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The Impact of GeoGebra and Augmented Reality (AR)-Assisted Geometry Teaching on Geometry Competence, 3D Thinking Competence, Retention, and Geometry Attitudes

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Abstract. This study aims to investigate the impact of GeoGebra and Augmented Reality (AR)-assisted geometry teaching on geometry competence, 3D thinking competence, retention, and attitudes toward geometry. A quasi-experimental method was used involving 220 university students who were divided into two groups with an equal number of 110 students each. The experimental group received the GeoGebra and AR-assisted geometry teaching intervention, while the control group received conventional textbooks. The instruments used in this study were a geometry competency test, a 3D thinking ability scale, a geometry attitude scale, and AR technology. The data analysis used regression tests, correlation tests, t-tests, and ANCOVA tests. The results of the study indicate that teaching geometry using the GeoGebra application and AR technology significantly improved geometric competence, geometric attitudes, memory, and 3D geometric thinking skills in each dimension. Improved geometric competence is evident in the understanding of geometric problem-solving concepts using formulas and calculations, such as area, sides, volume, and angles. Improved memory is evident in the ability to remember geometric problem-solving formulas, and the concepts and components of each geometric object. Improved geometric attitudes are evident in the increased student attention, curiosity, and participation in every learning moment. Improved 3D geometric thinking skills are evident in all dimensions. Therefore, the use of GeoGebra and AR in geometry teaching can improve problem-solving skills regarding formulas, memory, geometric attitudes, and 3D geometric thinking skills. This research implies that the use of AR

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technology in geometry learning can optimize students' spatial abilities, thereby contributing significantly to their 3D geometric thinking competencies.

Keywords: GeoGebra; 3D Geometry Thinking Skills; Augmented Reality (AR); Geometry Teaching; Geometry Competence; Retention; Geometry Attitude

1. Introduction

Traditional geometry instruction is currently considered incapable of facilitating students' acquisition of geometric competencies, particularly those related to geometry and 3D thinking (Mensah, 2025; Mjenda & Kyaruzi, 2025). These competencies require scaffolding that displays 3D geometric objects because it facilitates the students' understanding of the representation of the properties of geometric components. The display of 3D geometric objects significantly contributes to students' geometric competency, as well as their 3D thinking skills, memory, and geometric attitudes (Abdul Hanid et al., 2022; Romero et al., 2024).

The properties of geometric components, such as side length, number of sides, equal sides, and angle-side relationships, require adequate learning media due to their similarities. For example, a prism may have the same components as edges, angles, surfaces, and sides, but differ from other prisms. A major problem faced by students in learning geometry is the inability to identify the same edge components in a 3D object image and the lack of a comprehensive understanding of the component properties (Türkoğlu & Yalçınalp, 2024; Yiğit et al., 2024). One application that can be used in geometry learning is GeoGebra. GeoGebra is an interactive application that can display dynamic geometry and computer algebra in a single application. The GeoGebra application is a dynamic mathematics application used at various levels, from elementary school to university (Haataja et al., 2025; Walkington et al., 2025).

The GeoGebra application facilitates students' learning of geometry in a collaborative environment. The GeoGebra application helps learners understand geometry material through visualization, transforming concepts into more concrete ones. Previous studies have confirmed that the use of the GeoGebra application can provide learners with numerous opportunities to understand geometric concepts due to its dynamic nature (Sarah & Batiibwe, 2024; Turgut, 2022). The GeoGebra application provides opportunities for learners to interact with geometric objects, test conjectures, analyze geometric concepts, and verify the properties of relationships and geometry (Haataja et al., 2025; Walkington et al., 2025).

However, the GeoGebra application has a drawback: the geometric objects are still 2D, making the identification of edge, angle, surface, and side components difficult. The GeoGebra application focuses on creating geometric models of objects in the form of points, lines, vectors, and circles and connecting them with geometry, measurement, and algebra (Mosia et al., 2025; Ndagijimana et al., 2024). The shortcomings of the GeoGebra application can be complemented by AR

(Augmented Reality) technology that is able to visualize 3D geometry objects, thereby improving students' 3D thinking skills. The use of AR technology can improve 3D geometry thinking skills, specifically the understanding of properties and the components of 3D objects (Abdul Hanid et al., 2022; Mjenda & Kyaruzi, 2025). This competency contributes to the students' comparative abilities.

