Alifmatika: Jurnal Pendidikan dan Pembelajaran Matematika
Volume 7, Issue 1, 148-166, June 2025
e-ISSN: 2715-6109 | p-ISSN: 2715-6095
https://journal.ibrahimy.ac.id/index.php/Alifmatika

Students' conceptual understanding of transformation geometry based on Van Hiele's level assisted by GeoGebra

Agnes Stefine Luhukay[1*], Riskika Fauziah Kodri[2], A.N.M. Salman[3]

[1*,2]Teaching of Mathematics, Faculty of Mathematics and Natural Sciences, Bandung Insitute of Technology, West Java 40132, Indonesia

[3]Combinatorial Mathematics Research Group, Faculty of Mathematics and Natural Sciences, Bandung Insitute of Technology, West Java 40132, Indonesia

[1*]anespeping90@gmail.com, [2]fauziahriskika@gmail.com, [3]msalman@math.itb.ac.id

Received: March 15, 2025 | Revised: May 6, 2025 | Accepted: June 7, 2025 | Published: June 15, 2025

*Corresponding author

Abstract:
Mathematics has lower accomplishment than other subjects, according to TIMSS in 2011 and 2015 and PISA in 2015 and 2018. Geometry and measuring are the topics with the fewest right answers in the most recent National Exams, which were held in 2018 and 2019. According to the Minister of Education and Culture Regulation No. 16 of 2022, instructors must be able to use technology and communication devices in the learning process. The purpose of this study is to see how Van Hiele theory, helped by the Geogebra application, affects students' conceptual grasp of the geometry transformation topic taught in the D phase of the Merdeka Curriculum at the junior high school level. The subjects of this research were 55 students of grade IX who were divided into two groups, namely the experimental class which received learning with the application of Van Hiele theory assisted by the Geogebra application and the control class which applied conventional learning. The research was conducted using a mixed-methods approach, which combines both quantitative and qualitative methodologies. By using the Mann Whitney test on student score data of both class, it was concluded that there was no significant effect on level 0-visualization, level 1-analysis, and level 2-informal deduction, but there was a significant effect on students' abilities at level 3-deduction and level 4-rigor, which means that students who are taught using Van Hiele learning theory assisted by the Geogebra application have better conceptual understanding than students who are taught conventionally.

Keywords: Conceptual Understanding; Geogebra; Merdeka Curriculum; Transformation Geometry; Van Hiele Theory.

How to Cite: Luhukay, A. S., Kodri, R. F., & Salman, A.N.M. (2025). Students' conceptual understanding of transformation geometry based on Van Hiele's level assisted by GeoGebra. *Alifmatika: Jurnal Pendidikan dan Pembelajaran Matematika*, 7(1), 148-166. https://doi.org/10.35316/alifmatika.2025.v7i1.148-166

Introduction

Mathematics is a discipline that plays a crucial role in human life. Therefore, this field of study is introduced as early as the preschool years, continues through the 12 years of compulsory education, and is even included as a mandatory subject in most higher education programs during the initial years of university studies. Mathematics is highly beneficial in everyday life. It is a discipline that explores patterns and order, emphasizing the importance of recognizing and understanding mathematical structures. Mathematics educators are responsible for facilitating students' learning by guiding them to think through these existing patterns. Achieving proficiency in recognizing mathematical patterns requires proper education and systematic instruction (Gradini et al., 2025).

The urgency of mathematics education for students is recognized in Indonesia's education system as outlined in the Curriculum for Each Educational Unit (Kemendikbud, 2019). One of its main objectives is to give students the skills they need to understand mathematical ideas, explain how ideas relate to one another, and use ideas or algorithms in a flexible, correct, efficient, and acceptable way while solving problems.The mathematical literacy abilities of Indonesian pupils continue to lag well behind the average of other OECD nations, according to previous PISA evaluations conducted across a number of time periods (Zulkardi et al., 2020). The difficulties in Indonesian mathematics education have been repeatedly brought to light by the Programme for International Student Assessment (PISA) surveys. In 2018, Indonesia's average mathematics score of 379 placed it 73rd among the 79 participating countries (Tohir, 2019). The 2022 assessment, while showing a slight improvement in ranking to 69th out of 81 countries, revealed a further decline in the average score to 366. Both these scores are substantially below the OECD average of 472, indicating a persistent gap in mathematical literacy (OECD, 2023). Similarly, Indonesia ranked 46th out of 51 participating nations in the 2015 Trends in International Mathematics and Science Study (TIMSS) (Prastyo, 2020)(TIMSS, 2023). Reflecting on the results of the last National Exam (UN) held in 2019, it's evident that mathematics achieved the lowest average score compared to other subjects. Geometry, in particular, had the second least correct answers (Kemendikbud, 2025).

The difficulties and failures in understanding mathematical concepts are generally attributed to two primary factors: internal factors, such as students' interest and motivation, and external factors related to teaching methods: (a) Restating a topic is one of the NCTM's indications of conceptual knowledge; (b) Grouping items according to their characteristics; (c) Giving examples and examples of the idea; (d) Using different mathematical representations of the idea; (e) Creating sufficient or required conditions for an idea; and (f) Applying concepts or methods to solve issues, and g) Using, utilizing, and choosing particular procedures or activities (Nurjaman & Sari, 2017). One indicator of students' success in understanding mathematical concepts can be seen from their final grades. Higher academic achievement signifies a better understanding and mastery of the material, leading to improved learning outcomes (Mega et al., 2014).

In the process of understanding geometric concepts (Kemendikbudristek, 2024), a Dutch mathematics teacher, Van Hiele, conducted field research through observation and interviews, resulting in his dissertation in 1954. His study produced a number of findings about children's cognitive capacities for comprehending geometric ideas. Five degrees of geometric cognition were distinguished by Van Hiele (Mahlaba & Mudaly, 2022): visualization, analysis, abstraction, deduction, and rigor. Van Hiele's theory is a cognitive psychology theory that outlines the levels of mental development in geometry (Ghorbani et al., 2023).

