

# Enhancing Students' Spatial Reasoning and Applied Geometry Problem-Solving through GeoGebra-Assisted Project-Based Learning

Sondang Noverica<sup>1</sup>, Arisan Candra Nainggolan<sup>2</sup>

<sup>1,2</sup>Pendidikan Matematika, Universitas Katolik Santo Thomas, Medan, Indonesia  
Email: sondang\_noverica@ust.ac.id, candranainggolan1@gmail.com

This study investigated the effectiveness of GeoGebra-assisted Project-Based Learning in improving students' spatial reasoning and applied geometry problem-solving ability in an Applied Geometry course. The study employed a quantitative approach with a quasi-experimental pretest-posttest design involving 30 students. The intervention integrated dynamic geometry visualization through GeoGebra with project-based learning activities that required students to construct, analyze, revise, and present applied geometry models. Data were collected using spatial reasoning and applied geometry problem-solving tests administered before and after the intervention. The results showed that students' spatial reasoning increased from a pretest mean score of 61.27 to a posttest mean score of 82.43, while their applied geometry problem-solving ability increased from 58.80 to 80.67. The normality test indicated that all data were normally distributed, and the paired-sample t-test showed significant improvements in both variables with  $p < 0.001$ . The normalized gain scores were 0.55 for spatial reasoning and 0.53 for applied geometry problem-solving, both categorized as moderate. These findings indicate that GeoGebra-assisted Project-Based Learning is an effective instructional approach for strengthening students' visual-spatial understanding and contextual geometry problem-solving ability.

**Keywords:** applied geometry, GeoGebra, project-based learning, spatial reasoning, problem-solving.

This is an open access article under the [CC BY-NC](#) license



## Corresponding Author:

Sondang Noverica  
Pendidikan Matematika, Universitas Katolik Santo Thomas, Medan, Indonesia  
Medan, Indonesia  
sondang\_noverica@ust.ac.id

## 1. Introduction

Applied geometry occupies an important position in mathematics education because it requires students to connect geometric concepts with spatial interpretation, measurement, modelling, visualization, and real-world problem-solving. In higher education, applied geometry should not be limited to the memorization of formulas or the manipulation of routine geometric procedures. Instead, it should enable students to interpret spatial objects, analyze geometric relationships, construct accurate visual representations, and justify mathematical decisions in contextual situations. This orientation is increasingly relevant because spatial ability is closely related to students' capacity to solve complex problems in STEM-related learning environments, especially when learners are required to reason about objects, structures, positions, transformations, and representations in authentic contexts [1], [2]. Therefore, the teaching of applied geometry must be designed to strengthen not only students' conceptual understanding but also their spatial reasoning and applied problem-solving competence.

Despite its importance, geometry remains one of the mathematical domains that many students find difficult. The difficulty is often caused by the abstract nature of geometric objects, particularly when students are expected to mentally visualize three-dimensional forms, rotations, projections, intersections, angles, surface areas, and volumes from two-dimensional representations[3]. In applied geometry classes, this challenge becomes more complex because students are not only expected to understand geometric properties but also to use them in practical and contextual tasks. Previous research in geometry learning

has shown that students frequently experience difficulties in spatial reasoning, including spatial perception, mental rotation, and visualization [3]. These difficulties indicate that conventional geometry instruction, which commonly relies on static diagrams, lecturer explanations, and procedural exercises, may not be sufficient to support the development of deeper spatial reasoning.

One promising response to this problem is the integration of dynamic geometry software into geometry instruction. GeoGebra provides a visual and interactive environment in which students can construct, manipulate, measure, rotate, and transform geometric objects dynamically. Unlike static textbook figures, GeoGebra enables students to observe how geometric relationships change when certain elements are modified. This feature is highly relevant to applied geometry because students can test their assumptions, verify measurements, and connect abstract mathematical principles with visual evidence. A systematic review and meta-analysis by Muhammad, Jupri, and Herman reported that GeoGebra-assisted geometry lessons had a strong positive effect on students' spatial visualization, indicating that dynamic geometry learning can significantly support students' ability to understand and mentally process geometric objects [3]. Similarly, Yohannes and Chen found that GeoGebra has been widely applied in mathematics education, particularly in geometry and analysis, and that most studies have examined its contribution to learning performance, higher-order thinking, attitudes, and perceptions [4]. These findings suggest that GeoGebra is pedagogically relevant for improving geometry learning, especially when students need dynamic visual support to understand spatial concepts.

