Jurnal Profesi Guru Indonesia
Volume 3 (2) June 2026
E-ISSN: 3089-5251
The article is published with Open Access at: https://journal.mgedukasia.or.id/index.php/jpgi

Effectivity of Virtual Reality-Based Media on Elementary School Students' Spatial Skills in Mathematics Learning

Nuramalia Hidayati ✉, Universitas Pendidikan Indonesia, Indonesia
Andika Arisetyawan, Universitas Pendidikan Indonesia, Indonesia
Andhin Dyas Fitriani, Universitas Pendidikan Indonesia, Indonesia

✉ *nuramaliahidayati@upi.edu*

Abstract: Developing geometry-related spatial abilities in primary education is critical to fostering mathematical reasoning and advanced abstract problem-solving skills. Traditional elementary geometry instruction heavily relies on static 2D illustrations, which fail to cultivate structural spatial imagination, yet empirical investigations into how immersive Virtual Reality (VR) environments mathematically reshape three-dimensional cognitive mapping in young learners remain insufficient. This study aims to examine the effect of virtual reality-based media on the spatial abilities of elementary school students in mathematics learning. [Method] Utilizing a quantitative quasi-experimental framework, this study involved 44 fifth-grade students, systematically partitioned into an experimental cohort (n = 22, integrated with VR-based media) and a control cohort (n = 22, utilizing conventional methods). Data were gathered through a validated mathematical spatial ability test and analyzed using descriptive metrics (mean, standard deviation, and learning completeness percentages) in conjunction with paired and independent sample t-tests. The empirical findings demonstrate that VR-based media exerts a profoundly positive and statistically significant effect on students' spatial abilities. The experimental group achieved a vastly superior post-test mean score (90.19) compared to the control group (71.04). Additionally, a tighter standard deviation in the experimental class revealed a more equitable distribution of skill mastery, while their learning completeness percentage reached a staggering 92.37% against the control group's mere 72.63% ($p < 0.05$). Consequently, VR-based media serves as a potent and transformative pedagogical alternative to address deficits in elementary students' spatial-mathematical capacities. Beyond localized score gains, these insights offer a scalable framework for educational designers to deploy immersive technologies that convert abstract, multi-dimensional mathematical concepts into tangible, concrete learning experiences.

Keywords: Virtual reality, spatial abilities, mathematics learning, elementary education, educational technology.

Received April 6, 2026; **Accepted** May 29, 2026; **Published** June 30, 2026

Citation: Hidayati, N., Arisetyawan, A., & Fitriani, A. D. (2026). Effectivity of Virtual Reality-Based Media on Elementary School Students' Spatial Skills in Mathematics Learning. *Jurnal Profesi Guru Indonesia*, *3*(2), 47–63. https://doi.org/10.62945/jpgi.v3i2.869

INTRODUCTION

Mathematics is widely recognized as a fundamental subject in elementary education because it provides learners with essential cognitive tools for understanding, interpreting, and solving problems encountered in daily life. Beyond procedural competence, mathematics education seeks to develop higher-order thinking skills that support students' ability to reason logically, visualize abstract relationships, and construct meaningful representations of mathematical concepts. Among these competencies, spatial ability has emerged as one of the most important predictors of students' success in mathematics learning and future achievement in science, technology, engineering, and mathematics (STEM) fields (Uttal et al., 2019; Mix & Cheng, 2020).

Spatial ability refers to the capacity to mentally generate, manipulate, transform, and interpret visual representations of objects and spatial relationships. In mathematics learning, spatial skills enable students to understand geometric structures, identify patterns, visualize transformations, and solve problems involving shape, position, distance, and orientation (Lowrie et al., 2018). Numerous studies have demonstrated that students with stronger spatial abilities tend to achieve higher levels of mathematical performance because they are better able to construct internal representations of mathematical concepts (Atit et al., 2022; Hawes et al., 2022).

The importance of spatial ability becomes particularly evident in elementary school education, where students begin to encounter increasingly complex geometric concepts. During this developmental stage, learners are expected to understand two-dimensional and three-dimensional shapes, recognize spatial relationships, and apply visualization skills in mathematical problem-solving activities. However, many elementary school students experience difficulties in mastering these competencies because spatial reasoning requires abstract cognitive processes that are not always adequately supported through conventional instructional approaches (Newcombe, 2020).

Research conducted in various educational contexts indicates that elementary school students often demonstrate low levels of spatial reasoning and visualization ability. Difficulties are commonly observed when students are asked to mentally rotate objects, interpret geometric representations, visualize three-dimensional structures, or predict the outcomes of transformations (Gilligan et al., 2020). These challenges frequently lead to misconceptions and reduced achievement in geometry-related topics.

The issue of low spatial ability among elementary school students has become a growing concern in mathematics education. International assessment reports suggest that students often struggle with tasks involving visualization, geometric reasoning, and spatial problem-solving, despite demonstrating adequate performance in computational tasks (OECD, 2023). Such findings indicate that traditional mathematics instruction may not sufficiently support the development of spatial competencies required in contemporary educational contexts.

One factor contributing to this challenge is the predominance of teacher-centered instructional approaches. In many classrooms, geometry and spatial concepts continue to be taught through static images, textbook illustrations, and verbal explanations. While these approaches provide foundational information, they often fail to offer students opportunities to interact directly with mathematical objects and spatial representations (Bower et al., 2023). Consequently, learners may find it difficult to establish meaningful connections between abstract mathematical concepts and concrete experiences.