Article 7 of the Regulation of the Minister of Education, Culture, Research, and Technology (Permendikbudristek) Number 16 of 2022 indicates that using information tools and technology is one way to accomplish learning objectives (Permendikbudristek, 2022). Information and communication technology must be used in a way that is integrated, methodical, and efficient while taking into account the current circumstances. It is clear from the aforementioned remark that technology should be used to improve learning's efficacy and efficiency, with the aim of achieving educational objectives and providing meaningful learning experiences for students. In relation to the use of technology in the Merdeka Curriculum, teachers are encouraged to employ digital technology in the teaching and learning process. In mathematics education, GeoGebra, an application-based technology, has gained popularity as a learning tool. GeoGebra is expected to enhance students' interest, creativity, and conceptual understanding of geometric, as it enables them to visualize abstract objects quickly, accurately, and efficiently. This is consistent with study that showed GeoGebra can increase students' enthusiasm in learning (Arbain & Shukor, 2015; Handayani et al., 2022; Radović et al., 2020), which found that GeoGebra can foster student interest in learning. An activity that a person participates in during the learning process for enjoyment and free from coercion is known as learning interest (Akinpelu et al., 2025). hen students use GeoGebra to learn mathematics, their confidence in the subject increases and they become more motivated (Uwurukundo et al., 2022). According to earlier studies, it is advised to use dynamic software like GeoGebra as an auxiliary tool to supplement mathematics instruction, particularly in geometry,

Similar research was previously conducted by Primasatya and Jatmiko (2018) to examine the influence of the Van Hiele theory on geometry learning among fifth-grade elementary school students. The study revealed a significant difference in geometry learning outcomes between the group of students taught using the Van Hiele theory and those taught through conventional methods. The average score of the students in the experimental group was 42.48 points higher than that of the control group. Another study was carried out (Budiman & Rosmiati, 2020), which investigated the enhancement of mathematical reasoning abilities in eighth-grade junior high school students through the application of the Van Hiele learning theory supported by GeoGebra in learning geometric concepts. The results of this study also indicated that students in the experimental group generally demonstrated higher mathematical reasoning abilities compared to those in other classes.

The most recent study on the use of the Van Hiele learning theory supported by the GeoGebra application was conducted by Prastyo (2020): *Van Hiele Learning Theory Supported by GeoGebra to Improve Mathematical Representation Ability of Eighth Grade Students at SMP Negeri*. The findings concluded that students' mathematical representation abilities increased from an average score of 48.8 (*low category*) to 87.25 (*high category*) following the implementation of the Van Hiele theory with the support of GeoGebra. This study was conducted to examine whether the Van Hiele learning theory, supported by the GeoGebra application, can also enhance students' mathematical abilities in a specific sub-topic of geometry, namely geometric transformations. In this topic, students are not only expected to identify the elements of a geometric object, but also to observe and analyze the changes that occur when an object is transformed.

Geometric transformations are operations performed on geometric representations of things to change their size, orientation, or location (Hearn, Baker, & Carithers, 2010). The study of geometric transformations essentially examines how shifts, multiplications, rotations, and reflections alter an object's position, size, and even shape. Due to students' limited visualization skills and the need to memorize numerous formulas, many students struggle with conceptual understanding, logical thinking, and problem-solving in this area. Moreover, without visual aids, students may find it difficult to visualize the objects and their transformations involved in the given problems. A high level of visualization is necessary for students to effectively represent the results of transformations. Ultimately, teachers must provide repeated explanations and utilize visual aids or media to effectively demonstrate the processes and outcomes of geometric transformations.

Geometric transformations are taught in phase D of the Merdeka Curriculum with the learning outcome of students being able to perform single transformations (reflections, translations, rotations, and dilations) on points, lines, and plane Pictures in the Cartesian coordinate system and apply them to problem-solving (Badan Standar Kurikulum dan Asesmen Pendidikan, 2022). Conventionally, teachers typically begin by explaining the objects that will undergo transformation, such as points, lines, planes, and three-dimensional shapes. They then demonstrate the transformation process using sketches on the board and simple calculations involving translation, dilation, reflection, and rotation based on given problems. Afterward, students are assigned problems and expected to solve them by applying the concepts that have been taught. Teachers anticipate that students will be able to solve these problems using the provided concepts. However, a common challenge faced by educators is the lack of available teaching aids or tools that can effectively illustrate the concepts of geometric transformation. Additionally, teachers find it challenging to describe the transformation process using only drawings or graphs because pupils frequently struggle with spatial representation (Siagian et al., 2023). By employing Van Hiele's learning theory, it is expected that students' conceptual understanding of geometry, particularly geometric transformations, can be gradually constructed. Without a strong conceptual understanding, it's challenging for students to solve geometric transformation problems. Effective conceptual understanding involves higher-order thinking processes and facilitates problem-solving in mathematics.

The author develops the Student Worksheet (LKPD) in accordance with the learning outcomes outlined in the *Merdeka Curriculum*, following the sequential stages of Van Hiele's Theory as follows: (a) At the visualization stage, students can recognize different types of geometric transformations applied to objects without understanding their properties, (b) At the analysis stage, students can identify the properties of transformations (reflection, translation, rotation, and dilation), although they may not yet be able to formally and accurately classify them, (c) At the deduction stage, students can observe the relationships within transformation processes and directly identify the changes that occur in geometric objects during transformations, and (d) At the rigor stage, students can solve problems using advanced reasoning and accurate calculations. The subtopics covered include translation, reflection, rotation, and dilation, each applied to points, lines, plane Pictures, and three-dimensional shapes. Enrichment problems will be provided with solutions that involve either the use of GeoGebra or purely manual computations.

In every learning process, teachers emphasize students' mastery of concepts. A strong conceptual understanding facilitates higher-order thinking and enables students to solve mathematical problems more effectively. The ability of students to participate in learning activities is typically used to gauge the effectiveness of the learning process, especially in mathematics. When pupils show understanding and receive high final scores, this achievement is clear. Higher learning achievement indicates an improved understanding and mastery of the subject matter, leading to better learning outcomes (Schneider & Preckel, 2017). This study's major goal is to measure how incorporating Van Hiele's learning theory with GeoGebra affects students' conceptual grasp of mathematics, particularly in the area of geometric transformations in the junior high school curriculum. Furthermore, this study seeks to offer students direct, hands-on learning opportunities and to provide valuable insights that can enhance the overall quality of mathematics education for both students and educators.

Research Methods

This study employed a mixed-methods research approach, which combines both quantitative and qualitative research methods. Harvard states that mixed-methods research involves the integration of two approaches qualitative methods to answer the question “What” and quantitative methods to address the question “How” within a single research project (Pluye & Hong, 2014).

