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Comparative Study: Differences in Students' Geometric Reasoning Viewed from Van Hiele's Levels of Geometric Thinking

Thiara Ayu Sheila[1,*], Rika Mulyati Mustika Sari[2], Rafiq Zulkarnaen[3], Iyan Rosita Dewi Nur[4]
[1,2,3,4] University of Singaperbangsa Karawang, Karawang
*Corresponding Authors: 2510632050011@student.unsika.ac.id

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ABSTRACT

This study aims to determine the differences in students' geometric reasoning in terms of Van Hiele's thinking levels in spatial geometry. This study used an ex post facto method with a quantitative approach. The population of this study was ninth-grade female students at SMP Negeri 2 Majalaya, with a sample of 86 students selected using simple random sampling. Data were obtained through diagnostic tests, geometric reasoning tests, and unstructured interviews with several samples. This study uses several inferential statistical tests such as normality tests, homogeneity tests, and ANOVA. The results of this study indicate that there are significant differences between the geometric reasoning abilities of students at level 0 and level 1, as well as between level 0 and level 2. The number of students classified as level 0 (visualization) is 69.77%; level 1 (analysis) is 24.42%; and level 2 (informal deduction) is 5.81%. No students were classified as level 3 or 4.

Keywords: geometric reasoning; geometric thinking; Van Hieles's levels

INTRODUCTION

One of the fundamental disciplines that people should master is mathematics. Mathematics is very important to be taught in all schools because it is a basic science that serves as a benchmark for research and technological progress (Utami et al., 2025). The context of mathematics includes numbers, theorems, formulas, and methods for solving mathematical problems. In line with this, mathematics is a general science that studies numbers and logical thinking to understand patterns, space, shapes, and structures (Fatonah & Nur, 2023). In other words, learning mathematics requires a wide range of mathematical skills. Since learning mathematics involves a variety of mathematical skills, there is a need for something that can enhance those skills.

In the process of learning mathematics, geometry is involved in key ideas and is closely related to supporting rational, spatial, and essential thinking skills in daily activities and their application in various fields of study (Suheni et al., 2025). Therefore, mathematics is contained in various aspects of life or daily activities. By studying mathematics, students can think critically and calculate well, and can apply basic mathematical concepts to mathematics itself, other fields of study, and daily life (Afsari et al., 2021).

Learning mathematics involves the ability to reason about the mathematical elements within it. The reasoning process is a cognitive process that produces conclusions that follow correct rules or mutually agreed-upon truths and can be accepted as accountable truths about the problems faced (Masfingatin et al., 2020; Riera et al., 2022). The process of defining and inferring a geometric entity's properties using its intrinsic properties, relationships to other geometric entities, and the rules of inference that bind these properties in geometric

(Euclidean) space is known as geometric reasoning (Wing & Arbab, 1985; Sulistyo et al., 2021).

Indicators of students' geometric reasoning abilities include identifying geometric concepts, determining the relationships between geometric concepts, explaining the relationships between geometric concepts, and explaining the reasons needed to draw conclusions (Mudhiah & Shodikin, 2019). Since geometric reasoning forms a large part of the advanced mathematics that students will encounter in higher academic and professional settings, the importance of focusing on geometric reasoning becomes increasingly clear (Margaretha, 2025).

To determine students' level of geometric thinking, teachers must be able to describe the thinking process students use to solve problems, so that they can ascertain students' level of thinking (Musa, 2016). A exciting field of research at the moment is geometric reasoning based on Van Hiele's stages of thinking. In addition to classifying students' geometric reasoning skills into Van Hiele's levels of thinking, recent research focuses on finding these levels via in-depth study based on theory and empirical data. Van Hiele's level theory has been used to explain why a lot of children have trouble with higher-order cognitive skills, especially reasoning, which are necessary for success in geometry. This theory also offers solutions for progressing through the levels in a specific manner (Usiskin, 1982). In the context of teaching and learning, the Van Hiele levels serve as teachers who guide students using language appropriate to a particular level in order to reach a higher level of reasoning (Mbusi & Luneta, 2021).