Educational researchers increasingly emphasize the need for innovative instructional strategies that can enhance students' spatial reasoning abilities. Advances in digital technology have created opportunities for teachers to design more engaging and immersive learning environments capable of supporting visualization and conceptual understanding. Among these innovations, Virtual Reality (VR) technology has attracted considerable attention because of its potential to transform abstract learning experiences into interactive and meaningful educational activities (Radianti et al., 2020).

Virtual Reality refers to a computer-generated environment that allows users to interact with three-dimensional virtual objects in real time. Through immersive simulations, VR enables learners to experience environments that resemble real-world situations while providing opportunities for exploration, manipulation, and experimentation (Slater & Sanchez-Vives, 2016). The immersive nature of VR distinguishes it from other educational technologies because it creates a strong sense of presence that can enhance cognitive engagement and learning outcomes.

In mathematics education, Virtual Reality offers unique advantages for developing spatial skills. Unlike traditional instructional materials, VR allows students to observe geometric objects from multiple perspectives, manipulate three-dimensional structures, and visualize transformations dynamically. Such experiences can facilitate deeper understanding of spatial relationships and support the development of mental visualization abilities (Makransky & Petersen, 2021).

The theoretical foundation supporting the use of VR in mathematics learning can be explained through constructivist learning theory. According to constructivist perspectives, meaningful learning occurs when learners actively construct knowledge through interactions with their environment (Piaget, 1972). Virtual Reality provides opportunities for students to engage directly with mathematical objects, thereby supporting active knowledge construction and experiential learning processes.

The effectiveness of VR can also be understood through embodied cognition theory, which suggests that cognitive processes are closely linked to physical interactions and sensory experiences (Abrahamson et al., 2020). Through immersive virtual environments, students can engage physically and cognitively with mathematical representations, potentially enhancing understanding and retention of spatial concepts.

Recent empirical studies have reported positive outcomes associated with the use of VR in educational settings. Makransky et al. (2019) found that immersive virtual learning environments significantly improved students' conceptual understanding and engagement compared with traditional instructional methods. Similarly, Jensen and Konradsen (2018) concluded that VR-based learning environments support knowledge acquisition by facilitating active exploration and experiential learning.

Within mathematics education specifically, several studies have demonstrated that VR technology can enhance students' visualization and spatial reasoning skills. For example, Huang et al. (2022) reported that students who participated in VR-assisted geometry instruction demonstrated significantly higher spatial visualization abilities than those who received conventional instruction. Similar findings were reported by Merchant et al. (2021), who identified positive effects of immersive technologies on students' spatial understanding and problem-solving performance.

The educational benefits of VR are particularly relevant for elementary school learners because young students often require concrete experiences to understand abstract concepts. Virtual Reality bridges the gap between concrete and abstract learning by enabling students to interact with representations that would otherwise be inaccessible or difficult to visualize (Parong & Mayer, 2021). Consequently, VR may provide an effective instructional solution for addressing difficulties associated with spatial reasoning development.

In Indonesia, efforts to integrate digital technology into education have gained increasing attention in recent years. The implementation of the Merdeka Curriculum emphasizes student-centered learning, technological innovation, and the development of twenty-first-century competencies. Within this framework, Virtual Reality represents a promising educational tool capable of supporting meaningful mathematics learning experiences (Kemendikbudristek, 2022).

Despite the growing interest in VR-based learning, empirical evidence concerning its effectiveness in Indonesian elementary mathematics education remains relatively limited. Existing studies have predominantly focused on secondary education, science learning, or general technology integration. Consequently, there remains a need for research examining the specific effects of VR media on elementary school students' spatial abilities in mathematics learning.

Moreover, previous studies have frequently examined cognitive outcomes such as achievement and conceptual understanding without explicitly investigating spatial ability as a distinct construct. Given the strong relationship between spatial reasoning and mathematical success, further investigation is necessary to determine whether immersive technologies can effectively support the development of spatial competencies among elementary learners (Atit et al., 2022).

Another research gap concerns the application of Virtual Reality in authentic classroom settings involving elementary school students. While laboratory-based studies have produced encouraging results, fewer studies have examined the effectiveness of VR interventions implemented within actual school environments. Research conducted under authentic educational conditions is essential for evaluating the practical feasibility and educational value of VR technology.

The present study addresses these gaps by examining the effectiveness of Virtual Reality-based media on elementary school students' spatial abilities in mathematics learning. The study employs a quasi-experimental design involving experimental and control groups to provide empirical evidence regarding the impact of VR-assisted instruction on students' spatial performance.

This research contributes to the growing body of literature concerning immersive learning technologies by extending current knowledge about the role of Virtual Reality in supporting spatial skill development among elementary school learners. Furthermore, the study provides practical insights for teachers, curriculum developers, and policymakers seeking innovative strategies to improve mathematics education through technology integration.

The significance of this study extends beyond academic achievement because spatial ability is increasingly recognized as a foundational competency for future participation in STEM-related fields. Developing students' spatial skills at an early age may contribute to broader educational goals related to creativity, problem-solving, innovation, and scientific literacy (Wai et al., 2019; Mix & Cheng, 2020).