The subjects of this study were 55 students in grade nine at a private school in Papua Barat Daya province. They were divided into two groups: the experimental class, which consisted of 27 students who received Van Hiele theory level learning assisted by the Geogebra application, and the control class, which consisted of 28 students who used conventional learning. In the first analysis, descriptive statistics will be produced for the pre-test scores of both the control and experimental groups. To further confirm that the two groups' skills are comparable or not substantially different, normality tests, homogeneity tests, and independent samples t-tests will be conducted. This will make the groups appropriate for use as study samples (Kim & Park, 2019). In order to ascertain the impact of the treatment on each group's students' mathematical comprehension, a paired samples t-test using dependent data will then be employed to investigate the variation of mean scores between the tests for both the experimental and control groups to determine the effectiveness of the treatment given on students' mathematical comprehension in each group.The typical feature of paired instances is that a single person (research subject) receives two distinct treatments. Despite using the same subject, the researcher collects two sets of sample data: data from the first and second treatment (Montolalu & Langi, 2018). Furthermore, to determine whether the treatment had a significant impact, an independent samples t-test will be conducted using the post-test scores of the control and experimental groups. However, since the t-test can only be used if the sample data is normally distributed and homogeneous, normality and homogeneity tests will be performed beforehand. The statistical formula employed for conducting hypothesis testing on paired samples (dependent sample) is as follows:

$$t = \frac{\bar{d} - \mu_D}{S_d/\sqrt{n}}$$

where $\bar{d}$ is mean of the differences between paired observations, where each difference is calculated as $d_i = x_i - y_i$, μ_D is population mean difference under the null hypothesis (commonly assumed to be 0 when testing for no difference), S_d is the standard deviation of differences between paired data values and n is number of paired observations. Furthermore the The test statistic used in testing the difference between means (independent sample) is calculated as follows:

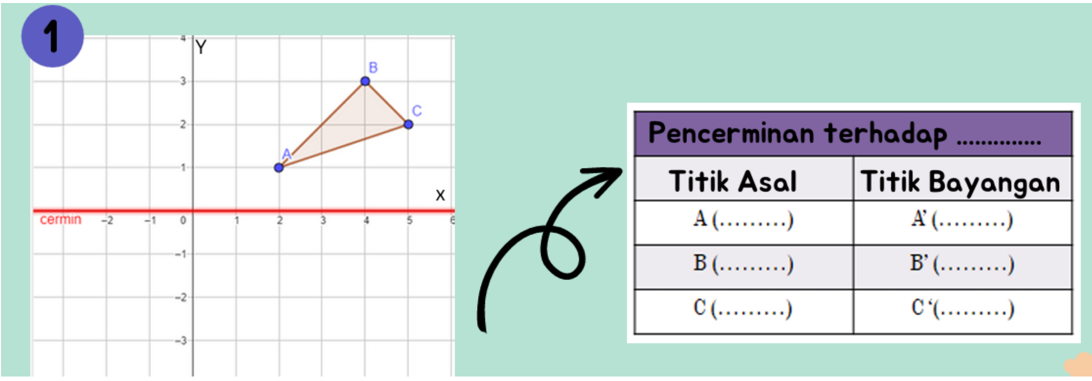
$$t = \frac{\bar{x}_1 - \bar{x}_2}{S\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$$

where $\bar{x}_1$ is the post-test mean score of the experimental group, $\bar{x}_2$ is the post-test mean score of the control group, n_1 is the number of subjects in experimental group, n_2 is the number of subjects in the control group and S denotes the pooled standard deviation.

Results and Discussions

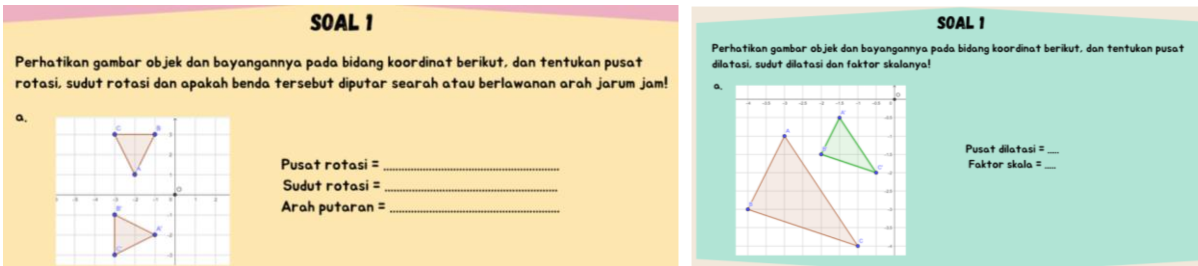
To support learning process with GeoGebra in the classroom, the researcher provides a learning module containing content on understanding the concept of geometric transformations, steps for using GeoGebra features to perform transformations of points, lines, and shapes as needed by students, followed by exercises from the module developed by the researcher. During the exercise session, guidance is provided to assist students in solving the problems. Feedback is given throughout the problem-solving process to ensure that students receive input for evaluating their answers, allowing them to make corrections and arrive at the correct solutions. Visually, GeoGebra provides a comprehensive representation of the required geometric objects. For instance, in line translation, students can create a line using the line feature from specific coordinate points, or they can utilize a given line equation to then perform the translation. Nevertheless, students in both classes are provided with the same quality of feedback and evaluation from the teacher to maintain the validity of the research results.

The Student Worksheet (LKPD) was validated by the school principal and mathematics teachers in terms of content, activities, language, and time allocation. The validation results indicated that the LKPD was deemed suitable for use, either with revisions or without revisions. In the LKPD, the author provides stimulating questions for each subtopic, along with systematically structured activities that progress according to the levels of the learning theory, ranging from 0 to 4. An example of a stimulus question in the dilation subtopic is: *"You have probably engaged in simple photography activities, such as taking formal pictures for school-related documents, including educational reports, student ID cards, or school profile requirements. Often, these photographs are printed in different sizes, such as 2×3, 3×4, or 4×6. Did you know that the difference in photo sizes is achieved using the concept of geometric transformation? What changes occur in the geometric object in this case, the photo?"*. Another example of a stimulus question related to reflection is: *"Have you ever looked at yourself in a mirror? When you do, observe yourself and your reflection. Do they have the same shape and size? Also, pay attention to the distance between yourself and the mirror. Is it the same as the distance between your reflection and the mirror?"*. In the first stage, namely visualization, students are presented with images of geometric object transformations and are asked to choose which type of geometric transformation is represented. Followed by questions at the analysis level to begin intuitively identifying the properties or elements present in a particular transformation.



