

Improving Students' Geometric Thinking Levels through a Van Hiele Learning Module Integrated with Ethnomathematics

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Article Information

Received : 09 July 2026

Revised : 18 August 2026

Accepted : 19 August 2026

Published : 29 August 2026

ABSTRACT

Analytic geometry learning often emphasizes symbolic procedures, while students' spatial visualization and geometric reasoning remain underdeveloped. This gap highlights the urgency of developing culturally contextualized learning materials that connect concrete spatial experiences with formal mathematical concepts. This study aims to develop and evaluate the effectiveness of a local wisdom-based analytic geometry module in improving students' geometric thinking levels (GTL). The study employed Research and Development (R&D) using the ADDIE framework, comprising Analysis, Design, Development, Implementation, and Evaluation. Participants were 36 third-semester pre-service mathematics teachers at Universitas Negeri Makassar, selected purposively. Data were collected through module validation sheets, student response questionnaires, and a seven-item open-ended Geometric Thinking Test, and analyzed descriptively and using the Wilcoxon Signed-Rank Test. The module achieved high validity based on subject matter (0.92) and cultural (0.80) expert validation and high practicality (83.79%). Wilcoxon analysis indicated a significant improvement in GTL ($Z = -5.233$; $p < 0.001$). Students reaching Level 3 (Formal Deduction) increased from 0% to 69.4%, while 2.8% reached Level 4 (Rigor). Integrating traditional-house wireframes and weaving patterns provided visual-cultural scaffolding that bridged spatial intuition and formal algebraic reasoning. These findings demonstrate the module's potential to strengthen formal geometric reasoning and support culturally responsive mathematics education. Future studies should examine its effectiveness using larger, diverse samples and comparative designs.

KEYWORDS

Learning Modules, Van Hiele, Ethnomathematics, Geometric Thinking Levels

ARTICLE DOI:

<https://doi.org/10.53696/venn.v5i5.557>

How to Cite : Ramadan, A., Naufal, M.A., Ashari, N.W., & Hassan, M.N. (2026). Improving Students' Geometric Thinking Levels through a Van Hiele Learning Module Integrated with Ethnomathematics. VENN: Journal of Sustainable Innovation on Education, Mathematics and Natural Sciences, 5(5), 1052–1061. <https://doi.org/10.53696/venn.v5i5.607>

A. Introduction

Geometry is a fundamental pillar of mathematics education that plays a critical role in developing core mathematical competencies, specifically logical thinking, spatial awareness, and formal reasoning (Chiossi, 2022; Jones, 2002). Specifically, geometry contributes to logical thinking by requiring learners to construct valid deductive chains, test conjectures, and identify structural relationships between geometric figures (Battista, 2007; Clements & Battista, 1992). It enhances spatial awareness through the dynamic mental manipulation, transformation, and visualization of two-dimensional shapes and three-dimensional spatial objects (Sinclair et al., 2016; Uttal et al., 2013).

Despite its crucial role, analytic geometry continues to present notable learning hurdles for undergraduate students (Naufal et al., 2025). Extant empirical research demonstrates that many secondary school students struggle to understand geometry concepts and fail to reach higher-order thinking levels (Naufal et al., 2020). When these students transition to the university level, these unresolved deficiencies in prerequisite knowledge and low spatial visualization skills persist, thereby hindering their ability to transform contextual problems into formal algebraic models (Naufal et al., 2020; 2025). For example, when asked to model physical or structural slants such as determining the pitch of a traditional roof or the alignment of support beams students frequently struggle to translate these visual-spatial observations into abstract coordinate systems. They often fail to identify key spatial references, map physical dimensions onto point coordinates (x_1, y_1, z_1) , and construct formal algebraic representations such as gradient formulas $m = \frac{y_2 - y_1}{x_2 - x_1}$ or symmetric vector line equations in three-dimensional space $\frac{x - x_0}{a} = \frac{(y - y_0)}{b} = \frac{(z - z_0)}{c}$. This disconnect highlights how low spatial visualization directly restricts students from operating at formal deductive levels.