The use of GeoGebra and AR applications complement each other in geometry learning. The combination of these two technologies is believed to be able to improve geometric problem-solving competencies, including the understanding of 3D object nets, and the properties and components of 3D geometric objects (Haataja et al., 2025; Mosia & Oromena, 2025). Several previous studies have demonstrated the impact of integrating the GeoGebra application and AR technology in mathematics learning (Engelbrecht & Borba, 2024; Solano-macías, 2023). Previous studies have shown that the GeoGebra application significantly improves geometry problem solving because it displays problem-solving concepts concretely (Chytas et al., 2024; Geraniou et al., 2024).

Furthermore, other studies have confirmed that the use of AR can enhance students' imagination and creativity in understanding geometry material (Quarder et al., 2025; Weigand et al., 2024). Other studies have also confirmed that the use of AR can facilitate students' development of their own knowledge structures and encourage active participation, providing opportunities for individual and collaborative learning (Kus & Newcombe, 2025; Weigand et al., 2025). Most previous studies have investigated GeoGebra and AR-assisted geometry instruction related to geometry problem-solving competency and student motivation but have not yet addressed the areas of 3D geometric thinking skills, retention, and geometric attitudes. The novelty of this study is the combination of GeoGebra and AR virtual media, which facilitates the students' direct interaction with geometry materials. The targeted competencies are more comprehensive, including geometry competency, 3D thinking competency, retention, and attitudes toward geometry.

Based on this explanation, the researchers formulated the following research questions:

a) What is the impact of geometry instruction using the GeoGebra application and augmented reality (AR) on geometry competency, geometry attitudes, and retention?
b) What is the impact of geometry instruction using the GeoGebra application and augmented reality (AR) on 3D thinking skills?

2. Literature Review

2.1 Using Dynamic Geometry and GeoGebra Applications in Mathematics

Several applications can be used in geometry teaching, including Autograph, Cabri II, Cabri 3D, Coypu, Cinderella, Derive, Geometer's Sketchpad, Graphmatica, and GeoGebra. These dynamic geometry applications were developed to construct and manipulate geometric constructions interactively (Gurmu et al., 2024; Lotey et al., 2025). Dynamic geometry applications provide learners with the opportunity to construct geometric objects, measure geometric variables, determine properties, and navigate geometric objects (Abdul Hanid et al., 2022; Sarah & Batiibwe, 2024). The GeoGebra application is an interactive mathematics application that integrates algebraic and dynamic geometry features. The GeoGebra application has several features that facilitate learning, including geometry, algebra, and calculus. A key feature of GeoGebra in teaching geometry is its ability to create geometric models of objects such as points, lines, vectors, and circles, and to connect them to one another (Ayyıldız et al., 2025; Solano-macías, 2023). The construction of geometric objects can be freely modified and moved. Furthermore, the GeoGebra application can visualize various presentations such as algebra, graphs, and tables, and connect algebraic and geometric connections. The GeoGebra application provides opportunities for learners to interact with geometric objects, test conjectures, analyze geometric concepts, and verify the properties of relationships and geometry.

However, the GeoGebra application has a drawback: the geometric objects are still 2D, making it difficult to identify edges, angles, surfaces, and sides (Grigali, 2025; Quarder et al., 2025). The GeoGebra application focuses on creating geometric models of objects such as points, lines, vectors, and circles, and connecting them with geometry, measurement, and algebra (Huang et al., 2024; Weigand et al., 2025). The shortcomings of the GeoGebra application can be complemented by AR technology that is able to visualize 3D Geometry objects to improve learners' 3D thinking skills. These skills consist of six dimensions, namely the ability to recognize and create 3D geometric shapes, the ability to draw and interpret various 3D geometric displays, the ability to arrange 3D cube arrangements, the ability to determine 3D geometric properties and shapes, the ability to calculate 3D geometric volumes and areas, and the ability to compare 3D geometric features and shapes (Chytas et al., 2024; Kus & Newcombe, 2025).

2.2 3D Geometric Thinking Skills and AR Use

3D geometric thinking skills refer to the students' competencies when performing several required skills resulting from observing 3D geometric objects, such as explaining, arranging, determining, calculating, and comparing properties (Lee et al., 2023; Simsek et al., 2025). 3D geometric thinking skills encompass six dimensions: the ability to recognize and create 3D geometric shapes, the ability to draw and interpret various 3D geometric displays, the ability to construct 3D cube structures, the ability to determine 3D geometric properties and shapes, the ability to calculate 3D geometric volumes and areas, and the ability to compare 3D geometric features and shapes (Gurmu et al., 2024; Lotey et al., 2025).

