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# Improving Students' Mathematical Spatial Ability in the Spatial Geometry Course Using GeoGebra

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**ABSTRACT**

This study aims to determine students' responses to the use of GeoGebra in spatial geometry courses and to determine the difference in significant improvement between the spatial mathematical ability of students taught using GeoGebra and those of students taught conventionally. The design of this study is *counterbalanced*. The research population is all Mathematics Tadris UIN Siber Syekh Nurjati Cirebon students who take the spatial geometry course in the odd semester of the 2024/2025 Academic Year, which consists of 3 classes: A, B, and C. For the research sample, two classes were selected from the research population, class A was selected as experimental class 1, consisting of 25 students, and class B as experimental class 2, consisting of 28 students. The sample was selected using a *cluster random sampling technique*. The research instruments are questionnaires and tests. Data analysis was carried out on the average results of students' spatial mathematical ability tests in the spatial geometry course. The results of the study showed that most students gave a positive response to the use of GeoGebra in spatial geometry courses, with an average percentage of 93.51%, including the strong category and the increase in the spatial mathematical ability of students who used GeoGebra in the spatial geometry course was significantly higher than the improvement of the spatial ability of students who were taught conventionally.

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## 1. INTRODUCTION

Geometry is one of the courses that must be studied by students majoring in mathematics education. This subject is crucial in equipping students with the foundational skills to analyze shapes, structures, and relationships. Among the various branches of geometry, one significant course is spatial geometry [1], [2], [3], [4], [5]. In this course, students delve into the concepts and calculations of three-dimensional shapes, including polygonal base solid and curved surface shapes. However, mastering spatial geometry requires mathematical computation skills and the ability to visualize and interpret spatial representations in two-dimensional and three-dimensional forms. These visualization skills are essential for accurately understanding and analyzing geometric concepts [6], [7], [8], [9], [10].

Spatial ability plays a central role in the study of spatial geometry. Linn and Petersen [11] define spatial ability as the mental process of perceiving, storing, recalling, creating, transforming, and communicating spatial structures. According to Tambunan and Marilah [12], spatial ability is an abstract concept encompassing spatial perceptions and understanding spatial relationships, including orientation and complex abilities such as mental manipulation and rotation. This implies that spatial skills are fundamental and multifaceted, demanding cognitive and imaginative capabilities [13]. With solid spatial skills, students can better grasp the concepts underlying spatial geometry, making the learning process more effective.

Amstrong [14] highlights spatial ability as the capacity to accurately perceive the spatial visual world and adjust using sight or imagination. This ability includes recognizing color, lines, shapes, space, and their interrelationships. Moreover, it involves effectively generating, articulating, and interpreting visual-spatial ideas. Meanwhile, Maier [15] emphasizes the relevance of spatial ability in daily life and categorizes it into five key elements: 1) Spatial Perception, the ability to identify an object’s position in horizontal or vertical planes; 2) Visualization, the skill to understand and demonstrate changes in an object’s form between two-dimensional and three-dimensional representations; 3) Mental Rotation, the capacity to rotate objects mentally with precision; 4) Spatial Relation, the understanding of how an object’s parts are arranged and related; and 5) Spatial Orientation, the ability to view an object from multiple perspectives. Gutierrez [16] further simplifies spatial ability into two primary components: orientation and visualization. These classifications underscore the complexity and significance of spatial ability in academic and practical contexts.

Mathematical spatial ability is imagining, comparing, estimating, determining, constructing, and extracting information from visual stimuli in spatial environments. This ability plays a critical role in enabling students to determine the position between elements in a geometric structure, identify and analyze geometric figures, visualize the shape or position of an object from a specific viewpoint, construct and represent geometric models on a flat plane within a spatial context, and explore the properties of geometric objects [17]. Furthermore, this skill is a foundation for understanding complex spatial relationships, essential in many fields, such as engineering, architecture, and data visualization. The indicators of mathematical spatial ability include 1) Spatial Perception, 2) Visualization, 3) Mental Rotation, 4) Spatial Relation, and 5) Spatial Orientation.

The spatial geometry course necessitates strong mathematical spatial abilities to achieve optimal learning outcomes. Therefore, efforts to enhance students' spatial mathematical skills in this course are essential. One effective approach is leveraging technology aligned with current advancements. Integrating technology into the classroom enhances engagement and provides practical tools to improve spatial reasoning. Among these technologies, the GeoGebra software is a valuable tool for spatial geometry instruction.