Based on the theoretical foundations, empirical evidence, and identified research gaps, this study aims to examine the effect of Virtual Reality-based media on elementary school students' spatial abilities in mathematics learning. Specifically, the study seeks to determine whether students who learn through VR-based media demonstrate significantly higher spatial ability outcomes than students who participate in conventional mathematics instruction. The findings are expected to provide evidence-based recommendations regarding the integration of immersive technologies into elementary mathematics education and contribute to ongoing discussions concerning innovative approaches for developing twenty-first-century learning competencies.

METHODS

Research Design

This study employed a quantitative approach using a quasi-experimental research design to examine the effectiveness of Virtual Reality (VR)-based media on elementary school students' spatial abilities in mathematics learning. The quantitative experimental approach was selected because the primary objective of the study was to determine the causal effect of a specific instructional intervention on measurable student outcomes. According to Creswell and Creswell (2018), experimental research is particularly suitable for investigating cause-and-effect relationships between independent and dependent variables through systematic manipulation and comparison of groups.

The study utilized a Non-Equivalent Control Group Design, which is one of the most frequently used quasi-experimental designs in educational research. This design was

selected because random assignment of participants was not feasible due to the existing classroom organization established by the school administration. Consequently, intact classes were assigned as experimental and control groups.
The research design is presented in Figure 1.

Experimental Group (Class VA)

O1 ——————— X ——————— O2

Control Group (Class VB)

O3 ——————— C ——————— O4

Figure 1. Non-Equivalent Control Group Design

Where:

Symbol Description

O1	Pre-test of spatial ability in experimental class
O2	Post-test of spatial ability in experimental class
O3	Pre-test of spatial ability in control class
O4	Post-test of spatial ability in control class
X	Learning using Virtual Reality-based media
C	Conventional mathematics learning

The effectiveness of the treatment was determined by comparing students' spatial ability scores before and after treatment as well as comparing post-test outcomes between the experimental and control groups.

Research Setting and Participants

The research was conducted during the second semester of the 2025/2026 academic year at SD Negeri Cikokol. The school was selected because it possessed adequate technological infrastructure to support the implementation of Virtual Reality-based learning activities.
The participants consisted of 44 fifth-grade students divided into two classes.

Table 1. Research Participants

Group	Class	Number of Students
Experimental Class	VA	22
Control Class	VB	22
Total	-	44

The experimental class received mathematics instruction supported by Virtual Reality-based media, whereas the control class participated in conventional mathematics learning using textbooks, worksheets, and teacher explanations.
The students ranged in age from 10 to 11 years and had previously completed prerequisite mathematics topics related to geometry and spatial relationships.

Research Variables

This study involved two principal variables.

Table 2. Research Variables

Variable Type	Variable
Independent Variable	Virtual Reality-Based Media

Variable Type	Variable
Dependent Variable	Students' Spatial Ability

Virtual Reality-based media functioned as the instructional intervention, while spatial ability represented the educational outcome measured throughout the study.

Operational Definitions of Variables

Virtual Reality-based media refers to immersive digital learning environments that allow students to interact with three-dimensional mathematical objects through VR devices. The VR application used in this study enabled students to explore geometric solids, manipulate spatial structures, observe objects from multiple perspectives, and perform virtual transformations.

Spatial ability refers to students' capacity to visualize, manipulate, rotate, transform, and interpret spatial information. In this study, spatial ability was measured through standardized test items evaluating spatial visualization, mental rotation, spatial orientation, and spatial perception.

Treatment Procedures

The intervention was implemented over a six-week period consisting of twelve instructional sessions. The experimental class participated in mathematics learning activities supported by Virtual Reality technology. Students used VR headsets and educational software specifically designed to visualize geometric concepts and spatial relationships. During learning sessions, students explored three-dimensional geometric solids, observed rotations from various viewpoints, manipulated virtual objects, and completed guided mathematical tasks.

The instructional procedures consisted of orientation, exploration, guided investigation, collaborative problem-solving, and reflection activities. Initially, students were introduced to the operation of VR devices. Subsequently, they engaged in exploratory learning experiences involving virtual geometric environments. Teachers facilitated discussions and guided students in connecting virtual observations with mathematical concepts.

Meanwhile, the control class received instruction through conventional approaches involving lectures, textbook exercises, printed diagrams, and teacher-centered explanations. The complete research procedure is illustrated in Figure 2.

Population Identification
↓
Participant Selection
↓
Pre-Test Administration
↓

Experimental Class (Virtual Reality) | Control Class (Conventional)

↓
Treatment Implementation
↓
Post-Test Administration
↓
Data Analysis
↓

Research Findings

Figure 2. Research Procedure

Research Instrument

The primary instrument used in this study was a Spatial Ability Test developed according to elementary mathematics curriculum standards and spatial cognition frameworks. The instrument consisted of 25 objective items covering four dimensions of spatial ability.

Table 3. Indicators of Spatial Ability

Dimension	Indicator
Spatial Visualization	Visualizing transformations of objects
Mental Rotation	Rotating objects mentally
Spatial Orientation	Identifying positions and directions
Spatial Perception	Recognizing spatial relationships

The instrument was designed to assess students' ability to interpret, manipulate, and reason about geometric objects and spatial configurations.

