals

Although S-5 correctly identified some quadrilaterals, he frequently relied on single properties and made logical mistakes. For example, he stated:

"*A rectangle is not a parallelogram because it has right angles, whereas a parallelogram does not*."

This demonstrates a limited understanding of subclass relationships, and his thinking remained between Level 0 and Level 1.

Classifying Quadrilaterals

In classification, S-5 grouped quadrilaterals based on formula similarities and shape resemblance:

"Because they are both squares in shape."

His classification indicated Level 0 thinking.

3. Analysis of Subject S-9

Drawing Quadrilaterals

S-9 drew six quadrilaterals, using sides, angles, and general properties as his basis:

"*Because when you observe the side lengths and their properties, they differ*."

His reasoning placed him between Level 0 and Level 1.

Identifying and Defining Quadrilaterals

Although S-9 could name quadrilaterals, his definitions were often incomplete or incorrect. For example, he mistakenly claimed that a square is not a rhombus:

"*No, because all four angles are right angles*."

This indicates a misunderstanding of hierarchical relationships. His thinking was classified at Level 0.

Classifying Quadrilaterals

In classification tasks, S-9 grouped shapes based on perimeter and properties without using clear criteria:

"*Because their properties and perimeters are the same*."

He remained at Level 0.

4. Analysis of Subject S-15

Drawing Quadrilaterals

S-15 drew six quadrilaterals, considering sides, angles, and generalized properties:

"*Because when you observe the properties, the angle measures and side lengths are different*."

Her thinking level was between Level 0 and Level 1.

Identifying and Defining Quadrilaterals

S-15 made several errors in classification. For instance, she claimed:

"*A rhombus is not a parallelogram because its properties are different*."

She lacked an understanding of class inclusion and relied on vague or inaccurate attributes. Her reasoning remained at Level 0.

Classifying Quadrilaterals

S-15 provided general reasons when grouping quadrilaterals:

"*Because they have the same properties and similar shapes*."

She was assessed at Level 0.

5. Analysis of Subject S-20

Drawing Quadrilaterals

S-20 drew six quadrilaterals, focusing on side lengths, sizes, and angles:

"*Because the side lengths are different.*"
"Because the sizes are different."

His thinking level was between Level 0 and Level 1.

Identifying and Defining Quadrilaterals

Although S-20 could name quadrilaterals, he frequently confused properties. For example, he stated:

"*A square is not a rhombus because it has right angles.*
"A rectangle is a parallelogram because opposite sides are equal."

His reasoning was classified at Level 0.

Classifying Quadrilaterals

S-20 grouped quadrilaterals based on inaccurate properties:

"*Because they both have right angles*."

His classification was at Level 0.

6. Analysis of Subject S-24

Drawing Quadrilaterals

S-24 drew six quadrilaterals, referring to sides, parallelism, and vertices:

"*Because they are not aligned parallelly, and the vertices differ*."

Her thinking level was between Level 0 and Level 1.

Identifying and Defining Quadrilaterals

S-24 provided unclear or incorrect properties. For example, she stated:

"*A square is not a rhombus because it doesn't have sides of equal length.*"
"A trapezoid has two squares with equal sides."

Her reasoning remained at Level 0.

Classifying Quadrilaterals

S-24 grouped quadrilaterals based on superficial characteristics:

"*Because they have two pairs of equal sides*."

She was classified at Level 0.

7. Analysis of Subject S-23

Drawing Quadrilaterals

S-23 was able to draw seven different quadrilaterals by considering variations in side lengths, angle measures, and overall shape configuration. He explained:

"*These shapes are different because the sides and angles are not the same."*

"Some have equal sides, others don't. Some have right angles, others don't."

This demonstrates that S-23 had begun to move beyond purely visual recognition by attending to geometric properties such as side and angle relationships. However, he did not demonstrate awareness of the infinite possibilities in constructing quadrilaterals. His thinking level was identified as Level 1 (Analysis).

Identifying and Defining Quadrilaterals

S-23 correctly identified and named several quadrilaterals, including the square, rectangle, rhombus, and parallelogram. When asked to describe their properties, he responded with property-based definitions, although sometimes incomplete or oversimplified. For example, she stated:

"*A rhombus has four equal sides but no right angles, so it's not the same as a square*."

"*A parallelogram has opposite sides that are the same, but not all sides like a rhombus*."

These explanations indicate a developing understanding of the internal properties of shapes, but also reveal conceptual confusion about subclass relationships, such as the idea that a square is a special type of rhombus and parallelogram. Despite these misconceptions, the emphasis on side and angle properties rather than mere appearance suggests reasoning consistent with Level 1.

