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PAPER

The Effects of Augmented Reality Geometry Learning Applications on Spatial Visualization Ability for Lower Primary School Pupils

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ABSTRACT

Geometry is considered a fundamental component to be mastered in the elementary school mathematics curriculum. Lower primary school pupils frequently experience obstacles because of the abstract nature of geometric concepts and the requirement for spatial visualization skills, which are necessary for strengthening their conceptual understanding. Augmented reality (AR) technology offers a promising solution by providing visual representations of geometric shapes. Thus, this study aimed to investigate the effects of AR technology in primary school education on pupils' spatial visualization abilities in geometry. Employing a quasi-experimental pre- and post-test research design, this study involved 61 second-grade pupils from two Northern Malaysian primary schools. The selection of schools followed cluster sampling techniques, while intact groups were utilized to select samples. Data were collected from two groups: an experimental group that utilized the LearnGeoAR applications and a control group that employed conventional teaching methods to learn geometric shapes. This study used the spatial visualization ability test (SVAT) instrument, grounded in Van Hiele's theory of geometric thinking. The findings revealed that the experimental group, which utilized AR applications, exhibited a higher mean score in pupils' spatial visualization ability in geometry compared to the control group. Additionally, the experiment demonstrated a moderate effect on both groups. This finding highlights the potential of AR technology in enhancing pupils' spatial visualization skills in geometry instruction, providing valuable insights for instructional methodologies.

KEYWORDS

augmented reality (AR), lower primary school, spatial visualization ability test (SVAT), geometry, Van Hiele's theory

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1 INTRODUCTION

Education is undergoing substantial development in the 21st century, driven by rising technologies. Within this technological landscape, the metaverse stands out as a virtual shared space that seamlessly incorporates augmented reality (AR) and virtual reality (VR). Within the metaverse, users can interact with digital environments, objects, and other participants in immersive ways. It offers personalized and adaptive learning experiences, making it a promising platform for education [1]. The 21st century demands a revolution in educational paradigms by providing innovative approaches to teaching and learning (T&L) [2]. This highlights the need to implement educational innovations as technology in education has evolved from being a choice to an essential requirement, given that conventional educational methods are no longer well-suited for future generations [3].

Geometry is a branch of mathematics closely related to shape and space. It holds considerable significance in fostering the cognitive development of pupils, particularly in enhancing their problem-solving capabilities [4] and practical applications of our daily lives, such as architecture, the arts, astronomy, and other disciplines. Despite its pervasive presence, learning geometry poses notable challenges for both primary and secondary school pupils [5–7]. Specifically, primary school pupils encounter significant hurdles in comprehending fundamental geometric concepts, geometric reasoning, and problem-solving in geometry. These challenges stem from geometry's incorporation of abstract ideas, necessitating adept spatial visualization skills, especially in grasping 2D and 3D shapes, alongside mastering problem-solving concepts [8–10].

A previous study examined factors contributing to challenges in learning geometry among a sample of 40 pupils [11]. The study revealed that 21% of pupils struggled with poor visualization ability, and 20% encountered obstacles in drawing 3D nets. Additionally, 19% faced difficulties merging 2D shapes into 3D shapes, and 13% found sketching 2D and 3D shapes difficult. Moreover, 9% faced issues distinguishing between straight and curved lines as well as comprehending the overall surface characteristics of shapes. Another 7 percent struggled to compute the edges of 2D and 3D shapes. The study concluded that the primary contributors to the complexities in learning geometry were the visualization process and foundational geometry knowledge [11], [12]. This difficulty is attributed to the abstract concepts and information in geometry, contributing challenges for pupils in grasping these principles.

Furthermore, prior study has consistently highlighted that the majority of pupils have low spatial visualization skills [13] [14]. As a result, the performance of these pupils in geometry is significantly affected by these deficiencies in spatial visualization abilities [15]. As per [16], pupils often experience a contradiction between the process of imagination and the representation of geometric shapes. Further studies have identified limited visualization skills as the primary variables influencing primary school pupils' understanding of geometry concepts [17].

Considering the problems pupils face in learning geometry, adopting AR holds promise in enhancing their understanding of geometry and serves as a support for learning facilities [18]. AR technology is defined as a tool enabling the incorporation of virtual objects into the physical world, coexisting in real-time within the same spatial location [19]. The advantages of AR in education can have a substantial impact on the T&L process, especially in subjects demanding spatial visualization skills and comprehension of abstract concepts. Moreover, the utilization of AR technology has the potential to create an immersive learning environment in mathematics, aiding pupils' developing a deeper conceptual grasp, particularly in geometry instruction [20].

Thus, this study explores how AR applications impact the spatial visualization ability of lower primary school pupils in learning geometry. This study will highlight the potential of AR applications to improve spatial visualization abilities in geometry learning for young pupils. By investigating the effect of AR, the study hopes to provide significant insights for teaching methods, improve geometry learning outcomes, and empower students to grasp complex concepts with greater ease. The following is the study question:

Does the augmented reality geometry learning application improve lower primary school pupils' spatial visualization skills for geometry learning compared to the conventional method?