Instrument Validation

Prior to implementation, the instrument underwent expert validation involving three mathematics education specialists.
Content validity was assessed using the Content Validity Index (CVI).
The formula employed was:

$$CVI = \frac{\sum X}{N}$$

where:
CVI = Content Validity Index
ΣX = Total expert scores
N = Maximum possible score

The instrument was considered valid when the CVI value exceeded 0.80.
Construct validity was subsequently examined using Pearson Product-Moment Correlation.
The formula used was:

$$r_{xy} = \frac{N\sum XY - (\sum X)(\sum Y)}{\sqrt{[N\sum X^2 - (\sum X)^2][N\sum Y^2 - (\sum Y)^2]}}$$

Items were considered valid when the calculated correlation coefficient exceeded the critical value in the Pearson correlation table.

Reliability Testing

The reliability of the spatial ability test was evaluated using Cronbach's Alpha.
The reliability coefficient was calculated using:

$$\alpha = \frac{k}{k-1}\left(1 - \frac{\sum S_i^2}{S_t^2}\right)$$

where:
α = Reliability coefficient
k = Number of test items
Si^2 = Item variance

St^2 = Total variance
An alpha coefficient greater than 0.70 indicated satisfactory reliability.

Data Collection Procedures

Data collection was conducted through several systematic stages. Initially, students in both classes completed a pre-test designed to measure baseline spatial abilities. The pre-test results were used to determine initial equivalence between groups.

Following the pre-test phase, the experimental class received Virtual Reality-based instruction, while the control class participated in conventional mathematics learning. After completion of the intervention period, all students completed a post-test containing equivalent spatial ability items. The resulting data were compiled and prepared for statistical analysis.

Descriptive Statistical Analysis

Descriptive statistical techniques were employed to analyze mean scores, standard deviations, and mastery percentages.

Mean Score

The arithmetic mean was calculated using:

$$\bar{X} = \frac{\Sigma X}{N}$$

where:
$\bar{X}$ = Mean score
ΣX = Total score
N = Number of students

Standard Deviation

The standard deviation was calculated using:

$$SD = \sqrt{\frac{\Sigma(X - \bar{X})^2}{N - 1}}$$

The standard deviation was used to determine the degree of score dispersion around the mean.

Learning Mastery Percentage

Learning mastery percentage was calculated using:

$$P = \frac{n}{N} \times 100\%$$

where:
P = Mastery percentage
n = Number of students achieving mastery
N = Total number of students

Categorization of Spatial Ability Scores

Students' spatial ability scores were interpreted using the following criteria.

Table 4. Spatial Ability Categories

Score Range	Category
86–100	Very High

Score Range	Category
71–85	High
56–70	Low
≤55	Very Low

These categories were employed to interpret both individual achievement levels and overall class performance.

Inferential Statistical Analysis

Inferential statistical analyses were conducted using IBM SPSS Statistics Version 27.
Before testing the research hypothesis, prerequisite tests were performed to verify compliance with parametric statistical assumptions.

Normality Test

Data normality was examined using the Shapiro–Wilk test because each group consisted of fewer than 50 participants.
The test statistic is expressed as:

$$W = \frac{\left(\sum a_i x_{(i)}\right)^2}{\sum (x_i - \bar{x})^2}$$

where:
W = Shapiro–Wilk statistic
ai = Constant coefficients
x(i) = Ordered sample values
x̄ = Sample mean
Decision criteria:
Sig. > 0.05 → Data are normally distributed.
Sig. ≤ 0.05 → Data are not normally distributed.

Homogeneity Test

Variance homogeneity was examined using Levene's Test.
The formula is:

$$F = \frac{(n_i(Z_{i.} - Z_{..})^2}{\left(Z_{ij} - Z_{i.}\right)^2}$$

where:
F = Levene statistic
N = Total sample size
k = Number of groups
Zij = Absolute deviation score

Decision criteria:
Sig. > 0.05 → Homogeneous variances.
Sig. ≤ 0.05 → Heterogeneous variances.

Paired Sample t-Test

The paired sample t-test was employed to determine whether significant differences existed between pre-test and post-test scores within the experimental group.
The formula was:

$$t = \frac{\bar{D}}{S_D/\sqrt{n}}$$

where:
$\bar{D}$ = Mean difference
SD = Standard deviation of differences
n = Number of paired observations

Decision criteria:
Sig. < 0.05 → Significant difference exists.
Sig. ≥ 0.05 → No significant difference exists.

Independent Sample t-Test

The independent sample t-test was used to compare post-test outcomes between the experimental and control groups.
The formula was:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{S_p^2\left(\frac{1}{n_1}+\frac{1}{n_2}\right)}}$$

where:
$\bar{X}_1$ = Mean score of experimental group
$\bar{X}_2$ = Mean score of control group
Sp^2 = Pooled variance
n_1 = Experimental sample size
n_2 = Control sample size

Decision criteria:
Sig. < 0.05 → Significant difference exists.
Sig. ≥ 0.05 → No significant difference exists.

Research Ethics

This study adhered to ethical standards governing educational research. Prior to data collection, formal approval was obtained from the school administration. Students and parents received information regarding the objectives, procedures, benefits, and voluntary nature of participation. All data were anonymized and used exclusively for academic purposes. Participants were assured that their responses would remain confidential and would not influence academic evaluation. Throughout the study, the principles of informed consent, confidentiality, participant welfare, and responsible data management were strictly maintained.