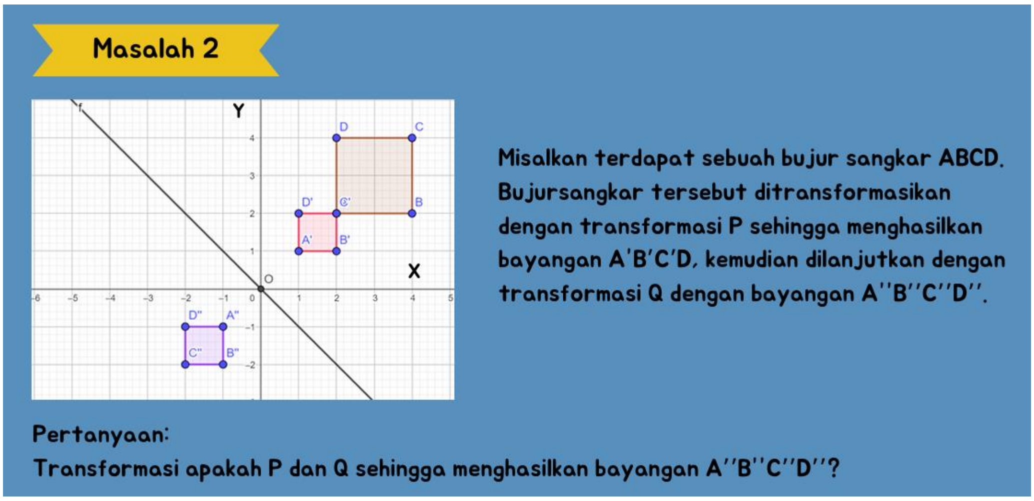
Picture 1. Example of activity at analysis level on the topic of reflection.

At the beginning of the introduction to GeoGebra, students experienced difficulties in recognizing its features. They were then guided through a tutorial provided in the LKPD, which included tasks such as rotating an object by determining the center of rotation, inputting the rotation angle, and specifying the direction of rotation. This process implicitly led students to identify the essential elements required for performing a rotation, thereby enhancing their understanding of the concept. Furthermore, the visualization of rotation was facilitated by the slider feature, allowing students to observe the object's rotation automatically without spending time manually drawing or merely imagining the transformation. Another conceptual understanding of dilation explored by the researcher through LKPD activities with GeoGebra involves presenting an image of a triangle along with its transformed image. Visually, students are instructed by the teacher to determine the center of dilation and then identify the scale factor using the given coordinate points. Similarly, in the translation subtopic, when a geometric object is displayed in GeoGebra, students need to determine from where the line should be drawn from the object's original position to its image using the line feature. They then analyze the displacement by identifying shifts to the left or right along the drawn line.



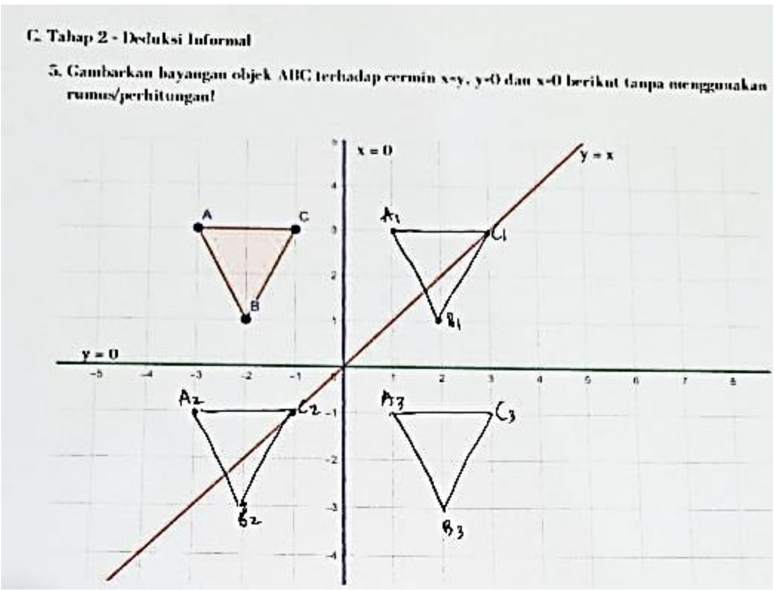
Picture 2. Example of questions at rigor levels on the topic of reflection and dilation.

In other subtopics, such as translation and dilation, students utilized GeoGebra's features to observe changes in the position and shape of objects along with their transformed images. This was accompanied by teacher-led questions, such as identifying the changes in the object, determining the extent of its displacement, and analyzing how many times the object's size increased or decreased. These prompts encouraged students to engage in higher-order thinking and critically analyze the transformations. When linked to manual calculations using formulas for each transformation type, students could relate their visual observations to the mathematical computations, rather than merely memorizing formulas presented in a table. A related research done by Hedi Budiaman and Mia Rosmiati, which evaluated the evolution of computer technology using GeoGebra software found that GeoGebra enables simple visualizations that can help enhance students' mathematical reasoning skills (Budiman & Rosmiati, 2020).



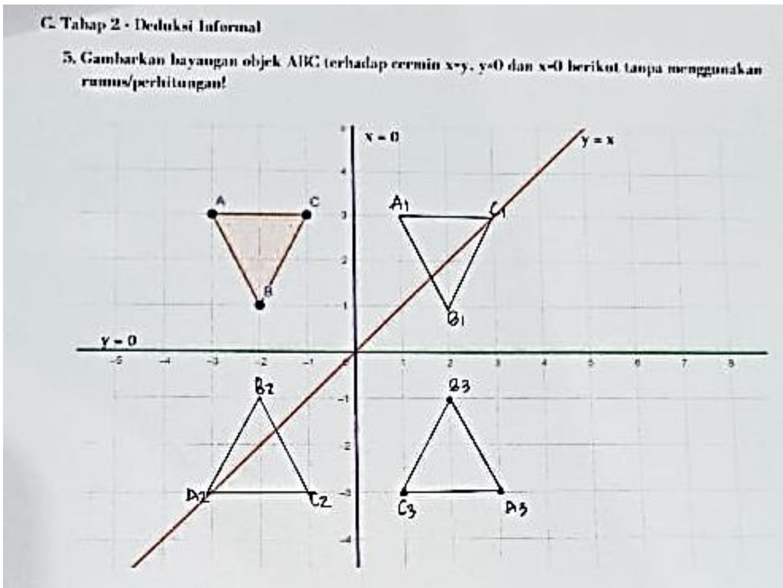
Picture 3. Example of questions at visualization and rigor levels on the topic of dilation.