GeoGebra, developed by Markus Hohenwarter in 2001 [18], offers robust support for teaching spatial geometry through its features for three-dimensional object manipulation and spatial constructions. GeoGebra is a dynamic and interactive software that significantly enhances learning and problem-solving capabilities in mathematics, particularly in geometry, algebra, and calculus. The software integrates various mathematical concepts, allowing students to visualize and manipulate mathematical objects, which fosters a deeper understanding of abstract concepts. Research has shown that GeoGebra effectively connects algebra and geometry, motivating students and consolidating their conceptual learning [19]. Furthermore, using GeoGebra has improved students' critical thinking abilities, particularly in geometry learning, where self-regulated learning plays a crucial role [20]. Its ability to visually represent complex geometric concepts makes it an invaluable asset for educators and learners. GeoGebra facilitates more precise visualization of spatial structures, encompassing both two-dimensional and three-dimensional forms. With its numerous features, GeoGebra enables the accurate depiction of spatial constructions, offers flexible and interactive rotation of three-dimensional objects, and allows realistic observation of these structures. This interactivity helps students better grasp abstract spatial concepts, making learning more effective and enjoyable.

This study aims to determine students' responses to using GeoGebra in spatial geometry courses and identify the differences in significant improvement between the spatial mathematical abilities of students taught using GeoGebra and those taught conventionally. This exploration aims to provide insights into how technology-enhanced learning tools like GeoGebra can influence students' understanding and mastery of spatial concepts. The hypothesis in this study posits that the improvement in spatial ability among students who use GeoGebra in spatial geometry courses is significantly higher than that observed in students taught using conventional methods. This research highlights the advantages of integrating dynamic mathematics software into teaching practices by comparing these approaches.

## 2. METHOD

The research method used in this study is quasi-experimental [21]. The experiment was carried out in a counterbalanced design. This research will be conducted in two classes with homogeneous abilities and two units of material comparable in difficulty, length, and complexity of the concepts they contain. The two classes are compared by giving different treatments.

Table 1. Counterbalanced Design

| Group / Material | Group 1 | Group 2 |
|---|---|---|
| Lesson 1 | X | - |
| Lesson 2 | - | X |

Note:
X: Treatment

The steps in this study are:

1. Determining the research population
2. Choosing a research sample, namely two classes with homogeneous characteristics and abilities. Two classes were selected from the research population, class A was selected as experimental class 1 and class B as experimental class 2.
3. Determine two units of subject matter that are comparable in difficulty, length, and complexity of the concepts they contain. Flat side space building materials and curved side space building materials were selected.
4. Giving a pretest to experimental class 1 and experimental class 2 to determine students' initial knowledge about polygonal base solid and curved surface shapes.
5. Carrying out learning of materials for polygonal base solid using GeoGebra in experiment class 1 and conventional learning in experiment class 2 for three meetings.
6. Providing a test at the end of learning to determine students' mathematical spatial ability for building flat side spaces.
7. Carrying out learning of materials to build curved surface shapes with conventional learning in experimental class 1 and using GeoGebra in experimental class 2 for three meetings
8. Give a test at the end of learning to determine the students' mathematical spatial ability to build materials for curved surface shapes.

An illustration of the design of this study is presented in the following table:

Table 2. Experimental Design Using Counterbalanced Design

| Class / Material | Experimental Class 1 | Experimental Class 2 |
|---|---|---|
| Pretest polygonal base solid and curved surface shapes | | |
| Polygonal base solid | Learning using GeoGebra | Conventional learning |
| Posttest polygonal base solid | | |
| Curved surface Shapes | Conventional learning | Learning using GeoGebra |
| Posttest curved surface shapes | | |

The research population is all Tadris Mathematics UIN Siber Syekh Nurjati Cirebon students who take the spatial geometry course in the odd semester of the 2024/2025 Academic Year, which consists of 3 classes: A, B, and C. For the research sample, two classes were selected from the research population: class A was selected as experimental class 1, consisting of 25 students, and class B as experimental class 2, consisting of 28 students. The sample was selected using a *cluster random sampling* technique because all classes have equal characteristics and academic abilities.