This phenomenon is corroborated by empirical data from preliminary research by Naufal et al. (2025), which indicates that the geometric thinking levels of prospective mathematics teachers in Indonesia are still dominated by lower-order thinking specifically the visualization and analysis levels with minimal formal understanding. According to the Van Hiele theory, learners must progress through a hierarchical and sequential series of thinking stages, spanning from Level 0 (Visualization), Level 1 (Analysis), Level 2 (Informal Deduction), Level 3 (Deduction), to Level 4 (Rigor). Empirical evidence confirms that students' persistent stagnation at lower van Hiele levels is heavily driven by traditional instructional approaches that are excessively theoretical, rote-memorization-oriented, and decontextualized (Atebe & Schäfer, 2011; Hanik & Nurtamam, 2017). When instruction relies solely on abstract algebraic procedures without grounding concepts in familiar physical or cultural contexts, learners are unable to form meaningful mental representations or internalize structural relationships between geometric properties (Battista, 2007; Trimurtini et al., 2022). Consequently, students remain trapped in passive visual recognition (Level 0) and isolated property analysis (Level 1), failing to progress toward formal deductive reasoning.

To bridge the gap between formal mathematical abstraction and students' lived realities, the ethnomathematics approach offers an integrative pedagogical solution (Rosa & Orey, 2011). Ethnomathematics examines how mathematical concepts are adapted and expressed within the cultural artifacts of a society (Marsigit, 2016). By integrating local cultural elements, mathematics initially perceived as abstract is transformed into a more concrete and meaningful subject (Wahyuni et al., 2013). In the South Sulawesi region, cultural objects such as the architectural structure of the *Balla' Lompoe* traditional house and the geometric patterns of silk weaving (*Lipa' Sabbe / Lurik*) are rich in embedded geometric concepts that can be productively explored.

Although previous studies have explored ethnomathematics and van Hiele's theoretical phases, a significant research gap remains. Most existing literature focuses primarily on elementary or

secondary geometry, addressing basic two-dimensional shapes while paying insufficient attention to complex spatial concepts in higher education. Furthermore, there is a lack of empirical research examining how local cultural artifacts can be systematically operationalized through van Hiele's learning phases to resolve cognitive stagnation in university-level analytic geometry. Addressing this gap is urgent, as pre-service mathematics teachers must master formal geometric deduction to effectively teach spatial concepts in their future classrooms. The unique contribution of this study lies in its novel pedagogical design: it structurally transforms local cultural artifacts specifically the 3D wireframe architecture of traditional houses and the geometric diagonal patterns of local weaving into concrete cognitive scaffolds mapped explicitly across van Hiele's five learning phases for 2D plane and 3D spatial linear equations. Therefore, the primary objective of this article is to delineate the feasibility quality (validity and practicality) and evaluate the effectiveness of this integrated module in systematically enhancing the geometric thinking levels of pre-service mathematics teachers at Universitas Negeri Makassar.

B. Research Methods

This study employs the Research and Development method ([Sugiyono, 2013](#)), using the ADDIE systematic development model, which comprises five operational phases: Analysis, Design, Development, Implementation, and Evaluation ([Branch, 2010](#); [Molenda, 2003](#)).

1. Analysis Phase: This includes needs analysis through student interviews, analysis of the MBKM curriculum, and the administration of a pretest to assess the subjects' initial level of geometric thinking.
2. Design Phase: Designing the initial format of the module, formulating the learning objectives for the material on linear equations, and mapping analytical geometry learning strategies to the five Van Hiele learning phases.
3. Development Phase: Transforming the conceptual draft into instructional materials and Student Worksheets (SWs), followed by a content validation process conducted by subject matter experts and cultural experts.
4. Implementation Phase: Conducting a limited-scale pilot study over four in-person class sessions with students in Class A13 of the Mathematics Education Program at the Faculty of Mathematics and Natural Sciences, UNM, for the 2025/2026 academic year. The researcher serves as the primary instructor in the class.
5. Evaluation Phase: Analyzing data from the student practicality response questionnaire and the posttest results on geometry skills to improve the final product.

The research was conducted during the 2025/2026 academic year at the Department of Mathematics, Universitas Negeri Makassar (UNM), Indonesia. The research subjects consisted of 36 undergraduate students enrolled in the Plane Analytical Geometry course.