Students' geometric reasoning skills remain very low, particularly when it comes to identifying the logical reasoning behind the solutions they write down. For example, a study conducted by Wulandari (2025) found that students at one of the Junior High School have very low geometric reasoning abilities dengan students at the medium ability level were able to achieve 1 indicator, and students at the low ability level were unable to achieve any geometric reasoning indicator. Many studies in Indonesia have examined students' geometric reasoning abilities, but these have not been categorized or analyzed based on Van Hiele's levels of thinking. Therefore, the researchers were interested in analyzing the characteristics of students' geometric reasoning based on the problem-solving tasks they completed at Van Hiele's levels of thinking. This research does more than just categorize students based on Van Hiele's stages of thinking; it also identifies and analyzes data collected from the students.

RESEARCH METHODS

This study used an ex post facto method with a quantitative approach. The population of this study was 9th grade students at Junior High School 2 Majalaya. The sample consisted of 86 students selected using simple random sampling. Because the selection process was random, every student had an equal chance of being chosen as a sample. This was done in order to reduce bias and ensure that the research was representative of the whole population. To determine the differences in students' geometric reasoning abilities in terms of Van Hiele's geometric thinking levels, two trials were conducted in this study. The first trial aimed to measure students' diagnostic abilities with questions adapted from Syarifuddin's (2023) study. The results of the first test will be used as a basis for classifying students into

Van Hiele thinking levels. The second test is a geometric reasoning test with contextual questions adapted from Fauziyah's (2022) study.

The dependent variable in this study is geometric reasoning, and the independent variable is the level of thinking according to Van Hiele. Based on Van Hiele's theory in (Anwar, 2019), students learn to think geometrically sequentially through five stages or levels, namely:

1. Level 0 (visualization). At this level, students only know geometric shapes as visual characteristics.
2. Level 1 (analysis). At this level, students start to comprehend the characteristics of the geometric shapes they observe.
3. Level 2 (informal deduction). At this level, students know and understand the characteristics of one geometric shape in relation to another.
4. Level 3 (deduction). At this level, students are capable of making logical inferences, i.e., draw general conclusions and move on to specific matters.
5. Level 4 (rigor). At this level, students start to understand how important it is for the concepts that underpin a proof to be accurate.

The hypothesis of this study is that there are differences in students' geometric reasoning based on Van Hiele's thinking levels. The inferential statistics used in this study are normality, homogeneity, and ANOVA tests using JASP software. To gather more important and comprehensive information, unstructured interviews with math teachers and a number of students were also carried out.

RESULTS AND DISCUSSION

From the data obtained, inferential statistical tests were conducted to determine differences in students' geometric reasoning abilities based on Van Hiele's thinking levels. The following are the results of normality, homogeneity, and ANOVA tests using JASP software.

Normality Test

Based on the independent and dependent variables studied from 86 ninth-grade students at Junior High School 2 Majalaya, a normality test was obtained using Shapiro-Wilk with the help of JASP software. The significance level used in the normality test was $\alpha = 0.05$. If the p-value $< \alpha$, then the data is not normally distributed, and if the p-value $> \alpha$, then the data is normally distributed. The statistical hypotheses tested in the normality test are as follows.

H_0: The data is not normally distributed.

H_1: The data is normally distributed.

Table 1. Normality Test

Descriptive Statistics

	Level 0	Level 1	Level 2
Valid	60	21	5
Mean	46.80	63.62	76.20
Std. Deviation	20.64	22.38	6.760
Shapiro-Wilk	0.911	0.784	0.931
P-value of Shapiro-Wilk	< 0.001	< 0.001	0.605

Minimum	0.000	2.000	67.00
Maximum	82.00	85.00	83.00

Table 1 shows the results of the normality test of 86 students. From the table of students' geometric reasoning results above, it can be seen that at levels 0 and 1, p-value < α or p-value < 0.05, which means H_0 is accepted and H_1 is rejected, or the data is not normally distributed. Meanwhile, at level 2, the p-value > 0.05, which means H_0 is rejected and H_1 is accepted, or the data is normally distributed. Since there are two data points that are not normally distributed and one that is normally distributed, it can be concluded that the data from the students' geometric reasoning is not normally distributed.