To obtain data in this study, two types of instruments were used: 1) Questionnaire to determine students' responses to the use of GeoGebra in the spatial geometry course, and 2) Test to determine the spatial mathematical ability of students in the spatial geometry course. Test questions to measure mathematical spatial ability are arranged based on indicators of mathematical spatial ability, namely: 1) *Spatial Perception*, which is the ability that requires the location of the object being observed horizontally or vertically; 2) *Visualization, which* is the ability to show the rules of change or movement of the constituent of a building, either three-dimensional to two-dimensional or vice versa, 3) *Mental Rotation* is the ability to rotate two-dimensional and three-dimensional objects precisely and accurately, 4) *Spatial Relation* is the ability to understand the arrangement of an object and its parts and their relationship to each other, and 5) *Spatial Orientation* is the ability to observe an object from various circumstances. Before being used, the mathematical spatial ability test instrument was tested first to class C as a trial class.

## 3. RESULTS AND DISCUSSION

### 3.1. Student Response to the Use of GeoGebra

To find out the students' response to the use of GeoGebra, a questionnaire containing 25 statements with five answer choices, namely strongly agree (SS), agree (S), hesitate (R), disagree (TS), strongly disagree (STS) to all students of experimental class 1 and experimental class 2. Based on the student's responses to the questionnaire, it was found that most students generally responded positively to using GeoGebra in the spatial geometry course, with an average percentage of 93.51%, including the strong category.

Figure 1. The Use of GeoGebra in the Spatial Geometry Course

### 3.2. Improvement of Students' Mathematical Spatial Ability

The spatial mathematical ability of students in the spatial geometry course was measured before (pretest) and after (posttest) treatment. The experimental group data is the test result data in the experimental class 1 and 2 when using GeoGebra, while the control group data is the test result data of the experimental class 1 and the experimental class 2 during conventional learning.

After processing the data of pretest scores and posttest of the mathematical spatial ability of students, the experimental group and the control group obtained the following results:

Table 3. Average Pretest and Posttest of Students' Mathematical Spatial Ability

| Material | Group | Pretest | Posttest |
|---|---|---|---|
| Polygonal base solid | Experiment | 38 | 94 |
| | Control | 41 | 81 |
| Curved surface shapes | Experiment | 42 | 96 |
| | Control | 40 | 80 |

From the table above, it can be seen that the average posttest score of the mathematical spatial ability of students in the experimental group using GeoGebra showed higher results compared to the control group, whose learning was conventional, both in the building material of the flat side space and in the building material of the curved side space.

Furthermore, to find out whether the difference in the improvement of students' mathematical spatial ability between the experimental group and the control group is significantly different, it is necessary to conduct a two-mean difference test. Normalized gain data formulated by Hake [22] improves students' mathematical spatial ability and qualifications. The normalized average gain illustrates the improvement of students' mathematical spatial ability.

$$\textit{Normalized gain}\ (\mathrm{g}) = \frac{\text{posttest score} - \text{pretest score}}{\text{ideal score} - \text{pretest score}} \tag{1}$$

The results of the gain index calculation are then interpreted using categories according to Hake [23], namely:

Table 4. Gain Classification (g)

| *Gain* (g) Score | Interpretation |
|---|---|
| g ≥ 0,7 | high |
| 0,3 ≤ g < 0,7 | moderate |
| g < 0,3 | low |

The results of the normalized gain data processing of the two groups on the building materials of the flat side space and the building materials of the curved side space are presented in the following table.

Table 5. Average Normalized Gain of Students' Mathematical Spatial Ability

| Material | Group | N | $\bar{x}$ | Gain *Qualification* | *S* |
|---|---|---|---|---|---|
| polygonal base solid | experiment | 25 | 0, 62 | moderate | 0,142 |
| | control | 28 | 0,33 | moderate | 0,151 |
| curved surface shapes | experiment | 28 | 0,81 | high | 0,121 |
| | control | 25 | 0,56 | moderate | 0,113 |

From the table above, it can be seen that the spatial mathematical ability of students who use GeoGebra (experimental group) has a higher average gain than the spatial ability of students whose learning is conventional (control group), both in the building material of the flat side space and in the building material of the curved side space. This shows that the improvement of the spatial mathematical ability of the experimental group students is higher than the improvement of the spatial mathematical ability of the control group students. To find out the significance of the truth of the above conclusion, it is necessary to test the difference between the two averages. Previously, normality and homogeneity tests were carried out on the gain in both data groups.