Below is the answer sheet from the pre-test of one student at the informal deduction stage.



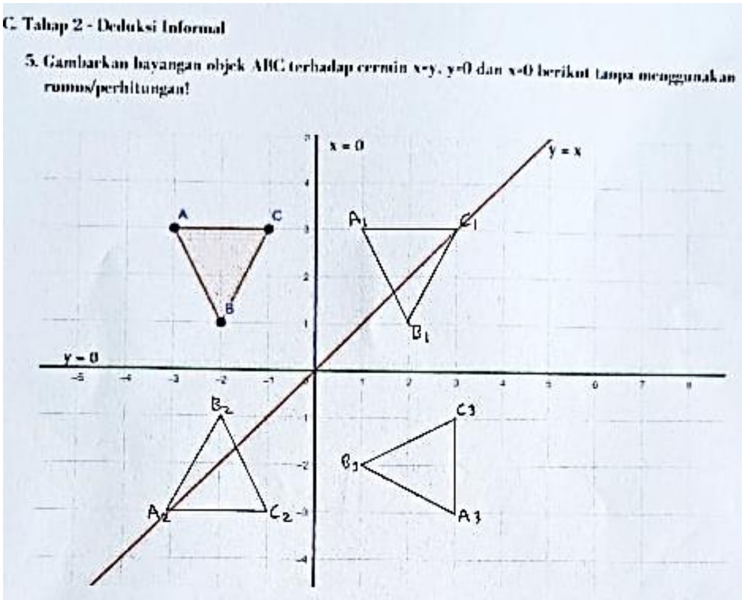
Picture 4. Pre-test result at the informal deduction stage of Student 1

The student appeared to have not yet understood the properties of reflection. They were unable to correctly solve problems involving reflection over the line *y = 0* and the line *y = x*. This can be compared with the student's work on the post-test in both classes.



Picture 5. Post-test result at the informal deduction stage of Student 1 from the control class

As shown in Picture 5, after receiving instruction on geometric transformations through conventional teaching methods, Student 1 who previously did not understand reflections over the lines *y = 0* and *y = x* began to show improvement in solving related problems. The student was able to accurately draw the image of an object reflected over the line *y = 0*, but still struggled to correctly represent the reflection over the line *y = x*.



Picture 6. Post-test result at the informal deduction stage of Student 2 from the experimental class

Meanwhile, as shown in Picture 6 above, a student from the experimental class was able to correctly solve reflection problems over the lines $x = 0$, $y = 0$, and $y = x$. Without using reflection formulas, the student accurately connected the given problems with the properties of transformations in accordance with the Van Hiele level of understanding. A student categorized at the visualization level (level 0) mentioned during the interview, "Using GeoGebra helped me see the object moving, but I still need help understanding what kind of transformation happened." This illustrates that while the tool enhanced their spatial visualization, conceptual clarity was still developing.

Another student at the abstraction level (level 2) reflected, "I now understand how reflection and rotation have specific rules. GeoGebra helped me try different options until I got the right one, and that made me remember better." Their post-test answers showed improved identification of transformation properties and more accurate sketching of images. In contrast, a high-achieving student at the rigor level (level 4) explained, "I didn't memorize the formulas. Instead, I could use GeoGebra to test patterns, then confirm the formula from what I saw." Their answer sheet demonstrated the ability to solve complex transformation problems using deductive reasoning without relying solely on rote formulas.

The experimental class's scores, the control class's pre-test results, the experimental class's post-test results, and the control class's post-test results are among the data gathered from the learning outcomes. Prior to being given to the students, the test items were validated and tested for reliability using a pilot class. There were ten questions on the pre-test and post-test. The item specifications can be found in Table 1.

Table 1. Spesification of pre-test and post-test question table

Questions Numbers	Types of Question	Levels of Teori Van Hiele
1	Short answer	Level 0 - Visualization
2	Short answer	Level 0 - Visualization
3	Marking	Level 1 - Analysis
4	Short answer	Level 1 - Analysis
5	Making sketch	Level 2 - Abstraction
6	Essay	Level 2 - Abstraction
7	Essay	Level 3 - Deduction
8	Essay	Level 3 - Deduction
9	Essay	Level 4 - Rigor
10	Essay	Level 4 - Rigor

Table 2 displays the item validity and reliability results based on the pilot testing that was done and the data analysis that was done using SPSS version 26.

Table 2. Table of questions validity result

Questions Numbers	r_{value}	Description
1	0,697	valid
2	0,610	valid
3	0,946	valid
4	0,864	valid
5	0,842	valid
6	0,376	valid
7	0,781	valid
8	0,784	valid
9	0,646	valid
10	0,470	valid

With 0,374 as r_{table}, the item analysis showed a correlation between individual item scores and the overall score, indicating that each item is valid by the value of $r_{value} > r_{table}$. A reliability test was performed to further confirm the questions' dependability, and the results are displayed in Table 3.

Table 3. Table of questions validity result

Questions Numbers	Coefficient of Cronbach's Alpha	Description
1	0,865	Reliable
2	0,871	Reliable
3	0,835	Reliable
4	0,849	Reliable
5	0,856	Reliable
6	0,893	Reliable
7	0,859	Reliable
8	0,862	Reliable
9	0,869	Reliable
10	0,884	Reliable

Table 3 shows Cronbach's Alpha values more than 0.7, showing the strong dependability of each item (Kusnendi, 2008). Given the validity and reliability of the items, they can be used as a reliable measurement tool in this study. The learning outcomes were analyzed based on the levels of Van Hiele's learning theory: level 0 (Visualization), level 1 (Analysis), level 2 (Abstraction), level 3 (Deduction), and level 4 (Rigor). The following section also presents a descriptive examination of the students' pre-test and post-test outcomes at each level of ability using the Van Hiele learning theory for both the control and experimental class.