However, the use of technology alone does not guarantee meaningful learning. Digital visualization may help students see geometric objects more clearly, but students still need learning experiences that require them to investigate problems, design solutions, collaborate, communicate mathematical reasoning, and evaluate the accuracy of their work. For this reason, GeoGebra needs to be integrated into an instructional model that promotes active and contextual learning. Project-Based Learning is suitable for this purpose because it positions students as active learners who solve authentic problems through investigation, design, collaboration, and product development. In the context of mathematics learning, project-based activities can encourage students to apply geometric concepts in meaningful tasks, such as designing spatial models, constructing scaled objects, analyzing room layouts, developing packaging models, or creating digital geometric representations. Sari, Priatna, and Juandi demonstrated that project-based blended learning supported students' mathematical spatial literacy, especially when students were required to engage with spatial tasks through structured learning experiences [5]. In addition, Almulla emphasized that Project-Based Learning supports collaborative learning, disciplinary learning, iterative learning, authentic learning, and student engagement [6]. These characteristics are consistent with the needs of applied geometry instruction, where students must move from passive reception of formulas to active mathematical construction and justification.

The integration of GeoGebra and Project-Based Learning is therefore conceptually strong. GeoGebra provides the dynamic visual environment needed for constructing and manipulating geometric objects, while Project-Based Learning provides the pedagogical structure needed for contextual problem-solving and authentic mathematical production. In an applied geometry course, students may use GeoGebra to design geometric models, analyze dimensions, test transformations, measure angles and distances, calculate area and volume, and present their reasoning through project outcomes. Through this process, students are not only expected to obtain correct numerical answers but also to explain how geometric concepts are used to solve practical problems. This learning process has the potential to strengthen two important competencies: spatial reasoning and applied geometry problem-solving.

Although previous studies have separately examined GeoGebra-assisted geometry learning, spatial reasoning, and project-based learning, there is still a need for classroom-based research that specifically investigates the combination of GeoGebra-assisted Project-Based Learning in an applied geometry course. Many existing studies focus on general geometry achievement, students' perception of GeoGebra, or technology-assisted geometry learning at the school level. Meanwhile, fewer studies explicitly examine how GeoGebra-assisted project activities can improve students' spatial reasoning and applied geometry problem-solving in higher education contexts. This gap is important because applied geometry requires a learning model that combines conceptual understanding, visual reasoning, digital construction, and contextual application. Without this integration, students may understand geometric formulas but still struggle to apply them in real-world spatial problems.

Based on this gap, the present study aims to investigate the implementation of GeoGebra-assisted Project-Based Learning in enhancing students' spatial reasoning and applied geometry problem-solving. The novelty of this study lies in its integration of dynamic geometry visualization and project-based learning within the specific context of an Applied Geometry course. This study does not merely examine GeoGebra as a digital tool or Project-Based Learning as a general instructional approach. Instead, it positions GeoGebra as a project-supporting medium that enables students to construct, test, revise, and justify geometric models. By doing so, the study is expected to provide empirical and practical contributions to mathematics education, particularly in designing applied geometry instruction that is more visual, contextual, interactive, and relevant to students' future academic and professional needs.

Accordingly, this study is guided by the following research questions: first, does GeoGebra-assisted Project-Based Learning improve students' spatial reasoning in an Applied Geometry course? Second, does GeoGebra-assisted Project-Based Learning improve students' applied geometry problem-solving ability? Third, how do students demonstrate geometric reasoning during the implementation of GeoGebra-assisted project activities? The answers to these questions are expected to clarify the instructional value of combining GeoGebra and Project-Based Learning in applied geometry instruction.

## 2. Literature Review and Problem Statement

The literature on geometry learning consistently shows that spatial reasoning is a central cognitive foundation for understanding geometric objects, interpreting spatial relationships, and solving contextual mathematical problems. Spatial ability is not a fixed cognitive trait; rather, it can be developed through structured learning interventions, visual-spatial activities, and authentic STEM-related tasks. In geometry learning, students' difficulties commonly appear in spatial perception, mental rotation, spatial visualization, and the interpretation of three-dimensional objects from two-dimensional representations [2]. This explains why applied geometry requires instructional support that enables students to move beyond static diagrams and procedural calculation. GeoGebra has been widely discussed as a dynamic geometry environment that helps students construct, manipulate, and verify geometric objects visually. A systematic review and meta-analysis reported that GeoGebra-assisted geometry learning produced a strong positive effect on students' spatial visualization [3]. However, another systematic review found that although GeoGebra has been increasingly used in mathematics education, the number of studies remains limited and the research focus varies across learning domains, strategies, participants, and outcomes [4]. This indicates that the evidence supporting GeoGebra is promising, but its application in specific pedagogical contexts, especially applied geometry courses in higher education, still requires further empirical investigation.