Classifying Quadrilaterals

In the classification task, S-23 attempted to group quadrilaterals by shared attributes, particularly side length and angle similarity. He explained:

"*These go together because they have equal sides."*

"These have at least one pair of equal angles, so I grouped them here."

Although he was beginning to analyze and compare shapes using formal attributes, his classification strategy lacked full logical consistency and did not fully reflect the hierarchical structure of quadrilateral families. This partial property-based grouping supports a diagnosis of Level 1 thinking, with evidence of analytical reasoning still developing.

8. Analysis of Subject S-25

Drawing Quadrilaterals

S-25 drew seven quadrilaterals with noticeable attention to structural differences in side lengths, angle measures, and symmetry. When asked to explain the distinctions, she stated:

"*Each shape is different because of how the sides are arranged and how big the angles are."*

"Some have right angles, some don't. The lengths of the sides also vary."

Her responses indicated a shift from purely visual recognition to an emerging analysis based on measurable properties. She demonstrated an ability to differentiate quadrilaterals by identifying concrete attributes, which is indicative of Level 1 (Analysis) thinking.

Identifying and Defining Quadrilaterals

S-25 was able to correctly name and describe several quadrilaterals, including the square, rectangle, and trapezoid. She articulated some defining properties, such as:

"*A square has all equal sides and all right angles."*

"A rectangle has opposite sides equal and all angles are 90 degrees."

"A trapezoid has only one pair of parallel sides."

However, she made a few classification errors. For instance, she commented:

"*A rhombus isn't a parallelogram because it has equal sides, not opposite sides*."

This statement reveals a misunderstanding of class inclusion, a common issue at this stage. Nonetheless, her consistent reference to side length, angle measure, and parallelism—rather than overall shape—demonstrates a reasoning style aligned with Level 1.

Classifying Quadrilaterals

When grouping quadrilaterals, S-25 attempted to use shared properties as the basis for classification. She explained:

"*These shapes are grouped because they all have two sides of the same length.*"
"I put these together because their angles are all the same."

Her classification reflected an emerging analytical approach, though not yet fully logical or hierarchical. She did not apply formal definitions to justify class inclusion or subclass relationships, which limited her reasoning. Even so, her attempt to compare internal attributes rather than rely solely on visual similarity is a clear indicator of Level 1 thinking.

Analysis of students' test responses revealed a varied distribution of geometric thinking levels according to the van Hiele framework. The majority of students were found to operate at Level 0 (Visualization) and Level 1 (Analysis), indicating an early stage of geometric understanding. Specifically, 50% of students demonstrated Level 0 thinking, characterized by recognizing quadrilaterals based solely on their overall appearance without reference to formal properties. These students often confused similar-looking shapes such as parallelograms and rhombuses.

Approximately 36% of the students in the study were classified as being in a transitional stage between Level 0 (Visualization) and Level 1 (Analysis) of van Hiele's geometric thinking framework. These students exhibited characteristics of both levels, demonstrating emerging analytical reasoning while still relying heavily on visual features. Only 14% reached Level 1 (Analysis), where they could identify and list individual properties of quadrilaterals (e.g., "a rectangle has four right angles") but showed limited ability to relate those properties to classification hierarchies.

No students in the sample demonstrated proficiency at Level 2 (Informal Deduction), Level 3 (Deduction), or Level 4 (Rigor), which require formal reasoning based on geometric theorems and logical proofs. This absence highlights a significant gap in formal geometric reasoning within the study population.

Common Misconceptions Identified

The test results and interview data revealed several persistent misconceptions:

1. Many students believed that a rhombus must have right angles, conflating it with a square.
2. Some participants identified any four-sided figure as a rectangle if it appeared elongated, regardless of angle or side equality.
3. When asked to explain why a square qualifies as both a rectangle and a rhombus, most students at Level 0 and Level 1 could not provide reasoning beyond visual similarity.

These misconceptions underscore a lack of relational understanding and an overreliance on shape appearance rather than structural properties.

Instructional Factors Observed

Classroom observations highlighted key instructional gaps. Teachers primarily focused on naming and defining quadrilaterals without emphasizing their interrelationships. There was minimal use of visual aids or dynamic geometry software, and most examples remained abstract, detached from students' real-life contexts. These observations suggest that instructional strategies did not sufficiently scaffold students through van Hiele levels, contributing to stagnation at the lower levels of geometric thinking.