Data collection instruments included a Module Validation Sheet, a Student Response Questionnaire, and the Geometric Thinking Test (GTT). The GTT was developed as an open-ended essay test consisting of 7 structured items. These items were strategically mapped across five hierarchical levels of the van Hiele geometric thinking model, adapted from [Usiskin \(1982\)](#) and [Rida \(2021\)](#). Specifically, Level 0 (Visualization) was measured by Item 1; Level 1 (Analysis) by Item 2 and Item 3; Level 2 (Informal Deduction) by Item 4; Level 3 (Formal Deduction) by Item 5; and Level 4 (Rigor) by Items 6 and 7. Content validity for all instruments was assessed using Gregory's validation coefficient index based on the evaluation of two expert validators.

To evaluate the effectiveness of the developed learning module, data from the pretest and posttest GTT scores were analyzed. The criterion for the module's effectiveness was determined by a statistically significant upward shift in students' van Hiele geometric thinking levels (GTL) post intervention. Given that the normality test using the Shapiro-Wilk formula indicated a non-normal data distribution ($p < 0.05$), hypothesis testing was conducted using the non-parametric Wilcoxon Signed-Rank Test via SPSS. The module is declared effective if the asymptotic significance value satisfies the condition Asymp. Sig. (2-tailed) < 0.05 .

C. Research Findings and Discussion

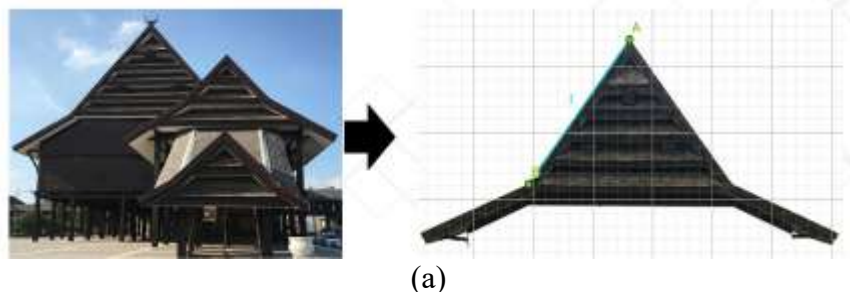
1. Results of the Module Analysis and Design Phase

In the analysis phase, the pretest results for 36 students revealed a very low level of geometric thinking: 24 students were at Level 0 (Visualization), 11 at Level 1 (Analysis), 1 at Level 2 (Informal Deduction), and none reached the levels of formal deduction or rigor. In interviews, students admitted to having difficulty visualizing abstract three dimensional spatial concepts.

Based on these findings, the module was designed by mapping the concept of linear equations onto the structure of local cultural objects. Its integration into Van Hiele's five learning phases is structured as follows:

- a. Information & Investigation Phase: Students observe visual representations of the roof of the Balla' Lompoa building to intuitively explore the concept of slope.
- b. Guided Orientation Phase: Structured worksheets are provided to guide students in calculating the gradient and the components of the direction vector of a straight line.
- c. Explanation Phase: Students present their group's findings, while the instructor clarifies formal mathematical terminology (e.g., the gradient formula $m = \frac{y_2 - y_1}{x_2 - x_1}$ and parametric form).
- d. Free Exploration Phase: Students are challenged to solve complex problems, such as reconstructing the diagonal line equations in Lurik/Batik fabric patterns in Cartesian coordinates.
- e. Integration Phase: Students create concept maps and final conclusions that link the visual architecture of traditional buildings with the algebraic formulas of formal spatial geometry.

To address the visual limitations of 3D space, the support pillars of Balla' Lompoa were modeled as precise wireframe representations within the module, helping students understand the positioning of formal lines and the concept of the direction cosine, as clearly illustrated in Figure 1.