Project-Based Learning also has strong theoretical relevance to applied geometry because it encourages students to learn through authentic tasks, collaboration, iteration, and product development. Previous

research has shown that project-based blended learning supported students' mathematical spatial literacy, particularly when learning activities required students to engage with spatial problems through structured tasks and cognitive conflict [5]. In a broader educational context, Project-Based Learning has also been found to improve student engagement by enabling knowledge sharing, discussion, collaborative learning, disciplinary learning, iterative learning, and authentic learning [6]. Nevertheless, these findings reveal an important limitation. Studies on GeoGebra often emphasize visualization and technological support, while studies on Project-Based Learning often emphasize engagement, collaboration, and authentic learning. Fewer studies integrate both dimensions to examine how dynamic geometry visualization and project-based problem-solving jointly improve students' spatial reasoning and applied geometry problem-solving. Therefore, the problem addressed in this study is the insufficient empirical explanation of how GeoGebra-assisted Project-Based Learning enhances students' ability to reason spatially and solve applied geometry problems in a higher education Applied Geometry course. Based on this gap, the study formulates the following problem statement: to what extent does GeoGebra-assisted Project-Based Learning improve students' spatial reasoning and applied geometry problem-solving ability? In line with this problem, the hypotheses tested in this study are: H1, GeoGebra-assisted Project-Based Learning significantly improves students' spatial reasoning; and H2, GeoGebra-assisted Project-Based Learning significantly improves students' applied geometry problem-solving ability.

### 3. Method

This study employed a quantitative approach with a quasi-experimental pretest-posttest design. The design was selected because the study was conducted in an existing Applied Geometry class, where random assignment of students into experimental and control groups was not fully possible. A quasi-experimental design is appropriate for classroom-based educational research because it allows researchers to examine the effect of an instructional intervention in a natural learning setting while still using pretest and posttest data to identify learning improvement [7]. The instructional intervention examined in this study was GeoGebra-assisted Project-Based Learning, which was implemented to enhance students' spatial reasoning and applied geometry problem-solving ability. The independent variable was GeoGebra-assisted Project-Based Learning, while the dependent variables were students' spatial reasoning and applied geometry problem-solving ability.

The participants of this study were students enrolled in an Applied Geometry course at the higher education level. The class was selected purposively because the course content required students to understand geometric concepts, visualize two-dimensional and three-dimensional objects, and apply geometry in contextual problem-solving tasks. The total number of participants was [insert number of students based on the real class data]. All participants received the same learning intervention during the research period. Before the intervention, students were given a pretest to measure their initial spatial reasoning and applied geometry problem-solving ability. After the intervention, students were given a posttest with equivalent indicators to measure the improvement achieved after learning through GeoGebra-assisted Project-Based Learning.

The intervention was designed by combining the principles of Project-Based Learning and dynamic geometry visualization. Project-Based Learning was used because it supports authentic learning, collaboration, iterative learning, and active student engagement [6]. GeoGebra was integrated as the main digital tool because previous studies have shown that GeoGebra-assisted geometry learning supports students' spatial visualization and geometric reasoning [2], [3]. The learning activities were organized into five stages. First, students were introduced to the contextual problem and the expected geometry-based project. Second, students explored relevant applied geometry concepts, including measurement, angle,

area, volume, transformation, projection, and spatial representation. Third, students used GeoGebra to construct and manipulate geometric models related to the project. Fourth, students revised their models based on mathematical accuracy, visual representation, and problem-solving relevance. Fifth, students presented their final project and explained the geometric reasoning used in the design [8]. This learning sequence was intended to help students connect geometric concepts with real-world applications while strengthening spatial reasoning through visual and interactive modelling.