DISCUSSION

The findings of this study indicate that the majority of eighth-grade students in Papua remain at Level 0 (Visualization) and Level 1 (Analysis) within the van Hiele framework of geometric thinking. Most students classified and recognized quadrilaterals based primarily on their visual appearance, without attending to formal attributes such as angle measures, side lengths, or parallelism. Common misconceptions included the belief that a square is not a rectangle or rhombus and the notion that a parallelogram must have unequal sides, while a rhombus has equal ones. These patterns suggest that students lacked understanding of the hierarchical relationships between geometric shapes, as conceptualized by van Hiele (Nahdi et al., 2024; Usiskin, 1982; Vieira & Cyrino, 2023). Similar misconceptions have been reported in prior studies, which found that students often rely on procedural knowledge rather than developing a deep conceptual grasp of geometric properties and classifications (Birgin & Özkan, 2024; Ekawati et al., 2023). These conceptual gaps are often exacerbated by limited exposure to tasks that promote abstraction and relational reasoning in classroom instruction (Deringöl, 2020; Uyen et al., 2021).

The dominance of surface-level reasoning also indicates a fragile conceptual schema that may hinder students' ability to transition toward higher-order geometric reasoning. Without explicit opportunities to compare, generalize, and justify the properties of quadrilaterals, students remain confined to fragmented and often inaccurate understandings. This lack of structural comprehension not only affects their classification accuracy but also compromises their ability to engage in meaningful problem-solving related to geometry (Harris et al., 2021). Furthermore, these misconceptions—if uncorrected—risk becoming fossilized and more resistant to instructional interventions in higher grade levels (Leton et al., 2020). As Lowrie & Logan (2023) argue, foundational misunderstandings in shape classification can persist into secondary education if educators fail to address them with developmentally appropriate, conceptually focused pedagogy. Therefore, early identification and targeted remediation of these misconceptions are crucial for nurturing robust and transferable geometric thinking skills.

The overreliance on visual characteristics was evident across many student responses, where quadrilaterals were grouped based on perceived similarity in overall shape rather than analysis of definitional attributes such as angle measures, side lengths, or symmetry. This tendency suggests that most students are still functioning at van Hiele Level 0, where geometric figures are recognized as holistic visual forms without decomposition into their component properties. Although some students began to mention attributes like the number of sides or the presence of right angles, these were not integrated into a systematic framework for classification. As a result, the transition from Level 0 to Level 1 appeared to be a major cognitive hurdle, aligning with findings from prior studies that emphasize the challenge of moving beyond purely visual recognition without appropriate instructional scaffolding (Nahdi et al., 2024; Usiskin, 1982). This indicates a disconnect between intuitive recognition and analytical understanding, which is essential for deeper geometric reasoning.

Compounding this issue was students' limited ability to communicate their geometric thinking using precise mathematical language. Many of the verbal and written justifications provided were vague or relied on informal expressions such as "it looks the same" or "the shape is similar," lacking formal terminology or logical connections. This linguistic limitation not only hindered students' ability to articulate their reasoning but also reflected a broader weakness in conceptual clarity (Han et al., 2025; Kartal et al., 2025; Lowrie & Logan, 2023). According to Uyen et al. (2021)The mastery of academic vocabulary is integral to transitioning between van Hiele levels, as language plays a critical role in structuring thought. Without targeted instruction that cultivates both geometric language and relational reasoning, students are likely to remain anchored in superficial strategies. As emphasized by Vieira & Cyrino (2023)Advancing geometric thinking requires deliberate attention to both the cognitive content and the discourse practices that support mathematical understanding. Therefore, improving students' conceptual development in geometry must go hand in hand with explicit support in the language of mathematics.

Instructional practices in the observed classroom contributed to the learning outcomes identified in this study. Teachers were primarily focused on naming and defining geometric shapes without encouraging students to explore relationships, hierarchies, or shared properties among the shapes. As a result, the learning process was heavily based on memorization rather than conceptual understanding. Visual aids and dynamic technologies such as GeoGebra were largely absent, and tasks tended to remain abstract, lacking connections to students' real-life experiences. This instructional pattern is consistent with prior studies indicating that the absence of visual-dynamic engagement and contextualized instruction hinders students' progression in geometric reasoning (Birgin & Özkan, 2024; Zhang et al., 2025). To address this, instructional strategies should adopt structured scaffolding aligned with the van Hiele levels, offering sequenced learning activities that promote gradual cognitive advancement (Uyen et al., 2021). Classroom activities like attribute-based classification, shape comparison, and the use of concrete manipulatives are essential to develop students' spatial reasoning and property recognition.