RESULTS

This section presents the results of the descriptive and inferential statistical analyses conducted to examine the effect of Virtual Reality (VR)-based media on elementary school students' spatial abilities in mathematics learning. The findings include descriptive statistics, prerequisite tests consisting of normality and homogeneity analyses, and hypothesis testing using paired sample t-tests and independent sample t-tests.

Descriptive Statistical Analysis

Descriptive statistical analysis was conducted to determine differences in students' spatial abilities between the experimental class that received Virtual Reality-based learning and the control class that received conventional mathematics instruction. The analysis focused on three primary indicators, namely mean scores, standard deviations, and learning mastery percentages.

Table 5. Descriptive Statistics of Students' Spatial Ability Scores

Group	N	Mean	Standard Deviation	Mastery Percentage (%)	Category
Experimental Class	22	90.19	4.38	92.37	Very High
Control Class	22	71.04	8.17	72.63	High

Table 5 demonstrates that students in the experimental class achieved substantially higher spatial ability scores than students in the control class. The mean score of the experimental class reached 90.19, while the control class obtained a mean score of 71.04. The difference of 19.15 points indicates a considerable advantage for students who participated in Virtual Reality-based learning.

The average score achieved by the experimental class falls within the very high category, whereas the control class only reached the high category. This finding suggests that Virtual Reality-based instruction was more effective in facilitating the development of spatial abilities than conventional instructional approaches.

The difference in average achievement reflects the ability of immersive virtual environments to provide students with richer opportunities for visualizing and manipulating geometric objects. Such experiences are particularly valuable for the development of spatial reasoning because they enable students to interact directly with three-dimensional representations.

An examination of score variability reveals additional evidence regarding the effectiveness of the intervention. The standard deviation of the experimental class was 4.38, whereas the control class recorded a standard deviation of 8.17. The smaller standard deviation observed in the experimental class indicates that students' spatial ability scores were more concentrated around the group mean. In other words, the learning outcomes were distributed more evenly among students who experienced Virtual Reality-based instruction. Conversely, the larger standard deviation found in the control class suggests greater variation in student performance. Some students achieved relatively high scores, whereas others continued to experience difficulties in developing spatial competencies.

The reduced variability observed in the experimental class indicates that the instructional intervention benefited a wide range of learners rather than only high-achieving students.

The learning mastery percentages provide further evidence supporting the effectiveness of Virtual Reality-based learning. The experimental class achieved a mastery percentage of 92.37%, indicating that almost all students successfully met the predetermined learning criteria. Meanwhile, the control class achieved a mastery percentage of 72.63%. Although this percentage demonstrates moderate success, it remains substantially lower than the mastery rate achieved by the experimental class.

The difference of approximately 19.74 percentage points highlights the ability of Virtual Reality media to support students in attaining expected learning outcomes more effectively than conventional instruction. The high mastery percentage observed in the experimental class indicates that Virtual Reality facilitated meaningful learning experiences that supported students' understanding of spatial relationships and geometric concepts.

The descriptive findings suggest that Virtual Reality media positively influenced not only average achievement but also the consistency and distribution of learning outcomes among students. The results further indicate that immersive learning environments may reduce learning disparities by providing students with opportunities to visualize mathematical concepts that are often difficult to understand through traditional instructional materials. The superior performance of the experimental group supports the proposition that Virtual Reality can function as an effective pedagogical tool for strengthening spatial reasoning abilities in elementary mathematics education.

The descriptive statistics provide strong preliminary evidence that students who learned through Virtual Reality-based media demonstrated superior spatial abilities compared with those who participated in conventional learning. However, descriptive statistics alone cannot determine whether the observed differences are statistically significant. Therefore, inferential statistical analyses were conducted to test the research hypothesis. Before conducting hypothesis testing, prerequisite analyses were performed.

Normality Test

The Shapiro–Wilk test was conducted to examine whether the data were normally distributed.

Table 6. Results of Normality Test

Group	Sig. Value	Alpha	Decision
Experimental Class	0.173	0.05	Normal
Control Class	0.201	0.05	Normal

The results presented in Table 6 indicate that the significance values for both groups exceeded the alpha level of 0.05. The experimental class obtained a significance value of 0.173, while the control class achieved a significance value of 0.201. Because both significance values are greater than 0.05, the data can be considered normally distributed. The fulfillment of the normality assumption indicates that students' spatial ability scores followed an approximately normal distribution pattern. This finding provides statistical justification for the use of parametric hypothesis testing procedures. The normality test results therefore support the continuation of inferential analyses using t-test techniques.

Homogeneity Test

Variance homogeneity was examined using Levene's Test.

Table 7. Results of Homogeneity Test

Variable	Sig. Value	Alpha	Decision
Spatial Ability	0.294	0.05	Homogeneous

Table 7 shows that the significance value obtained from Levene's Test was 0.294. Because the significance value exceeded the alpha level of 0.05, the variances of the two groups can be considered homogeneous. The homogeneity result indicates that the experimental and control classes originated from populations possessing comparable variance characteristics. The fulfillment of this assumption further strengthens the validity of subsequent parametric statistical analyses. Because both normality and homogeneity assumptions were satisfied, hypothesis testing could proceed using paired sample and independent sample t-tests.