Table 4. Pre-test and post-test findings for each level of Van Hiele's learning theory were descriptively analyzed for students in the experimental group using SPSS

Descriptive Statistics							
	N	**Range**	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**	**Variance**
Stage 0 Pretest Score	27	7	0	7	3.11	1.577	2.487
Stage 0 Posttest Score	27	8	6	14	9.70	3.061	9.370
Stage 1 Pretest Score	27	6	0	6	2.89	2.276	5.179
Stage 1 Posttest Score	27	15	6	21	12.44	5.983	35.795
Stage 2 Pretest Score	27	12	0	12	4.15	3.759	14.131
Stage 2 Posttest Score	27	20	8	28	14.22	6.110	37.333
Stage 3 Pretest Score	27	8	0	8	3.04	2.738	7.499
Stage 3 Posttest Score	27	30	2	32	10.44	7.511	56.410
Stage 4 Pretest Score	27	8	0	8	2.59	2.845	8.097
Stage 4 Posttest Score	27	16	2	18	6.85	5.238	27.439

Table 5. Pre-test and post-test findings for each level of Van Hiele's learning theory were descriptively analyzed for students in the control group using SPSS

Descriptive Statistics							
	N	**Range**	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**	**Variance**
Stage 0 Pretest Score	28	6	1	7	3.32	1.565	2.448
Stage 0 Posttest Score	28	7	7	14	9.61	2.097	4.396
Stage 1 Pretest Score	28	6	0	6	3.00	2.000	4.000
Stage 1 Posttest Score	28	6	6	12	8.82	2.816	7.930
Stage 2 Pretest Score	28	12	0	12	3.86	3.525	12.423
Stage 2 Posttest Score	28	12	8	20	11.14	3.979	15.831
Stage 3 Pretest Score	28	8	0	8	3.43	2.659	7.069
Stage 3 Posttest Score	28	20	0	20	6.36	4.990	24.905
Stage 4 Pretest Score	28	7	0	7	2.36	2.248	5.053
Stage 4 Posttest Score	28	8	0	8	3.36	3.058	9.349

Table 4 and 5 show a descriptive difference in the mean scores of the pre-test and post-test between the experimental and control groups. The Shapiro-Wilk test was employed in this research using SPSS version 26. The null hypothesis (H_0) states that the sample comes from a normally distributed population, while the alternative hypothesis (H_1) states that the sample comes from a population that is not normally distributed. The results of the normality test can be seen in Table 6.

Table 6. Summary of normality test for pre-test and post-test scores of the experimental group according to the levels of Van Hiele's learning theory

Levels	Pretest		Posttest	
	df	Sig.	df	Sig.
Level 0 (Visualization)	27	0,34	27	0.01
Level 1 (Analysis)	27	0,00	27	0.00
Level 2 (Abstraction)	27	0,01	27	0.02
Level 3 (Deduction)	27	0,01	27	0.00
Level 4 (Rigor)	27	0,00	27	0.00

Table 6 shows that only one dataset exhibits a normal distribution, namely the pre-test scores at level 0. Significant results below 0.05 suggest that the remaining datasets do not have a normal distribution. Table 7 presents a summary of the normality test for pre-test and post-test scores of the control group according to Van Hiele's learning theory's level.

Table 7. Summary of normality test for pre-test and post-test scores of the control group according to the levels of Van Hiele's learning theory

Levels	Pretest		Posttest	
	df	Sig.	df	Sig.
0 - Visualization	28	0,038	28	0.033
1 - Analysis	28	0,00	28	0.00
2 - Abstraction	28	0,00	28	0.00
3 - Deduction	28	0,011	28	0.0034
4 - Rigor	28	0,001	28	0.001

Table 8 shows that none of the data groups exhibit a normal distribution, as indicated by significance values less than 0.05. Given that all pre-test and post-test scores in both groups are not normally distributed, nonparametric statistics will be used to investigate the impact of Van Hiele's learning theory on students' conceptual understanding. The Wilcoxon signed-rank test will be employed to compare the paired mean differences between pre-test and post-test scores in both the experimental and control groups, while mean ranks of the post-test scores between the two groups compared using the Mann-Whitney U test.

When data does not follow a normal distribution, the Wilcoxon test can be used as an alternative to the paired t-test. The Wilcoxon test is a non-parametric statistical method, which is a distribution-free statistical approach since its test model does not impose specific assumptions about the distribution shape of the population parameters. There is no requirement for the sample to be drawn from a normally distributed and homogeneous population (BUDIONO & Prasetia, 2022). The statistical hypotheses for this test are H_0 and H_1. This test will be conducted twice, once for the experimental group and once for the control group. The results of the Wilcoxon signed-rank test for comparing the mean ranks of pre-test and post-test scores in the experimental group are presented in Table 8.

Table 8. Summary of normality test for pre-test and post-test scores of the experimental group according to the levels of Van Hiele's learning theory level

	Stage 0 Posttest Score - Stage 0 Pretest Score	**Stage 1 Posttest Score - Stage 1 Pretest Score**	**Stage 2 Posttest Score - Stage 2 Pretest Score**	**Stage 3 Posttest Score - Stage 3 Pretest Score**	**Stage 4 Posttest Score - Stage 4 Pretest Score**
Z	-4.470	-4.481	-4.217	-4.306	-3.822
Asymp. Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000

All Wilcoxon test results for each level shows that *Asymp Sig.(2-tailed)=0.00<0.05* therefore H_1 is accepted, meaning that the experimental group's mean scores on the pre-test and post-test differ significantly. Subsequently, the mean ranks of the pre-test and post-test results in the control group were compared using a Mann-Whitney U test. scores in the control group. The results are presented in Table 9.

Table 9. Summary of paired-samples t-test for pre-test and post-test scores in the control group at each level of Van Hiele's theory

	Stage 0 Posttest Score - Stage 0 Pretest Score	**Stage 1 Posttest Score - Stage 1 Pretest Score**	**Stage 2 Posttest Score - Stage 2 Pretest Score**	**Stage 3 Posttest Score - Stage 3 Pretest Score**	**Stage 4 Posttest Score - Stage 4 Pretest Score**
Z	-4.634	-4.412	-4.603	-3.621	-2.539
Asymp. Sig. (2-tailed)	.000	.000	.000	.000	.011

Wilcoxon test results of level 0 to level 3 shows the value of *Asymp Sig.(2-tailed) = 0.00 < 0.05* meanwhile on level 4 the value of *Asymp Sig.(2-tailed) = 0.0011 < 0.05* therefore H_1 is accepted, it indicates that the control group's mean scores from the pre-test and post-test differ significantly. Since the average post-test scores are higher than the pre-test scores, it can be concluded that each level of the Van Hiele learning theory, assisted by GeoGebra, can improve students' conceptual understanding.