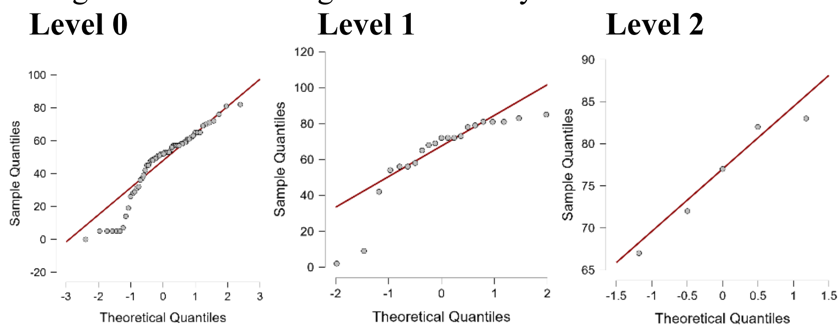

Figure 1. Q-Q Plot

Figure 1 above is a Q-Q plot diagram that can provide an overview of how data is distributed. The Q-Q plot above is an overview of data distribution from level 0 to level 1. The more points that are far from the diagonal line, the more the data tends to be non-normally distributed. Conversely, if the points are clustered directly above the diagonal line or close to the diagonal line, then the data is normally distributed. It can be clearly seen that at levels 0 and 1, many points are far from the diagonal line, which means that the data is not normally distributed. At level 2, however, the data is regularly distributed because the points tend to cluster around the diagonal line.

Homogeneity Test

The homogeneity of variance of the students' geometric reasoning data was examined using Levene's assumption test following a normality test. The significance level used in the homogeneity test here was α = 0.05. If the p-value was < α, the data was considered non-homogeneous, and if the p-value was > α, the data was considered homogeneous. The statistical hypothesis was written as follows.

H_0: The data is not homogeneous.

H_1: The data is homogeneous.

Table 2. Homogeneity Test

Test for Equality of Variances (Levene's)			
F	df1	df2	p
1.549	2.000	83.00	0.219

Based on the Table 2, the result of a homogeneity test to ensure that two or more data groups have the same or similar variance. From the table of students' geometric reasoning results above, it is obtained that the p-value is 0.219 or p-value > 0.05, which means that H_0

is rejected and H_1 is accepted. In other words, it can be concluded that each level is the same or the assumption of homogeneity is fulfilled.

Non-Parametric Test

To see the comparison or differences between data sets with more than two groups, an ANOVA test must be performed. The ANOVA test is a parametric test that demands that the data have a normal distribution and the assumption of homogeneity to be met. However, as described earlier, the study's homogeneity and normality test findings show that the homogeneity assumption is not satisfied and the data are not normally distributed. If the distribution of the data is not normal, then the ANOVA test cannot be used to find comparisons or differences. An alternative is to use the Kruskal Wallis non-parametric test.

The significance level used is $\alpha = 0.05$. If the p-value < α, then the data is said to have a significant difference, and if the p-value > α, then the data is said to have no significant difference. The statistical hypothesis is written as follows.

H_0: $\mu_1 = \mu_2 = \mu_3$, there is no significant difference.

H_1: $\mu_1 \neq \mu_2$, $\mu_2 \neq \mu_3$, or $\mu_1 \neq \mu_3$, there is a significant difference.

Table 3. Non-parametric Test

Kruskal-Wallis Test

Factor	Statistic	df	p
Level	22.03	2	< 0.001

Table 3 above is a non-parametric test, namely the Kruskal-Wallis test, because the distribution of the data is not normal. From the table above, we obtain that p-value < α or p-value < 0.05. With this, we can state that H_0 is rejected and H_1 is accepted, which indicates that there is a significant difference between the two groups. Due to this significant difference, we need to find out how big the difference is by conducting a post hoc test.

Post Hoc Test

Post hoc tests are conducted to determine the extent of the difference between one group and another. The type of post hoc test that can be used in non-parametric testing is the Dunn test.

Table 4. Post Hoc Test

Dunnett Post Hoc Comparisons - Level

Comparison	Mean Difference	SE	t	$p_{dunnett}$
1 - 0	16.82	5.232	3.215	0.004
2 - 0	29.40	9.604	3.061	0.006

Note. Results based on uncorrected means.