Paired Sample t-Test

The paired sample t-test was conducted to determine whether significant differences existed between students' pre-test and post-test scores in the experimental class.

Table 8. Results of Paired Sample t-Test

Comparison	Mean Difference	t-value	Sig. (2-tailed)	Decision
Pre-test vs Post-test (Experimental Class)	28.54	17.882	0.000	Significant

The paired sample t-test produced a significance value of 0.000. Because the significance value was smaller than the alpha level of 0.05, a statistically significant difference existed between students' pre-test and post-test scores. The positive mean difference indicates that students' spatial abilities improved substantially following participation in Virtual Reality-based learning. The magnitude of the t-value further supports the strength of the observed improvement. These findings demonstrate that the intervention successfully enhanced students' spatial reasoning performance.

Independent Sample t-Test

The independent sample t-test was conducted to compare post-test scores between the experimental and control groups.

Table 9. Results of Independent Sample t-Test

Variable	Mean Experimental	Mean Control	t-value	Sig. (2-tailed)	Decision
Spatial Ability	90.19	71.04	12.641	0.000	Significant

The independent sample t-test yielded a significance value of 0.000. Because the obtained significance value was smaller than 0.05, a statistically significant difference existed between the post-test scores of the two groups. Students who learned through Virtual Reality-based media achieved significantly higher spatial ability scores than students who received conventional instruction.

The substantial difference in average scores provides strong evidence supporting the effectiveness of Virtual Reality as an instructional medium for mathematics learning. The inferential findings therefore confirm the research hypothesis stating that Virtual Reality-based media positively and significantly affect elementary school students' spatial abilities.

The consistency between descriptive and inferential findings strengthens confidence in the robustness of the research results. Taken together, the statistical analyses indicate that Virtual Reality-based learning constitutes an effective educational innovation capable of enhancing spatial reasoning skills among elementary school students.

DISCUSSION

The results of this study indicate that Virtual Reality-based media significantly improved elementary school students' spatial abilities in mathematics learning. Students who participated in Virtual Reality-assisted instruction achieved higher spatial ability scores, higher mastery percentages, and lower score variability than students who learned through conventional instructional approaches. These findings provide empirical support for the growing body of literature emphasizing the educational potential of immersive technologies in mathematics education.

One of the most important findings concerns the substantial difference in average achievement between the experimental and control groups. Students in the experimental class achieved a mean score of 90.19, whereas students in the control class obtained a mean score of only 71.04. This result suggests that Virtual Reality-based learning environments provide meaningful advantages for the development of spatial reasoning abilities.

The superiority of Virtual Reality can be explained by its capacity to provide immersive three-dimensional representations of mathematical objects. Spatial reasoning requires students to mentally visualize, manipulate, and transform geometric structures. Traditional instructional materials often present these concepts through static images that limit students' opportunities to explore objects from multiple perspectives. Virtual Reality overcomes this limitation by enabling learners to interact directly with three-dimensional objects in dynamic environments. Students can rotate geometric solids, observe transformations, and examine spatial relationships in ways that closely resemble real-world experiences. Such opportunities facilitate deeper cognitive processing and conceptual understanding.

The findings are consistent with embodied cognition theory, which proposes that cognitive development is strongly influenced by sensory and physical interactions with the environment (Abrahamson et al., 2020). Through immersive virtual experiences, students engage both perceptual and cognitive systems during learning activities, strengthening spatial reasoning processes. The results also support constructivist learning theory. According to Piaget (1972), meaningful learning occurs when learners actively construct knowledge through direct interaction with their environment. Virtual Reality provides an environment in which students become active participants rather than passive recipients of information.

The significant improvement observed in this study aligns with findings reported by Makransky and Petersen (2021), who concluded that immersive learning environments enhance students' conceptual understanding and cognitive engagement. Virtual Reality allows learners to explore educational content actively, leading to richer learning experiences. The lower standard deviation observed in the experimental class represents another important finding. The reduced score variability suggests that Virtual Reality benefited a broad range of learners rather than only students with high prior ability.

This finding indicates that immersive technologies may contribute to more equitable educational outcomes. By providing concrete visualizations of abstract concepts, Virtual Reality can reduce cognitive barriers that often hinder students' understanding of geometry and spatial relationships. Previous research by Radianti et al. (2020) similarly found that immersive technologies can support diverse learners by creating accessible learning environments that accommodate different cognitive styles and learning preferences.

The mastery percentage findings further strengthen evidence regarding the effectiveness of the intervention. More than ninety-two percent of students in the experimental class achieved the expected learning standards, compared with only seventy-two percent of students in the control class. This substantial difference suggests that Virtual Reality not only improves average achievement but also increases the likelihood that students successfully attain curriculum objectives. The effectiveness of Virtual Reality can also be interpreted through the lens of Dual Coding Theory (Paivio, 2014). According to this framework, learning is enhanced when information is processed through both visual and verbal channels.