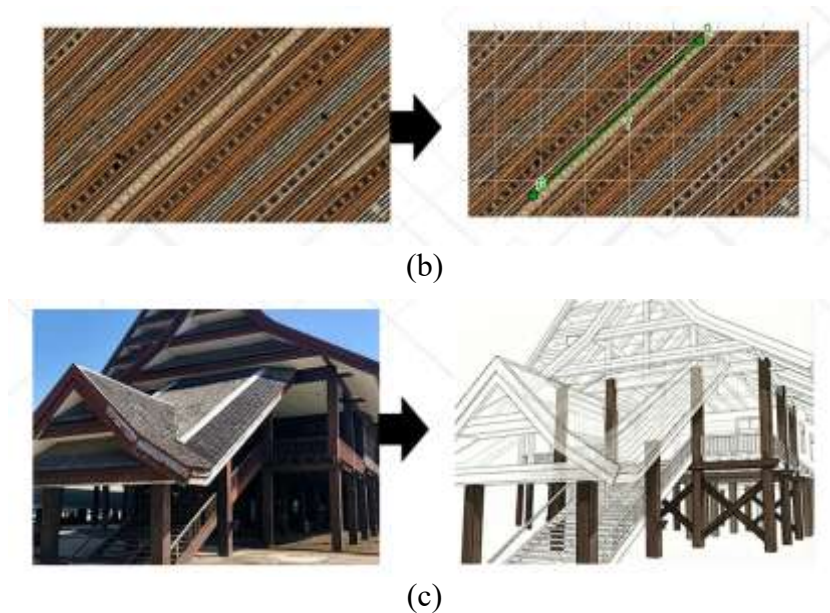


Figure 1. Geometric concept visualization in the developed module: (a) Roof of Balla' Lompoa traditional house, (b) Lurik weaving patterns, (c) Pillars of Balla' Lompoa traditional house.

To address the abstract visualization barriers in 2D and 3D coordinate systems, the module explicitly integrates local cultural artifacts through mathematical reconstruction. For 2D plane geometry, the intricate diagonal lines of Lurik/Batik patterns and the slope angles of the Balla' Lompoa traditional house's roof were mapped directly onto Cartesian coordinates. For 3D spatial geometry, the vertical support pillars of the Balla' Lompoa house were transformed into transparent wireframe models. This wireframe technique exposes the internal geometric lines and spatial intersections, enabling students to formulate direction cosines and vector orientations of lines in a 3D space (X, Y, Z) using concrete cultural anchors.

2. *Validity and Practicality of the Module*

Based on an analysis of the Gregory index using expert evaluations, this draft module has been found to meet the criteria for theoretical feasibility:

- a. Content Expert Validation: Achieved a validity coefficient of 0.92 (Highly Valid category).
- b. Cultural Equivalence Test: Achieved a validity coefficient of 0.80 (Highly Valid category).

In terms of practical implementation in the classroom, post-instruction survey data from 36 students indicated a high level of operational practicality. The average score was 43.5 out of a maximum ideal score of 52. In detail, the practicality percentages based on indicators include: material suitability (83.68%), language aspects (82.29%), and module appeal/design (85.41%), with an average cumulative practicality of 83.79% (Very Practical category).

3. *The Effectiveness of the Module in Improving Geometric Thinking Skills*

The effectiveness test was conducted by comparing cognitive achievement performance between the pretest and posttest. Based on the Shapiro-Wilk normality test, the p-values were 0.010 for the pretest and 0.000 for the posttest. Since $p < 0.05$, the data were confirmed to be non-

normally distributed, so the analysis proceeded using the non-parametric Wilcoxon Signed-Rank Test.

The results of the inferential statistical test yielded a Z -value of -5.233 with an Asymp. Sig. (2-tailed) of 0.000 . Since the significance value is much smaller than the significance level $\alpha = 0.05$ ($0.000 < 0.05$), the null hypothesis (H_0) is significantly rejected and the alternative hypothesis (H_a) is accepted. The rank data show that all 36 students (100%) experienced an even increase in cognitive scores, with no subjects experiencing a decrease (Negative Ranks = 0).

The shift in the distribution of students' Geometric Thinking Levels (GTL) is clearly shown in Figure 2.