2 LITERATURE REVIEW

The following literature review will provide an overview and analysis of study related to (i) augmented reality (AR) in mathematics education, (ii) spatial visualization ability in geometry, and (iii) Van Hiele's theory of geometry learning.

2.1 Augmented reality in mathematics education

The integration of AR in mathematics education aligns with the objective of the mathematics curriculum, which is to diversify T&L techniques employing technological tools. This approach seeks to foster conceptual understanding and promote meaningful learning experiences for students. Consequently, exploring the potential benefits of AR technology in mathematics education becomes crucial. AR has emerged as a significant technological tool within educational settings, proving to be instrumental in facilitating the T&L process [21]. Nonetheless, the conceptualization of AR varies across the literature. According to [22], AR represents a 3D technology that enriches users' sensory perception of the real world by overlaying a contextual layer of information. AR is also described as having three characteristics: (a) the combination of virtual and real-world elements; (b) operation in real-time with interactive features; and (c) registration in 3D shape.

As per previous study, geometry is the most used in learning mathematics with AR technology [23–26]. Besides, there are subjects such as probability [26], calculus [27], and vectors [9] applying AR in T&L. Furthermore, there are researchers who combine several topics in the mathematics curriculum in developing AR applications, such as algebra and geometry [28], arithmetic and geometry [29], statistics and probability [30], and fraction, percentage, and volume of liquid [31]. Most study demonstrates that AR applications have a positive impact on boosting pupils' spatial abilities. Thus, there is a promising trend toward using AR in the T&L of mathematics education.

2.2 Spatial visualization ability in geometry

Spatial visualization ability refers to one's aptitude to think in 2D and 3D, which involves various steps in the spatial transformation of an object and shape [32–34]. Spatial visualization is the ability to perceive an object and think in 2D and 3D, as well as manipulate the change of objects based on the mind [35]. On the other hand, visualization is a person's ability to construct, manipulate, and interpret images, shapes, patterns, or objects in their mind [36], [37]. Besides that, spatial ability was divided into three stages to determine pupils' cognitive development in geometry [38]. The pupils begin by working with 2D images and then progress to 3D objects. In the last stage, they found the connection between 2D or 3D objects. According to the definition given by earlier studies, it can be inferred that spatial visualization represents a person manipulating a 2D and 3D object that incorporates mental representation. Individuals can identify the relationship between objects and shapes more clearly if they have good spatial visualization abilities [39]. This is because the spatial visualization skill is one of the cognitive domains that involves mental thinking to manipulate visual and graphic information. Thus, visualization ability may be regarded as an essential aspect of the mathematics learning process since it assists pupils in comprehending concepts.

Previous study has shown a correlation between spatial visualization abilities and mathematics. For example, study by [40] evaluated the spatial visualization ability of mental rotation activities on the performance of six- to eight-year-old pupils in mathematics. In this study, pupils' achievement in addition and subtraction improved after implementing the mental rotation exercise. Furthermore, through video-based learning, researchers discovered a connection between spatial visualization ability and achievement in eight-year-old children based on rises in spatial visualization test scores and mathematical achievement tests [41]. Geometry indeed relies on strong spatial visualization skills, given its intrinsic connection to the construction and understanding of geometric concepts. Therefore, it is imperative for teachers to emphasize the incorporation of visual teaching strategies throughout the T&L process to enhance pupils' visualization abilities. This emphasis on visual strategies can significantly help pupils comprehend and master geometric concepts, thereby strengthening their spatial visualization skills, crucial for success in geometry topics.

2.3 The Van Hiele's theory of geometry learning

Van Hiele's theory of geometry learning outlines the pupils' development of geometric understanding [42]. It is frequently used in learning geometry to measure pupils' geometric thinking and guide mathematics instruction [43]. Van Hiele's theory furnishes a structured framework that delineates pupils' progression from visual recognition to abstract reasoning in geometry. This theory delineates five distinct levels of geometric thinking, organized hierarchically from basic to advanced.

i) **Level 1: Visualization**
Pupils can recognize and determine geometric shapes based on their visual perception. They can name and categorize the geometric shapes based on their physical characteristics, such as the number of sides.

ii) **Level 2: Analysis**
Pupils can recognize the characteristics of shapes through their specific characteristics and name them. However, pupils can still not relate the characteristics of two different classes of shapes.

iii) **Level 3: Informal deduction**
Here, pupils understand the relationships between the characteristics of 2D and 3D geometric shapes. They can use prior knowledge and form arguments to demonstrate generalizations about the characteristics of geometric shapes.

iv) **Level 4: Formal Deduction**
At this level, pupils can analyze and explain the relationship between shapes by deductively proving theorems, providing reasonable reasons for a statement during formal proofs, and understanding the role of axioms and related definitions.

v) **Level 5: Rigor**

The fifth level requires pupils to understand non-Euclidean geometry and can compare axiomatic systems.