After conducting a normality test and a homogeneity test on the gain in the students' mathematical spatial ability data group, it was shown that the gain data group of the experimental group and the control group on the flat side space building material and the curved side space building material, all came from the normally distributed population and had a homogeneous variance. Furthermore, a two-mean difference test was carried out to determine the significance of the average difference in improving the mathematical spatial ability of the two data groups.

To test the above hypothesis, the following statistical hypothesis is formulated:

$H_0$ : The improvement in the spatial ability of students who use GeoGebra in the spatial geometry course is significantly lower or equal to the improvement of the spatial ability of students who are taught conventionally.

$H_1$ : The improvement of the spatial ability of students who use GeoGebra in the spatial geometry course is significantly higher than that of students taught conventionally.

The calculation of the difference test of the two gain averages was carried out at the significance level of $\alpha = 0.05$, presented in the following table:

Table 6. Test of Average Gain of Students' Mathematical Spatial Ability

|  | Material | t | df | Sig. |
|---|---|---|---|---|
| Equal variances assumed | polygonal base solid | 6,754 | 51 | 0,000 |
|  | curved surface shapes | 9,283 | 51 | 0,000 |

From the table above, the p-value (Sig) of the average difference in improving the mathematical spatial ability of experimental and control group students in the flat side space building material is $0.000 < 0.05 = \alpha$. The p-value (Sig) is the average difference in the improvement of the mathematical spatial ability of the experimental and control group students in the curved side space building material is $0.000 < 0.05 = \alpha$, and then the H0 hypothesis is rejected. So, it can be concluded that the improvement of students' mathematical spatial ability, both in the building material of the flat side space and in the building material of the curved side space, which uses GeoGebra, is higher than the improvement of the mathematical spatial ability of students who are taught conventionally at the significance level of $\alpha = 0.05$.

From the hypothesis testing, it can be concluded that even though the research class/sample is exchanged and the material is also replaced, it turns out that the result of the improvement of the spatial ability of students who use GeoGebra is higher than the improvement of the spatial ability of students who are taught conventionally.

Figure 2. The Use of GeoGebra in Flat Side Space Building Materials

This study's results align with the research conducted by Suhaifi et al. [24], which showed differences in learning outcomes between students who used GeoGebra and those who used conventional. The results of this study are also in line with the results of research conducted by Ramantia [25], which shows that the use of GeoGebra affects students' ability to understand mathematical concepts.

Figure 3. The Use of GeoGebra in Building Materials for Arched Side Spaces

In this study, the things that support the mathematical spatial ability of students who use GeoGebra in spatial geometry courses are higher than students who are taught conventionally, one of which is because students in the experimental group, when using GeoGebra, get a more precise visualization or description of a spatial structure, both 2-Dimensional and 3-Dimensional images, many GeoGebra features that can make it easier to learn spatial geometry, can draw spatial structures more accurately, with GeoGebra can rotate or rotate a spatial structure flexibly, students can also observe spatial structures more realistically with the help of GeoGebra so that students become easier in learning spatial geometry. These GeoGebra advantages support improving students' spatial mathematical abilities in spatial geometry courses. Another advantage of using GeoGebra is that it helps students better understand the concept of spatial geometry and increases students' interest in learning spatial geometry because the appearance of GeoGebra can be changed in color, appearance, and size as desired.

## 4. CONCLUSION

This research demonstrates that the use of GeoGebra in spatial geometry learning has a positive impact on students' mathematical spatial abilities. Most students responded positively to using GeoGebra, with an average percentage of 93.51% categorized as strong. Furthermore, the improvement in the spatial mathematical abilities of students using GeoGebra was significantly higher than those taught using conventional methods. This result applies to polygonal base solid and curved-sided geometry topics. Using GeoGebra effectively enhanced students' visualization, comprehension, and interest in spatial geometry concepts. Therefore, integrating GeoGebra as a teaching tool in spatial geometry courses is recommended to improve the effectiveness of the learning process and student outcomes.

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