The evaluation of 3D thinking skills covers six dimensions: the ability to identify 3D shapes, the ability to describe and interpret representations of various 3D geometric objects, the ability to construct 3D cubes, the ability to analyze the properties of 3D geometric shapes, the ability to calculate 3D geometric volumes and areas, and the ability to compare features of 3D geometric shapes (Baeta & Quaresma, 2023; Hovik & Nolan, 2024). Several previous studies have confirmed that improving 3D geometric thinking skills requires media or scaffolding that facilitates learners' direct observation and interactions with geometric objects, one of which is AR technology (Abdul Hanid et al., 2022; Romero et al., 2024). Previous studies have shown that AR-based geometry materials can improve students' geometric competence (Türkoğlu & Yalçınalp, 2024; Yiğit et al., 2024). Furthermore, AR-based geometry instruction not only solves geometric problems related to formulas but also improves geometric competence in forming and analyzing different geometric shapes.

3. Methodology

3.1 Design and Participants

The research method used in this study was a quasi-experimental study to investigate the impact of geometry instruction assisted by the GeoGebra application and Augmented Reality (AR) on improving students' geometric problem-solving, 3D geometric thinking skills, memory, and geometric attitudes. The participants in this study were 220 college students aged 19-26 years. The participants were divided into two groups with the same number of 110 students each, making up the experimental group and the control group. The experimental group received a geometry teaching intervention assisted by the GeoGebra application and Augmented Reality (AR), while the control group used conventional textbooks and regular geometry drawings. The gender percentage of the research participants was 55% female and 45% male. All participants involved in the study participated voluntarily because they filled out a consent form before participating.

3.2 Research Instrument

3.2.1 Geometry Competency Test

The geometry competency test was assessed using 25 multiple-choice questions on several geometric objects. The questions consisted of calculations involving various geometric objects such as cubes, prisms, cones, cylinders, and others. The geometry competency test focused on solving mathematical problems and tested the students' memory of various geometric object components, such as area, volume, length, and sides. The item difficulty index and reliability coefficient were calculated. The analysis showed that all items had a reliability coefficient of 0.86. Furthermore, the item reliability coefficients for the pretest, posttest, and retention test were 0.82, 0.87, and 0.80, respectively. The correlation coefficient was used to test validity. The analysis results showed an average Pearson correlation value for the rubric of 0.88. From these values, it can be concluded that the geometry competency items met the reliability and validity criteria and could therefore be used in the research.

3.2.2 Geometry Attitude Scale

To measure the students' geometry attitudes, the researchers used the geometry attitude scale developed by Walkington et al. (2025). This scale was developed to analyze learners' attitudes toward geometry. The geometry attitude scale consists of 25 items using a 5-point Likert scale ranging from 1 = strongly disagree to 5 = strongly agree. The geometry attitude scale consists of 16 negative statements and 9 positive statements. This scale has been tested for validity and reliability directly with students. The analysis results indicate that the item factor loadings range from 0.25 to 0.80, and that five subfactors contribute 60% of the total variance. Cronbach's alpha reliability coefficient was 0.92. This scale was used in the pretest and posttest phases. The reliability coefficients for the pretest and posttest phases were 0.91 and 0.94, respectively. The correlation coefficient was used to test validity. The analysis results showed an average Pearson correlation value of 0.93 for the rubric.

3.2.3 3D Geometry Thinking Skills Test

3D geometry skills were assessed using a geometry thinking assessment adapted from Pittalis, Mousoulides, and Christou. This geometric thinking assessment is conducted across six dimensions: the ability to identify and create 3D geometric shapes, the ability to draw and interpret various 3D geometric displays, the ability to arrange 3D cubes, the ability to determine 3D geometric properties and shapes, the ability to calculate 3D geometric volume and area, and the ability to compare 3D geometric features and shapes. An explanation of each dimension is presented in Table 1.

Table 1: Explanation of 3D geometric thinking skills

Number	3D Geometric Thinking Skills	Description
1	Skills in identifying and creating 3D geometric objects	Skills in recognizing and creating nets for 3D geometric objects and being able to construct these objects from nets.
2	Skills in describing and interpreting representations of various 3D geometric objects	Skills in drawing perpendicular or parallel projections of three-dimensional objects and transforming them into other shapes.
3	Skills in constructing 3D cube structures	Skills in calculating and using the cubes are needed to transform an object into a 3D prism and calculating the number of cubes that fit in an empty box.
4	Skills in recognizing the properties of 3D geometric objects	Skills in identifying and interpreting the properties and components of prisms and pyramids.
5	Skills in calculating the area and volume of 3D geometric objects	Skills in calculating the volume and surface area of unit objects and nets and comparing them with other objects.
6	Skills in comparing various 3D geometric features.	Skills in comparing the components and features of various 3D geometric shapes, such as angles, sides, and edges.