Table 4 is a post hoc test to determine the mean difference between level 1-0 and level 2-0. The aforementioned data demonstrates that level 0 and level 1 students' geometric reasoning skills differ significantly with a p-value of 0.004, as well as a difference between levels 0 and 2 of 0.006. Therefore, it can be determined that there is a significant difference between the geometric reasoning of levels 0-1 and levels 0-2.

The geometric reasoning abilities of ninth-grade students at Junior High School 2 Majalaya are still relatively low. The number of students at each level demonstrates this. At level 0, there are 60 students, at level 1 there are 21 students, and at level 2 there are 5 students. This shows that more than 50% of the sample is still at the visualization stage, where students only know geometric shapes as visual characteristics.

In addition to reviewing the number of students at each level, students' geometric reasoning abilities can also be seen from the differences in the mean test results. At level 0, the mean was 46.80; at level 1, it was 63.62; and at level 2, it was 76.20. These data indicate that the average geometric are the results of the analysis for each Van Hiele thinking level in this study.

1. Level 0 (visualization). At this level, students are only able to recognize spatial figures visually and some of the elements contained in those figures. For example, students can tell the difference between a cube and a block just from their appearance. In addition, students can name some of the elements in a solid, such as points, edges, space diagonals, and so on. However, they are not yet able to identify all the elements.
2. Level 1 (analysis). At this level, students are able to identify all the elements in a solid figure. Students can even draw the side diagonals by drawing diagonal lines between one point and another.
3. Level 2 (informal deduction). At this level, students are able to identify the relationship between one solid figure and another, for example, stating the reason why cubes and blocks are classified as prisms.

In general, a large number of students failed to record the information they were aware of and the questions posed. Some of them wrote them down, but some points were still incorrect. There were also students who misidentified the shapes shown in the pictures. Geometric reasoning pays close attention to each step of the answer that students write, even if they do not write down what is known and what is asked, it has its own assessment for researchers. Geometric reasoning emphasizes logical precision: each step must have a strict basis and conditions. On the other hand, because it is related to problem solving, geometric reasoning emphasizes problem-oriented thinking (Li, 2025). Errors in recognizing spatial figures can lead to errors in applying formulas to solve problems in the questions. This is especially true if, from the outset, students do not identify the core of the problem given in the question. In addition, many of them do not write down the cubic units for the volumes they obtain, nor do they convert cm^3 to liters as requested in the question.

The problems may be caused by the unstructured writing of answers by students. This shows that their geometric reasoning has not been achieved properly. To improve understanding of geometry, each topic can be written in a more structured manner because each topic is related to the others. If the topics are written randomly without regard to their relevance, it will confuse students' reasoning. In addition, students' poor conceptual understanding and weak mastery of prerequisite material prior to studying this topic are believed to be the main causes of their poor geometric reasoning skills. Limited learning resources and time constraints during the test are other contributing factors.

Supportive learning materials, a comfortable learning environment, instructional materials aligned with learning objectives, and mind maps of the subject matter can help achieve learning objectives. Mind maps as a tool for reasoning and organization can be incorporated into teaching methods to improve student understanding and the effectiveness of geometry instruction (Menouer et al., 2025). Using digital instructional resources can help enhance students' geometric thinking abilities.

Students' low geometric reasoning skills may be due to a lack of enthusiasm in participating in classroom learning activities. We stress the significance of offering rich learning opportunities that challenge students to visualize potential object configurations prior to building, recognize similarities and differences, and use geometric language to describe and defend their designs (Downton & Livy, 2022).

CONCLUSION

Students' geometric reasoning based on Van Hiele's thinking levels is still relatively low. Of the 86 students sampled in this study, 69.77% were classified as level 0, 24.42% as level 1, and 5.81% as level 2. No students were classified as level 3 or 4. In other words, students were not yet able to draw deductive conclusions and realize how critical it is that the ideas that serve as the foundation for proof be accurate. This is in line with research on 8th grade students at a private junior high school in Karawang on geometric thinking ability based on the levels of geometric thinking according to Van Hiele's theory, which concluded that 74% were at the visualization level (level 0) and 55% at the analysis level (level 1). This was due to inaccuracy in understanding the questions and a lack of understanding of basic concepts (Arnita et al., 2024).

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