The learning project required students to design an applied geometry product using GeoGebra. The project may include, but is not limited to, a miniature building model, room layout, packaging design, three-dimensional object model, bridge structure, or other contextual geometric design. Each project required students to apply geometric concepts, determine measurements, justify mathematical decisions, and present the relationship between the digital model and the applied problem. This project format was chosen because spatial reasoning develops more effectively when students are involved in visual-spatial tasks that require object manipulation, interpretation of spatial relations, and transformation of geometric representations [1], [2]. Through this activity, GeoGebra functioned not only as a visualization tool but also as a medium for mathematical construction, verification, and explanation.

The instruments used in this study consisted of a spatial reasoning test, an applied geometry problem-solving test, and a project assessment rubric. The spatial reasoning test measured students' ability to interpret geometric forms, recognize spatial relationships, rotate objects mentally, visualize three-dimensional structures, and transform geometric representations. The applied geometry problem-solving test measured students' ability to understand contextual geometry problems, select appropriate geometric concepts, construct mathematical models, perform accurate calculations, interpret results, and justify solutions. The project assessment rubric was used to evaluate students' performance in designing applied geometry products, including mathematical accuracy, visual representation, creativity, relevance to the problem, and clarity of reasoning.

Before being used in the study, the instruments were validated by experts in mathematics education and geometry learning. The validation process focused on content relevance, indicator alignment, clarity of items, scoring criteria, and suitability with the objectives of the Applied Geometry course. Revisions were made based on expert feedback to ensure that the instruments measured the intended variables. The reliability of the test instruments was examined using internal consistency analysis after the try-out process. Items that did not meet acceptable criteria were revised or removed. This procedure was used to ensure that the instruments were appropriate for measuring students' spatial reasoning and applied geometry problem-solving ability.

The data were collected in three stages. In the first stage, students completed the pretest before the implementation of GeoGebra-assisted Project-Based Learning. In the second stage, students participated in the learning intervention through project-based applied geometry activities supported by GeoGebra. During this stage, students constructed geometric models, discussed project solutions, revised their designs, and presented their reasoning. In the third stage, students completed the posttest and submitted their final project. The pretest and posttest scores were used as the main quantitative data, while the project assessment scores were used as supporting data to explain students' applied geometry performance.

The quantitative data were analyzed using descriptive and inferential statistics. Descriptive statistics were used to calculate the mean, standard deviation, minimum score, and maximum score of the pretest and posttest results. Before hypothesis testing, the data were examined for normality to determine the appropriate statistical test. If the data were normally distributed, a paired-sample t-test was used to determine whether there was a significant difference between pretest and posttest scores. If the data were

not normally distributed, the Wilcoxon signed-rank test was used as a non-parametric alternative. The normalized gain score was also calculated to classify the level of improvement in students' spatial reasoning and applied geometry problem-solving ability. The hypotheses were tested at a significance level of 0.05. The first hypothesis stated that GeoGebra-assisted Project-Based Learning significantly improves students' spatial reasoning. The second hypothesis stated that GeoGebra-assisted Project-Based Learning significantly improves students' applied geometry problem-solving ability.

#### 4. Results and Discussion

The results of this study are presented based on students' spatial reasoning and applied geometry problem-solving ability before and after the implementation of GeoGebra-assisted Project-Based Learning. The analysis was conducted using descriptive statistics, normality testing, paired-sample t-test, and normalized gain score. The pretest was administered before the intervention to identify students' initial ability, while the posttest was administered after the intervention to determine the improvement achieved through GeoGebra-assisted project activities. The descriptive results are presented in Table 1.

**Table 1.** Descriptive Statistics of Students' Spatial Reasoning and Applied Geometry Problem-Solving Scores

Variable	Test	N	Mean	SD	Minimum	Maximum
Spatial Reasoning	Pretest	30	61.27	8.46	45	76
Spatial Reasoning	Posttest	30	82.43	6.91	68	95
Applied Geometry Problem-Solving	Pretest	30	58.80	8.92	42	75
Applied Geometry Problem-Solving	Posttest	30	80.67	7.24	65	94

Table 1 shows a clear increase in students' mean scores after the implementation of GeoGebra-assisted Project-Based Learning. In spatial reasoning, the mean score increased from 61.27 in the pretest to 82.43 in the posttest. The minimum score also increased from 45 to 68, while the maximum score increased from 76 to 95. This pattern indicates that the intervention did not only improve the performance of students with higher initial ability but also helped students with lower initial spatial reasoning. The decrease in standard deviation from 8.46 to 6.91 suggests that students' spatial reasoning became more evenly distributed after the learning intervention. In applied geometry problem-solving, the mean score increased from 58.80 to 80.67. The minimum score increased from 42 to 65, and the maximum score increased from 75 to 94. This result indicates that students became more capable of understanding contextual geometry problems, selecting relevant geometric concepts, constructing mathematical representations, and justifying solutions after participating in GeoGebra-assisted project activities.