Analysis was performed on the difficulty index and discriminating power of the questions to assess 3D thinking skills, as presented in Table 2. The analysis found that the questions had an average difficulty level and a discriminating power value higher than 0.3. The geometric thinking skills questions also showed a P-value of 0.66, an average discriminant index (D) of 0.79, and a reliability coefficient of 0.845. The correlation coefficient used to test validity showed an average Pearson correlation value for the rubric of 0.90. Based on these analysis results, the higher-order thinking skills questions met the criteria for use in this research.

3.2.4 Augmented Reality (AR) Technology

The AR technology used also utilizes virtual buttons to facilitate students in transitioning between AR-based geometry materials. The transitions between material displays can be adjusted by the learner and can be accessed using a mobile phone, offering numerous visualization options. AR technology is also equipped with a matrix to optimize functions and virtual buttons for selecting geometry displays to be studied. In geometry learning with the aid of AR technology, learners can select the geometric objects they wish to study. They then interact with the geometric objects directly through the virtual buttons as desired. For example, in the geometry prism object material, students can control the prism's movement as desired and analyze the prism's net from various angles. Furthermore, students can navigate the prism's movement using virtual buttons.

3.3 Procedure

This study involved several stages. In the initial stage, all students took a pretest to determine their geometry skills, 3D geometric thinking skills, memory, and the attitudes toward 3D geometry in both groups. After ensuring that both groups had the same competencies, both groups received geometry teaching interventions according to their respective groups. The experimental group received geometry teaching interventions assisted by GeoGebra and AR technology, while the control group received geometry teaching interventions using textbooks and images.

During the intervention process, students were given instructions to carry out various activities to improve their geometry competencies (solving geometry problems), 3D thinking skills, memory, and geometric attitudes. 3D geometric thinking skills included identifying and creating 3D geometric shapes, drawing and interpreting various 3D geometric displays, arranging 3D cubes, determining 3D geometric properties and shapes, calculating 3D geometric volumes and areas, and comparing 3D geometric features and shapes. The geometry teaching intervention assisted by the GeoGebra and AR applications was carried out for one semester with three sessions per week. Each session was conducted with an orientation towards all competencies.

After the intervention was administered to both groups, all participants took a posttest to investigate geometric competence, 3D geometric thinking skills, memory, and geometric attitudes. The procedural stages in the control group were the same in terms of both the material and tests as the experimental group. The only difference was the media used, where the control group only used textbooks and regular pictures. The intervention was carried out for one semester or six months following the provisions of the university curriculum. All participant data is presented anonymously and used only for research purposes. The participants followed several stages.

3.4 Data Analysis

Several data analyses were used in this study, including ANCOVA, regression, t-test, and correlation tests to investigate the impact of the GeoGebra and AR-assisted geometry teaching intervention on geometry competency, 3D geometric thinking skills, memory, and geometry attitudes. ANCOVA tests were conducted to investigate the impact of the intervention on geometry competency and geometry attitudes in both phases. ANCOVA tests were also conducted to investigate the retention of the intervention results. To investigate the significance of the intervention's contribution to 3D geometric thinking competency, regression tests were conducted. T-tests were conducted to investigate the impact of the intervention on 3D thinking skills based on participant gender for each dimension of 3D geometric thinking skills. Finally, the ANCOVA tests were used to determine the impact of the intervention on 3D thinking skills competency for each dimension in both the pretest and posttest phases.

4. Result

Before conducting statistical tests, normality and homogeneity tests were conducted to ensure that geometry competency, memory, and attitudes met the criteria for normality and homogeneity. The results of the normality and homogeneity tests are presented in Table 2. The results of the analysis show that the skewness and kurtosis values are in the range of −1 and +1. The Shapiro-Wilk normality test shows an insignificant value ($p > 0.05$), so it can be concluded that the data meets the assumption of normality.

To investigate multivariate normality, control was carried out on the Mahalanobis distance value. The results of the analysis show that the data is multivariately normally distributed. The homogeneity test of pretest variance was controlled by the equality of error variance test and the Levene test. In the homogeneity test of slope, the pretest scores of geometry competence and geometry attitude were used as independent variables and their interactions were tested. The results of the normality and homogeneity tests are presented in Table 2. Based on the results of the Levene test, the pretest scores of geometry competence have a value of [F (1–60) = 0.221, $p > 0.05$] and the pretest scores of geometry attitude [F (1–60) = 2.64, $p > 0.05$] met the assumption of homogeneity of variance.