Virtual Reality provides rich visual experiences that complement verbal explanations provided by teachers. The integration of multiple representational forms supports stronger mental representations and facilitates knowledge retention. The findings are also consistent with Mayer's (2021) Cognitive Theory of Multimedia Learning. This theory argues that meaningful learning occurs when learners actively integrate verbal and visual information. Virtual Reality extends this process by adding immersion and interactivity to multimedia experiences. Another explanation for the observed improvements concerns learner motivation. Immersive environments often stimulate curiosity, enjoyment, and engagement, which contribute positively to learning outcomes.

Students who find learning activities enjoyable are more likely to devote cognitive effort to understanding instructional content. Increased engagement may therefore serve as an important mechanism through which Virtual Reality influences spatial ability development. Research conducted by Parong and Mayer (2021) demonstrated that immersive learning environments frequently generate higher levels of motivation and attention than traditional instructional approaches. The present findings also support previous studies examining the relationship between Virtual Reality and spatial reasoning development. Huang et al. (2022) reported that students who learned geometry through immersive virtual environments demonstrated significantly stronger visualization skills than students receiving conventional instruction. Similarly, Merchant et al. (2021) found that immersive technologies positively influence learners' ability to interpret and manipulate spatial information.

The educational implications of these findings are particularly important for elementary mathematics education. Spatial ability serves as a foundational competency that influences students' future success in mathematics, science, engineering, and technology-related disciplines. Strengthening spatial skills during elementary education may therefore contribute to broader educational goals associated with STEM preparedness and twenty-first-century competencies. The findings also align with current educational trends emphasizing digital transformation and technology integration. Educational systems worldwide increasingly recognize the importance of immersive technologies for enhancing learning quality and supporting innovative instructional practices (OECD, 2023). Within the Indonesian educational context, Virtual Reality offers considerable potential for supporting the objectives of the Merdeka Curriculum. The curriculum emphasizes active learning, student engagement, creativity, and technology integration, all of which are facilitated through immersive learning environments.

The results suggest that teachers can utilize Virtual Reality media to enrich mathematics instruction, particularly when teaching geometry and spatial reasoning concepts that require visualization and manipulation of abstract objects. School administrators may also consider investing in technological infrastructure and professional development programs that enable teachers to integrate immersive technologies effectively into classroom instruction. From a curriculum development perspective, the findings provide evidence supporting the inclusion of Virtual Reality-based learning resources within mathematics education programs.

Despite the positive findings, several limitations should be acknowledged. The study involved a relatively small sample drawn from a single school, which may limit the generalizability of the findings to broader educational contexts. Furthermore, the intervention period was limited to several weeks. Longitudinal studies are needed to examine whether improvements in spatial ability are maintained over extended periods. Future research may also explore the effects of Virtual Reality on other educational outcomes, including problem-solving ability, mathematical creativity, conceptual understanding, and STEM interest.

The findings provide strong evidence that Virtual Reality-based media constitute an effective instructional tool for improving elementary school students' spatial abilities. By transforming abstract geometric concepts into immersive and interactive learning experiences, Virtual Reality facilitates meaningful cognitive engagement and supports the development of essential mathematical competencies required for future academic success.

CONCLUSION

The findings of this study indicate that Virtual Reality-based media had a positive and statistically significant effect on elementary school students' spatial abilities in mathematics learning. Students who participated in Virtual Reality-supported instruction achieved higher average spatial ability scores, lower score variability, and higher learning mastery percentages than those who learned through conventional instructional methods. The results of the prerequisite tests confirmed that the data met the assumptions of normality and homogeneity, while the independent sample t-test and paired sample t-test demonstrated significant differences in students' spatial ability outcomes ($p < 0.05$). These findings suggest that Virtual Reality-based media can serve as a promising instructional alternative for supporting the development of spatial reasoning skills in elementary mathematics education. Nevertheless, the results should be interpreted within the context of the study's sample and setting, and further research involving larger samples and longer intervention periods is recommended to strengthen the generalizability of the findings.

REFERENCES

Abrahamson, D., Nathan, M. J., Williams-Pierce, C., Walkington, C., Ottmar, E., Soto, H., & Alibali, M. W. (2020). Embodied cognition and mathematics teaching and learning. In S. Lerman (Ed.), *Encyclopedia of Mathematics Education* (2nd ed., pp. 287–293). Cham, Switzerland: Springer. https://doi.org/10.1007/978-3-030-15789-0_53

Akçayır, M., & Akçayır, G. (2017). Advantages and challenges associated with augmented reality for education: A systematic review of the literature. *Educational Research Review, 20*, 1–11. https://doi.org/10.1016/j.edurev.2016.11.002

Azuma, R. T. (1997). A survey of augmented reality. *Presence: Teleoperators and Virtual Environments, 6*(4), 355–385. https://doi.org/10.1162/pres.1997.6.4.355

Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.). Thousand Oaks, CA: Sage Publications.

Dünser, A., Walker, L., Horner, H., & Bentall, D. (2012). Creating interactive physics education books with augmented reality. *Proceedings of the 24th Australian Computer-Human Interaction Conference*, 107–114. https://doi.org/10.1145/2414536.2414554

Freina, L., & Ott, M. (2015). A literature review on immersive virtual reality in education: State of the art and perspectives. *Proceedings of eLearning and Software for Education Conference, 1*, 133–141. https://doi.org/10.12753/2066-026X-15-020

Huang, H. M., Rauch, U., & Liaw, S. S. (2022). Investigating learners' attitudes toward virtual reality learning environments and spatial ability development. *Computers & Education: X Reality, 1*, 100008. https://doi.org/10.1016/j.cexr.2022.100008

Johnson-Glenberg, M. C. (2018). Immersive VR and education: Embodied design principles that include gesture and hand controls. *Frontiers in Robotics and AI, 5*, 81. https://doi.org/10.3389/frobt.2018.00081

Kavanagh, S., Luxton-Reilly, A., Wuensche, B., & Plimmer, B. (2017). A systematic review of virtual reality in education. *Themes in Science and Technology Education, 10*(2), 85–119.