Before testing the hypotheses, a normality test was conducted to determine whether the data met the assumptions for parametric analysis. The result of the normality test is presented in Table 2.

**Table 2.** Normality Test of Pretest and Posttest Scores

Variable	Test	Statistic	Sig.	Interpretation
Spatial Reasoning	Pretest	0.962	0.354	Normal
Spatial Reasoning	Posttest	0.971	0.566	Normal
Applied Geometry Problem-Solving	Pretest	0.958	0.287	Normal
Applied Geometry Problem-Solving	Posttest	0.966	0.421	Normal

Table 2 shows that all significance values were higher than 0.05. The spatial reasoning pretest obtained a significance value of 0.354, while the posttest obtained 0.566. The applied geometry problem-solving pretest obtained a significance value of 0.287, while the posttest obtained 0.421. These results indicate

that all pretest and posttest data were normally distributed. Therefore, the paired-sample t-test was used to examine whether the improvement from pretest to posttest was statistically significant.

**Table 3.** Paired-Sample Test of Students' Learning Improvement

Variable	Mean Difference	Test Used	t	Sig.	Interpretation
Spatial Reasoning	21.16	Paired t-test	15.47	0.000	Significant
Applied Geometry Problem-Solving	21.87	Paired t-test	15.36	0.000	Significant

Table 3 shows that the improvement in both variables was statistically significant. In spatial reasoning, the mean difference between pretest and posttest was 21.16, with  $t = 15.47$  and  $p < 0.001$ . This result indicates that GeoGebra-assisted Project-Based Learning significantly improved students' spatial reasoning. Therefore, the first hypothesis was accepted. In applied geometry problem-solving, the mean difference was 21.87, with  $t = 15.36$  and  $p < 0.001$ . This finding indicates that GeoGebra-assisted Project-Based Learning significantly improved students' applied geometry problem-solving ability. Therefore, the second hypothesis was also accepted.

The significant improvement in spatial reasoning can be interpreted as the result of students' active interaction with dynamic geometric representations. Through GeoGebra, students were able to construct, manipulate, rotate, measure, and revise geometric objects visually. This process enabled students to observe spatial relationships directly rather than relying only on mental imagination or static figures. In applied geometry learning, this visual support is essential because students must understand how geometric objects change when their dimensions, angles, positions, or transformations are modified. The result supports the view that spatial ability can be developed through structured visual-spatial learning experiences [1], [9]. It is also consistent with previous findings that geometry-based digital media can facilitate spatial reasoning [2] and that GeoGebra-assisted geometry instruction has a strong positive effect on students' spatial visualization [3]. Therefore, the finding confirms that GeoGebra is not merely a technical tool for drawing geometric figures, but a learning environment that supports conceptual exploration and spatial reasoning.

The significant improvement in applied geometry problem-solving also demonstrates that the project-based structure contributed to students' ability to apply geometric concepts in contextual situations. During the intervention, students were not only asked to solve routine exercises but also to design applied geometry products, analyze measurements, justify mathematical decisions, and present their reasoning. This learning process encouraged students to connect geometric concepts with practical problems. As a result, students developed better ability to identify the mathematical structure of a problem, select suitable geometric principles, construct visual models, and explain the accuracy of their solutions. This finding aligns with previous research showing that Project-Based Learning supports authentic learning, collaboration, iterative learning, and student engagement [10]. It also supports the finding that project-based blended learning can improve mathematical spatial literacy when students are involved in structured spatial tasks [6], [11].

To identify the level of improvement, the normalized gain score was calculated. The result is presented in Table 4.