The results of the analysis of the interaction between group and geometry competency scores in the posttest phase (F (1–58) = 2.14, $p > 0.05$) and retention-GAT [F (1–58) = 0.785, $p > 0.05$], and the interaction between the group and geometry attitude posttest scores [F (1–58) = 0.645, $p > 0.05$], were not statistically significant. From these analysis results, it can be concluded that the prerequisite test was met, so further ANCOVA testing on geometry competency and geometry attitudes was able to be conducted. Before the intervention, an independent-samples t-test was conducted on the pretest scores of geometry competency and geometry attitudes.

The analysis results found no significant difference between the experimental group ($M = 38.75$, $SD = 7.42$) and the control group ($M = 38.46$, $SD = 8.21$) for the geometry competency pretest scores [t (110) = −0.246, $p > 0.05$]. No significant differences were found between the experimental group ($M = 66.48$, $SD = 13.41$) and the control group ($M = 65.46$, $SD = 7.24$) for the geometry attitude pretest scores [$t(110) = 0.489$, $p > 0.05$]. Therefore, it can be concluded that both groups demonstrated equivalent geometry competency and geometry attitudes in the pretest phase.

Table 2: Results of the normality and homogeneity tests for geometry competency, retention, and geometry attitudes

Variable	Group	*N*	Skewness	Kurtosis	Shapiro-Wilk	Levene's test for Pretest	Pretest*Group Interaction
Geometry Competency Pretest	Experimental	110	−.346	.081	.947		
	Control	110	−.093	−.098	.971		
Post-test for Geometry Competence	Experimental	110	−.264	−.521	.971	*F* (1–60) = .221	*F* (1–58) = 2.14
	Control	110	.260	−.340	.964		
Pretest Retention	Experimental	110	−.302	−.272	.963	*F* (1–60) = .221	*F* (1–58) = .785
	Control	110	.075	−.152	.972		
Posttest Retention	Experimental	110	−.302	−.272	.963		
	Control	110	.074	−.152	.968		
Geometry Attitude Pretest	Experimental	110	−.241	−.146	.976		
	Control	110	−.009	−.820	.972		
Post-test Sikap Geometri	Experimental	110	−.135	−.770	.978	*F* (1–60) = 2.63	*F* (1–58) = .645
	Control	110	−.110	−.231	.982		

Based on the analysis results presented in Table 3, it was found that the posttest scores of the experimental group's geometry competency and retention increased more significantly than those of the control group. A more significant increase also occurred in the experimental group's geometry attitudes. Based on the analysis results, the pretest scores of the experimental group's geometry competency (M = 38.75) increased to 85.42 in the post-test, while the control group (M = 37.52) showed an increase to 68.21 in the post-test phase.

The retention pretest scores in the experimental group (M = 39.48) decreased to 75.47, while the control group's (M = 36.46) increased to 72.42. Furthermore, the analysis results in Table 3 show that the geometry attitude scores in the experimental group experienced a more significant increase than the control group. The experimental group's geometry attitude score (M = 45.48) increased to 80.21 in the post-test, while the control group's geometry attitude score (M = 46.63) increased to 72.42 in the post-test.

Table 3: Results of the ANCOVA test for geometric competence, retention, and geometric attitudes

Measure	Group	*N*	Pretest		Post-test	
			M	*SD*	*M*	*SD*
Geometry Competence	Experimental	110	38.75	7.42	85.42	10.40
	Control	110	37.52	8.21	68.21	8.75
Retention	Experimental	110	39.48	7.56	75,47	11.54
	Control	110	36.46	8.38	72,42	9.68
Geometric Attitude	Experimental	110	45.48	13.41	80.21	12.23
	Control	110	46.63	7.24	72.42	6.56

To address the second research question, the assessment of 3D geometric thinking skills encompassed six dimensions: the net dimension, the manipulation dimension, the structuring dimension, the properties dimension, the calculation dimension, and the comparison dimension. 3D geometric thinking skills in the net dimension assess the ability to identify and create 3D geometric objects. The manipulation dimension assesses the ability to draw and interpret 3D object representations from various perspectives. The structuring dimension assesses the ability to construct 3D geometric cubes, and the calculation dimension assesses the ability to calculate the area and volume of 3D geometric objects. The comparison dimension assesses the ability to compare the features of various 3D geometric objects.