The normality test revealed that the data for each level of the Van Hiele theory is not in the form of normal distribution. Therefore, a nonparametric test, the Mann-Whitney U test, was employed. This test was used to determine whether there was a significant difference in mathematical abilities between the experimental and control groups, thereby indicating the effectiveness of the Van Hiele learning theory. The null hypothesis for this test is (H_0) the mean post-test scores of the experimental group are equal to the mean post-test scores of the control group, implying that there is no significant effect of the Van Hiele learning theory on students' mathematical understanding. Meanwhile, (H_1) states that the mean post-test scores of the experimental group are not equal to the mean post-test scores of the control group, indicating a significant effect of the Van Hiele learning theory on students' mathematical understanding. The results of the Mann-Whitney U test comparing the pre-test and post-test scores in the experimental group are presented in Table 10.

Table 10. Summary of the independent samples t-test for mean scores between the experimental and control groups on each level of Van Hiele's theory

Test type	***Asymp Sig. (2-tailed)***
0 - Visualization	0.759
1 - Analysis	0.05
2 - Abstraction	0.054
3 - Deduction	0.03
4 - Rigor	0.015

At level 0, the significance value of 0.759 is greater than 0.05; at level 1, the significance value is 0.05; and at level 2, the significance value of 0.054 is greater than 0.05. This indicates that the conceptual understanding of students in the experimental group at these initial three levels is not significantly different from that of the control group. In other words, the Van Hiele learning theory did not have a significant impact on students' mathematical understanding at these levels. However, at level 3, the significance value of 0.03 is less than 0.05, and at level 4, the significance value of 0.015 is also less than 0.05. Furthermore, considering the higher mean post-test scores of the experimental group compared to the control group. Consequently, it shows that the conceptual understanding of students in the experimental group at the final two levels is significantly higher than that of the control group. This implies that the Van Hiele learning theory has a significant effect on improving students' mathematical understanding.

Conclusions and Suggestions

Based on the quantitative and qualitative analysis of students' pre-test and post-test data at each level of Van Hiele's theory, it can be concluded that the implementation of the Van Hiele learning theory assisted by the GeoGebra application has a significant impact on improving students' conceptual understanding in the topic of geometric transformations, particularly at the deduction (level 3) and rigor (level 4) levels. This is evidenced by the results of the Mann-Whitney U test, which indicated a statistically significant difference between the experimental and control groups at these two levels. At the lower levels (visualization, analysis, and abstraction), although both groups showed an increase in scores, the differences between the groups were not statistically significant. This suggests that at the initial stages, conventional approaches may still contribute to the development of conceptual understanding. However, the integration of Van Hiele's theory with GeoGebra proved to be highly effective in promoting higher-order thinking skills, particularly in constructing deductive reasoning and solving problems analytically and systematically. This indicates a significant impact of implementing the Van Hiele learning theory with GeoGebra on enhancing students' mathematical conceptual understanding.

This study aimed to investigate students' conceptual understanding of transformation geometry based on Van Hiele's levels, using GeoGebra as a technological aid. When comparing the test scores of students who used GeoGebra (experimental group) to those who did not (control group), the study found that the experimental group performed significantly better. This indicates that applying the Van Hiele theory with GeoGebra was effective in enhancing students' understanding of transformation geometry. Both the experimental and control groups showed improvement from the pre-test to the post-test. However, the experimental group demonstrated more substantial progress, particularly at the higher Van Hiele levels of geometric thinking. The use of GeoGebra enabled students to better visualize and engage with geometric transformations, facilitating deeper conceptual learning. Overall, the findings of this study address the research question by confirming that the application of the Van Hiele-based instructional approach integrated with GeoGebra significantly enhances students' conceptual understanding in learning geometric transformations compared to conventional methods. These results support the use of dynamic visual technology in mathematics instruction and recommend the broader implementation of this approach in secondary geometry education.

In conclusion, the integration of GeoGebra with the Van Hiele learning model proved to be more effective than conventional methods. Students who learned through this approach showed greater improvement in their conceptual understanding of transformation geometry compared to those taught using traditional instruction.

Acknowledgements

The researcher is grateful to thank all parties involved with the participants and their assistance throughout the research process in successfully conducting and completing this study.

References

Akinpelu, G. A., Akinpelu, S. A., Folorunsho, M. S., Ameen, K. S., Adebayo, S. R., & Daramola, C. Y. (2025). Impact of mastery learning instructional scheme on post-basic school students' engagement levels in mathematics in Osogbo, Nigeria. *Discover Education*, *4*(1), 1–18. https://doi.org/10.1007/s44217-025-00535-1

Arbain, N., & Shukor, N. A. (2015). The effects of GeoGebra on students achievement. *Procedia-Social and Behavioral Sciences*, *172*(1), 208–214. https://doi.org/10.1016/j.sbspro.2015.01.356

Badan Standar Kurikulum dan Asesmen Pendidikan. (2022). Capaian pembelajaran mata pelajaran matematika fase A - fase F [Learning outcomes for mathematics subjects phase A - phase F]. *Kementrian Pendidikan Dan Kebudayaan Riset Dan Teknologi Republik Indonesia*, 11–12.

Budiman, H., & Rosmiati, M. (2020). Penerapan teori belajar van hiele berbantuan geogebra untuk meningkatkan kemampuan penalaran matematis siswa [Application of Van Hiele's learning theory assisted by Geogebra to improve students' mathematical reasoning abilities]. *Prisma*, *9*(1), 47.

https://doi.org/10.35194/jp.v9i1.845

Budiono, & Prasetia, A. (2022). Studi perbandingan hasil uji Wilcoxon pada data hasil pengukuran dan hasil kategori data penelitian kesehatan tingkat stress tekanan darah dan motorik halus [Comparative study of the results of the Wilcoxon test on measurement data and the results of health research data categories on stress levels, blood pressure and fine motor skills]. *Jurnal Ilmiah Pamenang*, *4*(2), 8–15. https://doi.org/10.53599/jip.v4i2.94

Ghorbani, M., Izadi, F. S., Roshan, S. S., & Ebrahimpour, R. (2023). Assessing prospective teachers' geometric transformations thinking: A Van Hiele theory-based analysis with eye tracking cognitive science method. *Technology of Education Journal (TEJ)*, *18*(1), 67–88. https://doi.org/10.22061/tej.2023.10350.2997