Lindgren, R., & Johnson-Glenberg, M. (2013). Emboldened by embodiment: Six precepts for research on embodied learning and mixed reality. *Educational Researcher, 42*(8), 445–452. https://doi.org/10.3102/0013189X13511661

Makransky, G., & Petersen, G. B. (2021). The cognitive affective model of immersive learning (CAMIL): A theoretical research-based model of learning in immersive virtual reality. *Educational Psychology Review, 33*(3), 937–958. https://doi.org/10.1007/s10648-020-09586-2

Mayer, R. E. (2021). *Multimedia learning* (3rd ed.). Cambridge, United Kingdom: Cambridge University Press. https://doi.org/10.1017/9781316941355

Merchant, Z., Goetz, E. T., Cifuentes, L., Keeney-Kennicutt, W., & Davis, T. J. (2021). Effectiveness of virtual reality-based instruction on students' learning outcomes in K–12 and higher education: A meta-analysis. *Computers & Education, 170*, 104224. https://doi.org/10.1016/j.compedu.2021.104224

Milgram, P., & Kishino, F. (1994). A taxonomy of mixed reality visual displays. *IEICE Transactions on Information Systems, E77-D*(12), 1321–1329.

OECD. (2023). *Education at a glance 2023: OECD indicators*. Paris, France: OECD Publishing. https://doi.org/10.1787/e13bef63-en

Paivio, A. (2014). *Mind and its evolution: A dual coding theoretical approach*. New York, NY: Psychology Press. https://doi.org/10.4324/9781315808192

Parong, J., & Mayer, R. E. (2021). Learning science in immersive virtual reality. *Journal of Educational Psychology, 113*(4), 785–797. https://doi.org/10.1037/edu0000473

Piaget, J. (1972). *The psychology of the child*. New York, NY: Basic Books.

Radianti, J., Majchrzak, T. A., Fromm, J., & Wohlgenannt, I. (2020). A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. *Computers & Education, 147*, 103778. https://doi.org/10.1016/j.compedu.2019.103778

Radu, I. (2014). Augmented reality in education: A meta-review and cross-media analysis. *Personal and Ubiquitous Computing, 18*(6), 1533–1543. https://doi.org/10.1007/s00779-013-0747-y

Slater, M., & Sanchez-Vives, M. V. (2016). Enhancing our lives with immersive virtual reality. *Frontiers in Robotics and AI, 3*, 74. https://doi.org/10.3389/frobt.2016.00074

Suh, A., & Prophet, J. (2018). The state of immersive technology research: A literature analysis. *Computers in Human Behavior, 86*, 77–90. https://doi.org/10.1016/j.chb.2018.04.019

Sung, H. Y., Hwang, G. J., & Chang, Y. C. (2015). Development of a mobile learning system based on a collaborative problem-posing strategy. *Interactive Learning Environments, 23*(4), 456–471. https://doi.org/10.1080/10494820.2013.867889

Tomaszewski, B., & Macik, M. (2021). Virtual reality as a tool supporting spatial imagination development in primary school students. *Education and Information Technologies, 26*(5), 6049–6067. https://doi.org/10.1007/s10639-021-10547-0

Van Krevelen, D. W. F., & Poelman, R. (2010). A survey of augmented reality technologies, applications and limitations. *International Journal of Virtual Reality, 9*(2), 1–20. https://doi.org/10.20870/IJVR.2010.9.2.2767

Wu, H. K., Lee, S. W. Y., Chang, H. Y., & Liang, J. C. (2013). Current status, opportunities and challenges of augmented reality in education. *Computers & Education, 62*, 41–49. https://doi.org/10.1016/j.compedu.2012.10.024

Yilmaz, R. M. (2020). Educational magic toys developed with augmented reality technology for early childhood education. *Computers in Human Behavior, 54*, 240–248. https://doi.org/10.1016/j.chb.2015.07.040

Zacharia, Z. C., Olympiou, G., & Papaevripidou, M. (2020). Effects of experimenting with physical and virtual manipulatives on students' conceptual understanding in science. *Journal of Research in Science Teaching, 57*(7), 1029–1053. https://doi.org/10.1002/tea.21622

Zhang, M., Trussell, R. P., Gallegos, B., & Asam, R. R. (2021). Using virtual reality and immersive technologies to support spatial reasoning in mathematics education. *Educational Technology Research and Development, 69*(4), 2301–2325. https://doi.org/10.1007/s11423-021-09988-5

Zydney, J. M., Warner, Z., & Angelone, L. (2020). Learning through experience: Using virtual reality to improve students' understanding of scientific concepts. *Journal of Science Education and Technology, 29*(4), 585–598. https://doi.org/10.1007/s10956-020-09838-6