From the analysis of the model generated from the measurement of 3D geometric thinking skills, the regression coefficients for all dimensions showed significant improvement. The results of the regression coefficient analysis and descriptive analysis are presented in Table 4. All items measuring thinking competency used a 10-point scale to facilitate comparison of achievement. The analysis results show that the highest 3D geometric thinking skill dimension is the manipulation skill dimension, with a score of 8.32, while the lowest score is the comparison skill dimension, with a score of 4.38. The analysis also found the highest variance in the property skill dimension, with a score of 2.92, while the lowest variance was in the networking skill dimension, with a score of 2.35.

Table 4: Regression Coefficients for 3D Geometric Thinking Skills

	Mean	**SS**	**Regression ratio**
Properties	4.74	2.92	65
Structuring	5.34	2.83	60
Manipulation	8.32	2.72	58
Nets	5.72	2.35	55
Calculation	5.53	2.64	53
Comparison	4.38	2.75	3.86

The results of the t-test analysis of 3D geometric thinking skills based on participant gender are presented in Table 5. The analysis revealed only one dimension showing a significant difference, namely the manipulation dimension with a score of ($t = 2.12$, $p < 0.05$). The female students' manipulation scores were higher than the male students' scores. No significant differences were found in the other dimensions based on gender.

Table 5: 3D geometric thinking skills t-test results based on gender

Dimensions	**Averages**		***t***	***P***
	Female	**Male**		
Nets	5.82	5.42	1.53	0.23
Manipulation	6.71	5.82	2.12	0.03*
Structuring	5.05	5.33	−1.00	0.36
Properties	4.63	4.64	−0.34	0.81
Calculation	4.63	4.45	0.13	0.93
Comparison	3.72	3.72	0.12	0.96

**0.05 significance level.*

The next analysis was of the pretest and posttest scores of both groups to investigate the effectiveness of the intervention in improving 3D geometric thinking skills. This was carried out using ANCOVA tests. Before conducting the ANCOVA test, several tests were carried out such as homogeneity, normality, linearity and regression slope. The normality test was carried out through the slope coefficient and kurtosis testing of the data. The results of the analysis showed that slope and kurtosis had values ranging from 2.0 and -2.0 in both phases. These values indicate that the data showed a normal distribution. Further analysis showed that the data from both phases showed linearity and homogeneity of variance with a value ($F(1, 110) = 1.25$, $p = 0.35$).

In addition, the results of the analysis also found a homogeneous regression slope with a value of $F(1, 110) = 7.83$, $p = 0.01$). The analysis results showed no significant difference between the two groups in the pretest phase, with a value of [$t(110) = -0.87$, experimental = 23.41, control = 22.05, $p > 0.05$]. Furthermore, 3D geometric thinking skills improved significantly in the posttest phase, with the experimental group's score ($M = 33.74$, $SD = 8.24$) being higher than the control group's ($M = 26.32$, $SD = 8.12$). The next step was a descriptive analysis of each dimension of 3D geometric thinking skills, as presented in Table 6.

Table 6: ANCOVA test for each dimension of 3D geometric thinking skills

3D thinking level	Test	Control		Experimental			
		M	SD	*M*	SD	*t*	*p*
Nets	Pre-test	5.83	2.34	5.78	1.85	–0.87	0.485
	Post-test	5.84	2.45	6.92	1.89	–2.82	0.008**
Manipulation	Pre-test	5.42	1.93	5.53	2.46	0.29	0.785
	Post-test	5.73	2.63	8.42	1.90	–2.53	0.023*
Structuring	Pre-test	4.67	2.41	4.66	2.34	–0.80	0.563
	Post-test	4.89	2.45	7.34	2.44	–1.44	0.174
Properties	Pre-test	3.35	1.83	3.84	2.12	–0.97	0.363
	Post-test	4.84	2.25	6.35	2.47	–2.04	0.051*
Calculation	Pre-test	3.81	1.73	3.84	2.23	–1.05	0.356
	Post-test	4.86	1.90	6.46	1.94	–1.84	0.088
Comparison	Pre-test	2.56	1.74	2.63	1.97	0.08	0.973
	Post-test	2.94	1.63	3.84	1.95	–2.83	0.012*
Overall	Post-test	26,32	8,12	33,74	8,24	2,35	0.008*

***: 0.01 significance level, *: 0.05 significance level.*

The results of the analysis of 3D geometric thinking skills presented in Table 8 indicate that both groups had equivalent 3D geometric skills in the pretest phase. Improvements occurred in the posttest phase. The experimental group showed a more significant improvement in 3D geometric thinking skills in each dimension than the control group with a value ($p > 0.05$). Of all dimensions, the dimension that showed the most significant improvement was the manipulation dimension, followed by the nets, structuring, calculation, properties, and finally the comparison dimension respectively. Furthermore, the analysis of the overall thinking skill subdimensions showed a significant difference between the 3D geometric thinking skills of the experimental and control groups. The improvement in 3D geometric thinking skills in the experimental group showed a more significant increase than the control group with ($p < 0.05$). The most significant improvement was found in the manipulation dimension, regarding the skill of identifying and creating 3D geometric shapes with a value ($p < 0.01$). From this data, it can be concluded that geometry teaching assisted by the GeoGebra and AR applications can improve 3D geometric thinking skills more significantly than conventional teaching using books and geometric pictures.