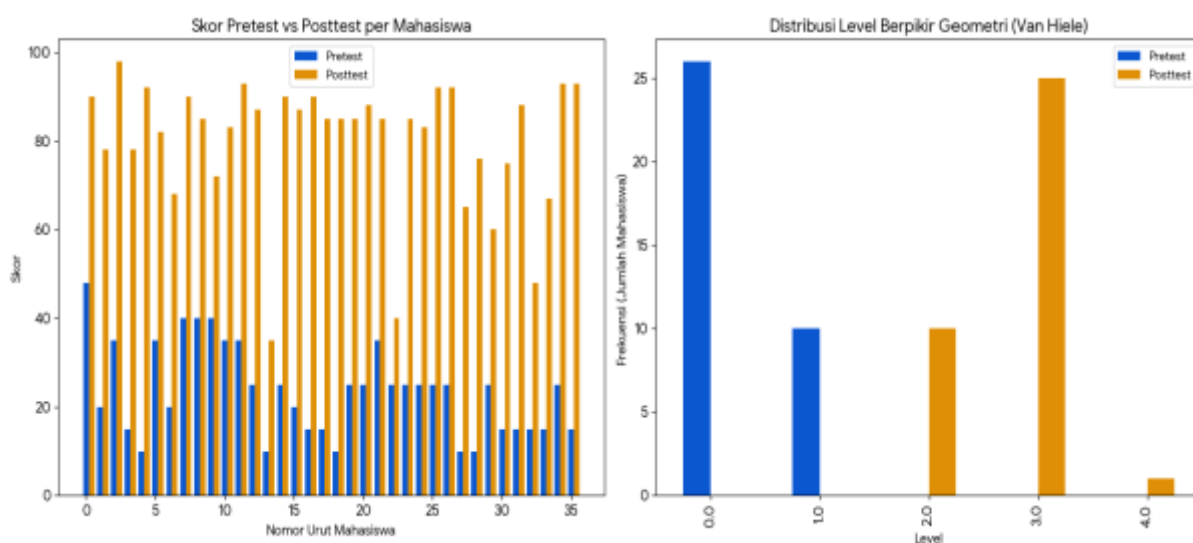


Figure 2. TBG Pretest and Posttest Results

Based on the test results, the students' abilities showed a significant improvement: whereas in the pretest 24 students were at Level 0 and 10 at Level 1, by the posttest 10 students had reached Level 2 (Informal Deduction), 25 had reached Level 3 (Formal Deduction), and 1 had reached Level 4 (Rigor).

These data clearly demonstrate that the implementation of the module successfully moved students from lower levels of thinking (Level 0 and Level 1) toward mastery of formal logical deduction.

4. Discussion

The observed enhancement in students' geometric thinking is empirically reflected in the synergistic operationalization of two key instructional elements: van Hiele's hierarchical learning phases and ethnomathematical contextual anchors. Rather than acting as isolated drivers, empirical observation during class implementation indicates that these two components worked complementarily to scaffold cognitive progression. In the instructional process, ethnomathematics provided familiar, concrete visual stimuli during the initial phases (Information and Guided Orientation), where students explored spatial slants using the rooflines of traditional houses and the diagonal patterns of local weaving. This aligns with findings that traditional house structures embed rich geometric regularities — such as symmetry, roof-slope proportions, and measurement relationships — that can be productively drawn upon in culture-based mathematics instruction

([Ashari et al, 2025](#)). Comparable evidence comes from an analysis of the Bola Pa'borongan house of the Kajang community, where roof triangles, trapezoidal facades, and reflective symmetry across the central roof axis were identified as concrete, everyday embodiments of angle, plane-figure, and transformation concepts ([Ashari et al, 2026](#)). Similarly, studies of vernacular architecture such as the Balla Lompoa house have shown that everyday building forms encode geometric concepts including symmetry and proportion through shapes like cubes, rectangles, and rhombuses, reinforcing their pedagogical value as concrete entry points for abstract geometric reasoning ([Asdar, A & Ashari, 2024](#)). This concrete anchor prevented cognitive overload when transitioning to abstract coordinate systems. Concurrently, van Hiele's structured learning phases served as the pedagogical roadmap that systematically guided students from these concrete observations toward formal mathematical language (Explication) and independent problem-solving (Free Exploration and Integration). These empirical observations align with the findings of [Heswari & Patri \(2021\)](#) and [Yudianto et al., \(2022\)](#), who demonstrated that coupling culturally contextualized tasks with structured van Hiele learning phases effectively reduces spatial abstraction barriers and optimizes students' logical geometric reasoning.