In addition, the integration of dynamic geometry tools has been shown to significantly improve both visual and conceptual understanding, particularly in middle school settings (Gurmu et al., 2024). However, in educational contexts such as Papua, limited access to technological infrastructure and insufficient professional development for teachers present substantial barriers to the adoption of such tools. Therefore, localized instructional adaptations are essential. Incorporating low-cost visual materials and embedding culturally relevant elements, such as indigenous patterns, traditional house structures, or local artifacts, can make abstract geometry more relatable and accessible to learners (Ayan-Civak et al., 2021; Hermansyah & Aqil, 2024; Yalley et al., 2021). This approach not only bridges the gap between formal mathematical concepts and students' everyday experiences but also reinforces engagement through cultural affirmation. As noted by Ramírez-Uclés & Ruiz-Hidalgo (2022), culturally responsive pedagogy is a critical component of effective mathematics instruction in diverse learning environments. Consequently, improving geometry education must involve both cognitive and contextual considerations tailored to the realities of local classrooms.

The incorporation of culturally relevant materials can also bridge formal geometric content with students' lived experiences. Integrating traditional Papuan elements—such as indigenous patterns, house architecture, or symbolic artifacts—can increase the relevance and accessibility of geometry for learners in remote areas (Hermansyah & Aqil, 2024; Yalley et al., 2021). When students are engaged with geometric ideas embedded in familiar cultural contexts, they tend to exhibit stronger motivation and a deeper understanding of concepts (D'Ambrosio, 2020; Rosa & Orey, 2016). These culturally embedded tasks function as cognitive anchors, helping students map abstract properties like symmetry, congruence, or parallelism onto real-world patterns present in their environment. Additionally, connecting mathematical concepts to indigenous knowledge systems not only promotes comprehension but also affirms students' cultural identity, contributing to more inclusive educational practices (Ramírez-Uclés & Ruiz-Hidalgo, 2022). In contexts where formal resources may be lacking, these strategies provide low-cost, high-impact pathways for improving learning outcomes.

The theoretical contribution of this study lies in its contextual application of the van Hiele model in a culturally rich and educationally underrepresented setting. While the van Hiele framework has demonstrated consistent success in various international contexts, such as in Turkey and Malaysia (Deringöl, 2020; Naufal et al., 2020)Its implementation in Papua reveals new insights into how cultural and instructional realities intersect with cognitive development in geometry. These findings underscore the need for adaptable and inclusive pedagogical approaches that reflect both the hierarchical structure of geometric thinking and the sociocultural landscape of learners. Developing hybrid instructional models that merge the van Hiele progression with mathematics-based culture perspectives could offer more relevant and effective strategies for teaching geometry in multicultural environments (Uyen et al., 2021; Vieira & Cyrino, 2023). Such an approach would not only localize curriculum content but also democratize access to meaningful mathematical learning for students in marginalized communities.

Despite these contributions, the study has several limitations. The participant pool was limited to a single school, which may not represent the diversity of educational contexts across different regions. The qualitative nature of the research also limits the generalizability of the findings to broader populations. Although data validation techniques such as triangulation and member checking were applied, the potential for subjective interpretation cannot be fully eliminated. Moreover, the study did not include a pre- and post-assessment design, which could have provided a clearer view of students' learning progression over time. The methods used primarily focused on individual responses through drawing tasks and interviews, which may not capture the collaborative and social aspects of classroom learning. Future research should compare geometric thinking between urban and rural students, explore the influence of teaching resources and classroom environments, and develop instructional models that integrate local cultural knowledge. Longitudinal studies would also be valuable in examining how students' conceptual understanding evolves with sustained culturally responsive instruction.

CONCLUSION

This study found that most eighth-grade students in a Papuan junior high school demonstrated geometric thinking limited to van Hiele Level 0 (Visualization) and Level 1 (Analysis), with none attaining the higher deductive reasoning levels. Their understanding of quadrilaterals was often based on surface-level visual similarities rather than formal geometric properties, resulting in persistent misconceptions, particularly regarding the classification and hierarchical relationships of shapes such as squares, rhombuses, and parallelograms. These conceptual gaps were compounded by instructional practices that emphasized rote memorization over relational understanding and lacked culturally relevant materials or dynamic visual tools. The findings underscore the importance of implementing pedagogical strategies that align with the van Hiele framework, incorporate cultural context, and promote progressive cognitive development in geometry. Future research is recommended to expand the study across diverse educational settings in Papua and beyond, compare rural and urban student performance, and explore the longitudinal impact of culturally responsive and technology-supported instruction. Additionally, developing and testing hybrid instructional models that integrate local cultural knowledge with structured geometric learning could offer valuable insights into improving mathematics education in marginalized communities.

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Author Contribution	:	All authors contributed equally to the design, implementation, analysis, and writing of this study. Author 1 led the research design and data collection process. Author 2 was responsible for data analysis and interpretation. Author 3 contributed to the theoretical framework and literature review. Author 4 supervised the research process and provided critical revisions to the manuscript. All authors read and approved the final version of the manuscript.
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