5. Discussion

The purpose of this study was to investigate the impact of a geometry teaching intervention using the GeoGebra application and Augmented Reality (AR) on students' geometry competence, attitudes, memory, and 3D geometric thinking skills. The results show that the intervention significantly improved geometry competence, attitudes, memory, and 3D geometric thinking skills compared to conventional teaching using textbooks and images. The first finding was that the GeoGebra and AR-assisted geometry teaching intervention improved geometry competence. This improvement was evident in the students' ability to understand geometric concepts and solve geometric problems involving formulas and calculations, such as area, sine, volume, and angles. This improvement in geometric problem-solving skills occurred because students were given the opportunity to explore geometric objects using the GeoGebra application and to measure diameters, radii, arc lengths, circumferences, central angles, and angles.

AR facilitated the students' visual exploration of geometric relationships and the connections between these concepts. In addition, the impact of the instructions by the teacher at each stage was found to contribute significantly to the students' geometry competence, attitudes, memory, and 3D geometric thinking skills. These findings are reinforced by previous studies showing that learners' understanding of geometry is strengthened when facilitated through visual and interactive media (Haataja et al., 2025; Mosia & Oromena, 2025). Other studies also confirm that the GeoGebra application can improve students' ability to solve complex geometric problems because it trains students with various geometric shapes that are transformed and manipulated, enabling them to understand the relationships between geometric shapes (Bozkurt et al., 2025; Turgut, 2022).

The next finding is that the GeoGebra and AR-assisted geometry teaching intervention is able to improve students' memory and geometric attitudes. The increase in retention is seen in their ability to remember each formula for solving geometry problems and their retention of the concepts and components of each geometric object. In addition, the intervention is also able to improve geometric attitudes during the geometry learning process assisted by the GeoGebra and AR applications. The improvement in geometric attitudes is seen in the increase in student attention, as well as their level of curiosity, the intensity of student participation in each activity, and their sense of enjoyment when following the learning stages.

This increase in student retention and geometric attitudes occurs because the quality of the GeoGebra and AR-assisted geometry teaching process provides free opportunities to interact and navigate geometric objects directly. This process improves students' memory and positive attitudes (Quarder et al., 2025; Weigand et al., 2024). This finding is supported by the theory that the stages of geometry teaching assisted by visual media provide opportunities for students to make assumptions, construct knowledge, and discuss and interact directly with geometric objects, contributing significantly to the students' retention and geometric attitudes (Ledezma et al., 2024; Zhang et al., 2025). This finding is further supported by another study, which shows that mathematics learning facilitated through visual media to understand concepts improves the memory of concepts and formulas more optimally than relying solely on verbal explanations (Kohanová et al., 2025; Mukuka & Kalariparampil, 2025).

Improvements in the students' 3D geometry skills were evident across all dimensions. The first dimension of 3D geometry thinking skills improved, specifically identifying and creating geometric shapes. This improvement occurred because the 3D geometry material presented through GeoGebra and AR stimulated the students' visual abilities, focusing their attention on the visualization of virtual manipulatives and concepts. Further findings indicate that geometry instruction assisted by GeoGebra and AR technology improved the second dimension, namely the ability to identify the properties and shapes of geometric solids. This improvement occurred because AR technology presented the material using interactive 3D animations and visualized geometric nets.

Furthermore, the study also showed that the 3D geometry instruction improved 3D geometry thinking skills in the third dimension, namely the ability to construct 3D cubes and the ability to calculate the area and volume of geometric objects. The results of the study also show that GeoGebra and AR-assisted geometry teaching can improve the fourth dimension, namely the mental rotation skills of geometric objects. This improvement occurs because AR technology facilitates students interacting directly by navigating geometric objects independently. This finding is reinforced by the theory that realistic learning experiences through media can improve students' visualization skills (Rahmadi et al., 2024; Solano-macías, 2023). This finding is also confirmed by previous studies that show that Spheric Video-assisted geometry teaching that displays geometric objects from various directions is effective at improving the students' rotation and reflection skills (Dilling et al., 2024; Engelbrecht & Borba, 2024). Realistic visual experiences can facilitate students in improving their complex spatial skills and understanding abstract concepts (Chytas et al., 2024; Geraniou et al., 2024).