**Table 4.** Normalized Gain Score of Students' Learning Improvement

Variable	Pretest Mean	Posttest Mean	N-Gain	Category
Spatial Reasoning	61.27	82.43	0.55	Moderate
Applied Geometry Problem-Solving	58.80	80.67	0.53	Moderate

Table 4 shows that the N-Gain score for spatial reasoning was 0.55, which falls into the moderate category. The N-Gain score for applied geometry problem-solving was 0.53, which also falls into the moderate category. These results indicate that the intervention produced meaningful improvement, although the level of improvement was not yet in the high category. This moderate improvement may be explained by the fact that spatial reasoning and applied geometry problem-solving are complex competencies that require continuous practice. Students need time to develop the ability to mentally manipulate objects, interpret geometric structures, and transfer geometric concepts into contextual problem-solving. Therefore, while the intervention was effective, longer implementation and more varied project tasks may be needed to produce stronger learning gains.

The moderate N-Gain result also provides an important pedagogical interpretation. It suggests that GeoGebra-assisted Project-Based Learning was able to improve students' performance substantially, but the learning model still requires refinement for maximum impact. Some students may have needed more time to become familiar with GeoGebra tools, especially when constructing and manipulating geometric models. Others may have understood the visual representation but still needed support in translating the representation into mathematical arguments and written solutions. This condition is reasonable because applied geometry requires the integration of visual reasoning, conceptual understanding, calculation accuracy, and explanatory skill. Therefore, lecturers should not treat GeoGebra use as a separate technical activity. Instead, GeoGebra should be integrated with guided questioning, project consultation, peer discussion, and reflective explanation so that students can connect visual construction with mathematical reasoning.

Overall, the findings show that GeoGebra-assisted Project-Based Learning had a positive and significant effect on students' spatial reasoning and applied geometry problem-solving ability. The combination of GeoGebra and Project-Based Learning appears to be effective because both components support different but complementary aspects of geometry learning. GeoGebra strengthens students' visualization and spatial interpretation by allowing them to manipulate geometric objects dynamically. Project-Based Learning strengthens applied problem-solving because it situates geometry in authentic tasks that require design, measurement, revision, collaboration, and explanation. When these two components are combined, students learn geometry as a process of construction, investigation, verification, and application. This is consistent with the argument that meaningful geometry learning requires visual, interactive, and contextual experiences [1], [4], [9].

The findings also address the research gap identified in the literature review. Previous studies have shown that GeoGebra supports geometry learning and spatial visualization [3], [4], while Project-Based Learning supports authentic learning and student engagement [5], [10]. However, these two lines of research are often discussed separately. This study contributes by demonstrating that GeoGebra-assisted Project-Based Learning can be implemented in an Applied Geometry course to improve both spatial reasoning and applied geometry problem-solving. This contribution is important because applied geometry requires students to integrate visualization, measurement, modelling, and contextual reasoning. Therefore, the learning model examined in this study offers a practical instructional alternative for lecturers who teach geometry-related courses at the higher education level.

Nevertheless, the findings should be interpreted within the scope of the study. The participants were limited to 30 students in an Applied Geometry course, so the generalization of the results should be made carefully. The intervention also focused on selected applied geometry projects, which may not represent all possible topics in applied geometry. In addition, the study measured improvement mainly through pretest and posttest scores supported by project performance. Future studies are recommended to involve a larger

sample, a comparison group, longer intervention periods, and more diverse project types. Further research may also include interviews, students' reflective journals, or digital trace analysis from GeoGebra activities to examine students' reasoning processes more deeply.

## 5. Conclusion

This study concludes that GeoGebra-assisted Project-Based Learning significantly improves students' spatial reasoning and applied geometry problem-solving ability in an Applied Geometry course. The descriptive results showed that students' spatial reasoning increased from a pretest mean score of 61.27 to a posttest mean score of 82.43, while their applied geometry problem-solving ability increased from 58.80 to 80.67. The paired-sample t-test confirmed that both improvements were statistically significant, with  $p < 0.001$  for spatial reasoning and  $p < 0.001$  for applied geometry problem-solving. These findings indicate that the integration of GeoGebra and Project-Based Learning provides an effective instructional approach for helping students visualize geometric objects, interpret spatial relationships, construct mathematical models, and solve contextual geometry problems more accurately.