Gradini, E., Noviani, J., & Ulya, K. (2025). Fostering higher-order thinking skills in mathematics education: Strategies, challenges, and classroom practices. *Prisma Sains: Jurnal Pengkajian Ilmu Dan Pembelajaran Matematika Dan IPA IKIP Mataram*, *13*(2), 135–163. https://doi.org/10.33394/j-ps.v13i2.15099

Handayani, E. D., Kusnawati, E., Sari, N. M., Yaniawati, P., & Zulkarnaen, M. I. (2022). Implementation of geogebra-assisted creative problem-solving model to improve problem solving ability and learning interest students. *Al-Jabar: Jurnal Pendidikan Matematika*, *13*(1), 33–48. https://doi.org/10.24042/ajpm.v13i1.11341

Hearn, D. D., Baker, M. P., & Carithers, W. (2010). *Computer graphics with open GL. Prentice Hall Press.*

Kemendikbud. (2019). Peraturan Menteri Pendidikan dan Kebudayaan Republik Indonesia nomor 6 tahun 2019 tentang pedoman organisasi dan tata kerja satuan pendidikan dasar dan menengah [Regulation of the Minister of Education and Culture of the Republic of Indonesia Number 6 of 2019 concerning guidelines for the organization and work procedures of elementary and secondary education units]. *Peraturan Menteri Pendidikan Dan Kebudayaan Republik Indonesia*.

Kemendikbud, K. P. dan K. (2025). *Hasil UN - pusat asesmen dan pembelajaran [UN Results - assessment and learning center]*. Pusat Asesmen Dan Pembelajaran (Pusmenjar).

Kemendikbudristek. (2024). *Peraturan Menteri Pendidikan, Kebudayan, Riset, dan Teknologi Nomor 032/H/KR/2024 [Regulation of the Minister of Education, Culture, Research, and Technology Number 032/H/KR/2024]* (Issue 021).

Kim, T. K., & Park, J. H. (2019). More about the basic assumptions of t-test: normality and sample size. *Korean Journal of Anesthesiology*, *72*(4), 331–335. https://doi.org/10.4097/kja.d.18.00292

Kusnendi, M. S. (2008). *Model-model persamaan struktural [Structural equation models].* Alfabeta.

Mahlaba, S. C., & Mudaly, V. (2022). Exploring the relationship between commognition and the Van Hiele theory for studying problem-solving discourse in Euclidean geometry education. *Pythagoras*, *43*(1), 1–11. https://doi.org/10.4102/pythagoras.v43i1.659

Mega, C., Ronconi, L., & De Beni, R. (2014). What makes a good student? How emotions, self-regulated learning, and motivation contribute to academic achievement. *Journal of Educational Psychology*, *106*(1), 121. https://doi.org/10.1037/a0033546

Montolalu, C., & Langi, Y. (2018). Pengaruh pelatihan dasar komputer dan teknologi informasi bagi guru-guru dengan uji-T berpasangan (paired sample T-test) [The effect of basic computer and information technology training for teachers using paired sample T-test]. *D'CARTESIAN*, *7*(1), 44. https://doi.org/10.35799/dc.7.1.2018.20113

Nurjaman, A., & Sari, I. P. (2017). The effect of problem posing approach towards students' mathematical disposition, critical & creative thinking ability based on school level. *Infinity Journal*. https://doi.org/10.22460/infinity.v6i1.223

OECD. (2023). *PISA 2022 Results (Volume II)*. OECD. https://doi.org/10.1787/a97db61c-en

Permendikbudristek. (2022). P Peraturan menteri pendidikan kebudayaan riset dan teknologi tentang standar proses pada pendidikan usia dini, jenjang pendidikan dasar dan jenjang pendidikan menengah [Regulation of the Minister of Education, Culture, Research and Technology concerning process standards in early childhood education, elementary education and secondary education]. *Peraturan Menteri Pendidikan Dan Kebudayaan Republik Indonesia Nomor 16 Tahun 2022 Tentang Standar Proses Pendidikan Dasar Dan Menengah*, *1*(69), 5–24.

Pluye, P., & Hong, Q. N. (2014). Combining the power of stories and the power of numbers: mixed methods research and mixed studies reviews. *Annual Review of Public Health*, *35*(1), 29–45. https://doi.org/10.1146/annurev-publhealth-032013-182440

Prastyo, H. (2020). Kemampuan matematika siswa indonesia berdasarkan TIMSS [Indonesian students' mathematical abilities based on TIMSS]. *Jurnal Padegogik*, *3*(2), 111–117. https://doi.org/10.35974/jpd.v3i2.2367

Primasatya, N., & Jatmiko, J. (2018). Implementation of geometry multimedia based on van Hiele's thinking theory for enhancing critical thinking ability for grade v students. *International Journal of Trends in Mathematics Education Research*, *1*(2), 56–59. https://doi.org/10.33122/ijtmer.v1i2.40

Radović, S., Radojičić, M., Veljković, K., & Marić, M. (2020). Examining the effects of Geogebra applets on mathematics learning using interactive mathematics textbook. *Interactive Learning Environments*, *28*(1), 32–49. https://doi.org/10.1080/10494820.2018.1512001

Schneider, M., & Preckel, F. (2017). Variables associated with achievement in higher education: A systematic review of meta-analyses. *Psychological Bulletin*, *143*(6), 565. https://doi.org/10.1037/bul0000098

Siagian, T. A., Sumardi, H., Bimansah, R., & Nesta, R. A. (2023). *29218-Article Text-83318-97525-10-20240111*. *21*(02), 329–342.

TIMSS. (2023). TIMSS 2015. In *the OSCE Code of Conduct on Politico-Military Aspects of Security*.

Tohir, M. (2019). *Hasil PISA Indonesia Tahun 2018 [Indonesian PISA Results 2018]*. Paper of Matematohir.

Uwurukundo, M. S., Maniraho, J. F., & Tusiime, M. (2022). Enhancing students' attitudes in learning 3-dimension geometry using GeoGebra. *International Journal of Learning, Teaching and Educational Research*, *21*(6), 286–303. https://doi.org/10.26803/ijlter.21.6.17

Zulkardi, Z., Meryansumayeka, M., Putri, R. I. I., Alwi, Z., Nusantara, D. S., Ambarita, S. M., Maharani, Y., & Puspitasari, L. (2020). How students work with pisa-like mathematical tasks using covid-19 context. *Journal on Mathematics Education*, *11*(3), 405–416. https://doi.org/10.22342/jme.11.3.12915.405-416