The posttest results demonstrated a measurable upward shift in the distribution of students' van Hiele geometric thinking levels. While pretest reasoning was heavily concentrated at lower-order levels—specifically Level 0 (66.7%, 24 students) and Level 1 (30.6%, 11 students) posttest data revealed a clear redistribution toward higher-order levels, with 27.8% (10 students) advancing to Level 2 (Informal Deduction), 69.4% (25 students) reaching Level 3 (Formal Deduction), and 2.8% (1 student) achieving Level 4 (Rigor). Theoretical conventions by van Hiele state that geometric reasoning levels are strictly hierarchical and sequential; under conventional instruction, learners rarely transition across multiple levels within short instructional intervals. However, this observed progression can be academically justified through the systematic design of the ADDIE-developed module. The integration of van Hiele's five learning phases served as an explicit cognitive scaffold. In the Information and Guided Orientation phases, concrete visual-cultural wireframes provided initial contextual grounding, preventing cognitive overload during the transition from 2D plane geometry to 3D spatial coordinate systems. Furthermore, the Explication and Free Exploration phases required students to articulate their visual observations using formal mathematical terminology and algebraic proofs, such as vector parameterization and normal line equations. This structured scaffolding offers a practical alternative to the patterns reported by [Wicaksono \(2022\)](#), who observed persistent student stagnation at the analysis level. Structurally reconstructing local cultural artifacts into formal coordinate equations provided a dual-coding cognitive mechanism (visual-cultural and algebraic-formal), enabling students to systematically master formal logical deduction.

D. Conclusion

Based on the research findings, it can be concluded that the developed Van Hiele model-based analytical geometry learning module integrated with ethnomathematics is highly valid, practical, and effective in significantly improving the Geometric Thinking Level (GTL) of undergraduate mathematics students at UNM. This success is empirically demonstrated by a major upward shift in student achievement. The subjects' geometric reasoning, which was initially dominated by lower-order levels (Visualization and Analysis) during the pretest, shifted to higher-order levels, predominantly reaching Level 3 (Formal Deduction) in the posttest.

Mechanistically, the integration of local cultural artifacts such as the structural wireframes of the *Balla' Lompoa* traditional house and the geometric patterns of silk weaving served as an effective dual-coding scaffolding that bridged concrete spatial intuition with formal algebraic equations. These

pedagogical outcomes imply that embedding ethnomathematical contexts within structured van Hiele learning phases can effectively resolve chronic cognitive stagnation in abstract geometry courses. Future research is encouraged to scale up the implementation across broader mathematical topics and investigate the long-term retention of these advanced geometric thinking skills.

PERNYATAAN PENGGUNAAN KECERDASAN ARTIFISIAL

.	<i>Penulis menggunakan [claude ai, sonnet 5 dan gemini ai, 3.1 pro] untuk menyunting bahasa dan merapikan tata tulis. Seluruh keluaran telah diperiksa dan diverifikasi oleh penulis, dan penulis bertanggung jawab penuh atas isi artikel.</i>
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PERNYATAAN KONTRIBUSI PENULIS

Arman Ramadan	<i>Konseptualisasi, metodologi, pengumpulan data uji coba pada 36 mahasiswa, analisis data, dan penulisan draf awal.</i>
Muhammad Ammar Naufal	<i>Supervisi utama, konseptualisasi, validasi instrumen, serta penulisan dan ulasan naskah.</i>
Nur Wahidin Ashari	<i>Supervisi, validasi, dan penelaahan naskah.</i>
Muhammad Nasiru Hassan	<i>Penelaahan naskah dan penyuntingan akhir.</i>

PERNYATAAN PENDANAAN

	<i>Penelitian ini tidak menerima pendanaan dari lembaga mana pun, baik pemerintah, swasta, maupun nirlaba.</i>
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PERNYATAAN KONFLIK KEPENTINGAN

	<i>Penulis menyatakan tidak terdapat konflik kepentingan terkait penelitian, kepenulisan, maupun penerbitan artikel ini.</i>
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