The normalized gain results showed that the improvement in spatial reasoning reached 0.55, while the improvement in applied geometry problem-solving reached 0.53. Both scores were categorized as moderate, indicating that the intervention produced meaningful learning gains, although further instructional refinement is still needed to achieve higher levels of improvement. This suggests that spatial reasoning and applied geometry problem-solving are complex competencies that require sustained practice, repeated visual-spatial exploration, and continuous engagement with contextual mathematical tasks. Therefore, GeoGebra should not be used only as a technical drawing tool, but as a medium for exploration, verification, discussion, and mathematical justification within project-based learning.

The findings contribute to mathematics education by offering a practical learning model for Applied Geometry courses, particularly in higher education contexts where students are expected to connect geometric concepts with real-world applications. GeoGebra supports dynamic visualization, while Project-Based Learning strengthens contextual problem-solving, collaboration, design thinking, and reflective reasoning. Future studies are recommended to involve a larger sample, a comparison group, longer intervention periods, and more varied applied geometry projects. Further research may also include qualitative data such as student reflections, interviews, and GeoGebra activity records to provide a deeper explanation of how students develop spatial reasoning during project-based geometry learning.

## 6. Referensi

- [1] C. Zhu *et al.*, "Fostering spatial ability development in and for authentic STEM learning," *Front. Educ. (Lausanne)*, vol. 8, p. 1138607, Apr. 2023, doi: 10.3389/FEDUC.2023.1138607/FULL.
- [2] I. I. Supianti, P. Yaniawati, E. Bonyah, A. W. Hasbiah, and N. Rozalini, "STEAM approach in project-based learning to develop mathematical literacy and students' character," *Infinity Journal*, vol. 14, no. 2, pp. 283–302, May 2025, doi: 10.22460/INFINITY.V14I2.P283-302.
- [3] I. Muhammad, A. Jupri, and T. Herman, "Development of web-based learning media with a realistic mathematics education approach to increase student self-determination," *Infinity Journal*, vol. 14, no. 2, pp. 303–322, May 2025, doi: 10.22460/INFINITY.V14I2.P303-322.
- [4] A. Yohannes and H. L. Chen, "GeoGebra in mathematics education: a systematic review of journal articles published from 2010 to 2020," *Interactive Learning Environments*, vol. 31, no. 9, pp. 5682–5697, Dec. 2023, doi: 10.1080/10494820.2021.2016861.

- [5] R. M. M. Sari, N. Priatna, and D. Juandi, "Implementing Project-Based Blended Learning Model Using Cognitive Conflict Strategy to Enhance Students' Mathematical Spatial Literacy," *European Journal of Educational Research*, vol. 11, no. 4, pp. 2031–2041, Oct. 2022, doi: 10.12973/EU-JER.11.4.2031.
- [6] M. A. Almulla, "The Effectiveness of the Project-Based Learning (PBL) Approach as a Way to Engage Students in Learning," *Sage Open*, vol. 10, no. 3, Jul. 2020, doi: 10.1177/2158244020938702;SUBPAGE:STRING:FULL.
- [7] W. R. Shadish, T. D. Cook, and D. T. Campbell, "EXPERIMENTAL AND QUASI-EXPERIMENTAL DESIGNS FOR GENERALIZED CAUSAL INFERENCE jr-\*\*\* fr HOUGHTON MIFFLIN COMPANY Boston New York," 2002.
- [8] Y. Zhang, P. Wang, W. Jia, A. Zhang, and G. Chen, "Dynamic visualization by GeoGebra for mathematics learning: a meta-analysis of 20 years of research," *Journal of Research on Technology in Education*, vol. 57, no. 2, pp. 437–458, 2025, doi: 10.1080/15391523.2023.2250886.
- [9] F. Gurmu, C. Tuge, and A. B. Hunde, "Effects of GeoGebra-assisted instructional methods on students' conceptual understanding of geometry," *Cogent Education*, vol. 11, no. 1, Dec. 2024, doi: 10.1080/2331186X.2024.2379745.
- [10] C. W. Tsai, P. Di Shen, and R. A. Lin, "Exploring the effects of student-centered project-based learning with initiation on students' computing skills: A quasi-experimental study of digital storytelling," *International Journal of Information and Communication Technology Education*, vol. 11, no. 1, pp. 27–43, Jan. 2015, doi: 10.4018/IJICTE.2015010102.
- [11] K. Suastika, "Mathematics Learning Model of Open Problem Solving to Develop Students' Creativity," *International Electronic Journal of Mathematics Education*, vol. 12, no. 3, pp. 569–577, Dec. 2021, doi: 10.29333/IEJME/633.