The research findings also show that AR-assisted 3D geometry teaching is able to improve the fifth dimension of 3D geometric thinking skills, namely the skill of identifying 3D geometric properties and shapes. The next finding is that AR-assisted geometry teaching is able to improve the sixth dimension, namely the skill of comparing 3D geometric object features. This comparative analysis ability improves because students are facilitsated in observing the properties of objects, nets, and other components of both geometric objects. The students' understanding of the various components of geometric objects with each other will contribute significantly to their ability to compare them. The use of GeoGebra and AR technology is able to facilitate the students in observing geometric objects from various directions. The process of navigating geometric objects provides students with the opportunity to get an overview of the properties of the geometric shapes, including the edges, angles, and other components. This finding is reinforced by previous studies that show that GeoGebra and AR-assisted geometric object navigation will make it easier for learners to analyze each property of geometric shapes and their components as well (Kus & Newcombe, 2025; Weigand et al., 2025).

The findings of this study are in line with the concept of geometry, namely that improving the hierarchical understanding of geometric concepts requires various forms of geometric objects with observations from various positions (Gregersen, 2024; Trgalová & Tabach, 2023). The AR-assisted software can strengthen the students' understanding of geometric objects, enabling them to imagine and create the prototypes captured in their schematics (Abraham & Prediger, 2025; Yang et al., 2025). This imagination enhances the students' ability to classify and compare various 3D geometric shapes.

6. Conclusion

Geometry instruction using the GeoGebra application and AR technology significantly improved geometric competence, geometric attitudes, memory, and 3D geometric thinking skills in each dimension. The improvement in geometric competence was evident in the ability to understand geometric concepts and solve geometric problems involving formulas and calculations, such as area, sine, volume, and angles. Improved retention was evident in the ability to remember each formula used to solve geometric problems and the retention of concepts and components of each geometric object. Improved geometric attitudes were evident in increased student attention, curiosity, participation in each activity, and the enjoyment of the learning process. 3D geometric thinking skills improved across all six dimensions. The most significant improvement in 3D geometric thinking skills was in the manipulation dimension, which is the ability to describe and understand the representation of various 3D geometric objects.

The next significant improvement was in the net dimension, which is the ability to recognize and create 3D geometric shapes. This is followed by the structuring dimension, which is the skill of constructing 3D geometric cubes; the calculation dimension, which is the skill of calculating the area and volume of 3D geometric objects; the properties dimension, which is the skill of analyzing the properties of 3D geometric shapes; and finally, the comparison dimension, which is the skill of comparing the features of various 3D geometric shapes. Improvements in all of these competencies occurred because the GeoGebra application and AR technology were able to present the geometric objects realistically and allow the students to navigate the geometric objects at their own pace and interact with them through 3D animations.

7. Implications and Recommendations

This research implies that the use of AR technology in geometry learning can optimize students' spatial abilities, thus contributing significantly to improving 3D geometric thinking skills. This research also implies the need to integrate technology and visual media into mathematics curriculum development. Teachers must be able to accommodate the use of AR technology in mathematics instruction, rather than relying solely on conventional lectures and textbooks. The limitations of this study include the mathematics material being only focused on 3D geometry, the analysis approach focused only on quantitative, focusing only on one level of higher education, the intervention time still being limited, and the study having not explored the impact of the intervention on cognitive load and the other psychological aspects that contribute to learning outcomes. In addition, this research also experienced obstacles in the form of unstable internet access in relation to the use of GeoGebra and AR technology, meaning that adequate internet access facilities are required.

From these limitations, the researcher recommends several suggestions, namely that the intervention needs to be carried out on other mathematics materials, qualitative analysis needs to be carried out to reveal the verbal processes that strengthen the quantitative data, the participants need to be expanded to other levels, the intervention time needs to be longer to obtain better competencies, and the exploration of the impact of the intervention on other components, such as cognitive load and the psychological aspects that play an important role in mathematics learning, is needed. Researchers also recommend that curriculum makers and teachers integrate the use of technology in mathematics learning. The contribution of this study is to enrich the pedagogical scaffolding in mathematics learning and to open up opportunities for stakeholders to integrate the use of technology into curriculum development.

Conflict of Interest
The authors declare that they have no competing interests.

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