On the other hand, this study specifically concentrated on spatial visualization ability, which is grounded on three levels of Van Hiele's geometric thinking and targeted in primary school geometry lessons [44], [45]. According to [46], geometry learning that emphasizes geometric thinking should offer a meaningful learning experience and aid in the development of spatial ability. This emphasizes the importance of nurturing geometric thinking to enhance spatial abilities effectively.

3 METHODOLOGY

The study employed a quasi-experimental, unbalanced group research design, as outlined in Table 1. This experimental approach is often utilized when researchers are unable to select random samples [47]. Additionally, it proves useful when studying the effects of a specific teaching method, module, or training course in real classroom settings where implementing a true experimental design is unfeasible [48]. Therefore, a quasi-experimental design was adopted as this study compared the effect and outcome of the intervention between two groups in different school: the experimental group (School A), and the control group (School B).

Table 1. Quasi-experimental of unbalanced group research design

Group	Pre-Test	Teaching Approach	Post-Test
Control (School A)	O_1	Geometric Shape Models	O_2
Experimental (School B)	O_3	LearnGeoAR Applications	O_4

According to Table 1, the pre-test measured the initial ability level of pupils, denoted as O_1 and O_3. The post-test, which measured performance after the intervention, was marked as O_2 and O_4. This experiment was implemented to determine the effectiveness of the intervention given. The primary aim of this experiment was to ascertain the effectiveness of the intervention. In this study, the experimental group utilized the LearnGeoAR applications as a learning aid, while the control group used geometric shape models for learning purposes.

3.1 Sample group

The study involved A total of 61 grades two pupils, aged 8, from two primary schools located in Northern Malaysia were selected as the study samples. Among these, 31 pupils from School A comprised the control group, while 30 pupils from School B comprised the experimental group. Cluster sampling was employed to select the schools, as it offered efficiency in obtaining a representative sample from a larger population [49]. The selected sample consisted of intact groups, avoiding the need for disruptive sample selection procedures during the learning process as the existing class structure was maintained [50]. Each group received instruction from a mathematics teacher at their respective schools, both possessing more than 10 years of teaching experience.

3.2 Research instrument

The SVAT test is adapted from a previous study [51]. The SVAT instrument aims to look at the pupils' spatial visualization ability scores to determine the difference in mean scores between pupils in the control and experimental groups. This instrument comprises six subjective questions that address the three stages of geometric thinking outlined in Van Hiele's theory, as detailed in Table 2. The SVAT instrument has a total score of 60 marks, which is converted to a percentage scale equivalent to 100%.

Table 2. Items based on the three levels of Van Hiele's geometric thinking

Levels of Geometric Thinking in Van Hiele's Theory	Item	Description
Visualisation	Complete the information about the 3D shape.	Pupils can identify a variety of shapes.
	Draw a 2D shape.	
Analysis	Draw a 3D net.	Pupils can identify the characteristics of different shapes and recognize the transformation of 3D shapes to 2D shapes.
	Match the 2D shapes correctly.	
Formal Deduction	Draw 3D models using various shapes.	Pupils can build relationships between shapes through the design of 3D models and 2D objects and can explain the use of various shapes.

Six experts in mathematics education evaluated the validity of the SVAT instruments. The chosen experts are four mathematics lecturers from the Teacher's Education Institute and two mathematics teachers from primary schools with experience in teaching mathematics for more than five years. As part of the verification procedure, the experts evaluate the elements that align with the pupils' spatial visualization abilities. The content validity index (CVI) method is used to evaluate the validity of the instrument, as shown in Table 3.

Table 3. Validity of SVAT instrument

Item	Experts Score						
	E1	E2	E3	E4	E5	E6	I-CVI
1	1	1	1	1	1	1	1.00
2	1	1	1	1	1	1	1.00
3	1	1	1	1	1	1	1.00
4	1	1	1	1	1	1	1.00
5	1	1	1	1	1	1	1.00
6	1	1	1	1	1	1	1.00
Average Expert Agreement	**1**	**1**	**1**	**1**	**1**	**1**	**1.00**
I-CVI Total Score							**6.00**
S-CVI							**1.00**

Note: E-Expert.

The instrument's scale content validity index (S-CVI) value is 1.00. This value has a high validity rating since all experts agree on all the items. The Cronbach's alpha coefficient reliability test was then utilized to verify the instrument's reliability. Following the assessment of validity, the instrument's reliability was evaluated using the Cronbach's alpha coefficient. The obtained Cronbach's alpha value is 0.78, surpassing the acceptable threshold for reliability [52].

3.3 Research procedure

The study procedure is conducted in three stages: (1) group formation and pre-test; (2) intervention and data collection; and (3) post-test evaluation. They are illustrated in Figure 1.

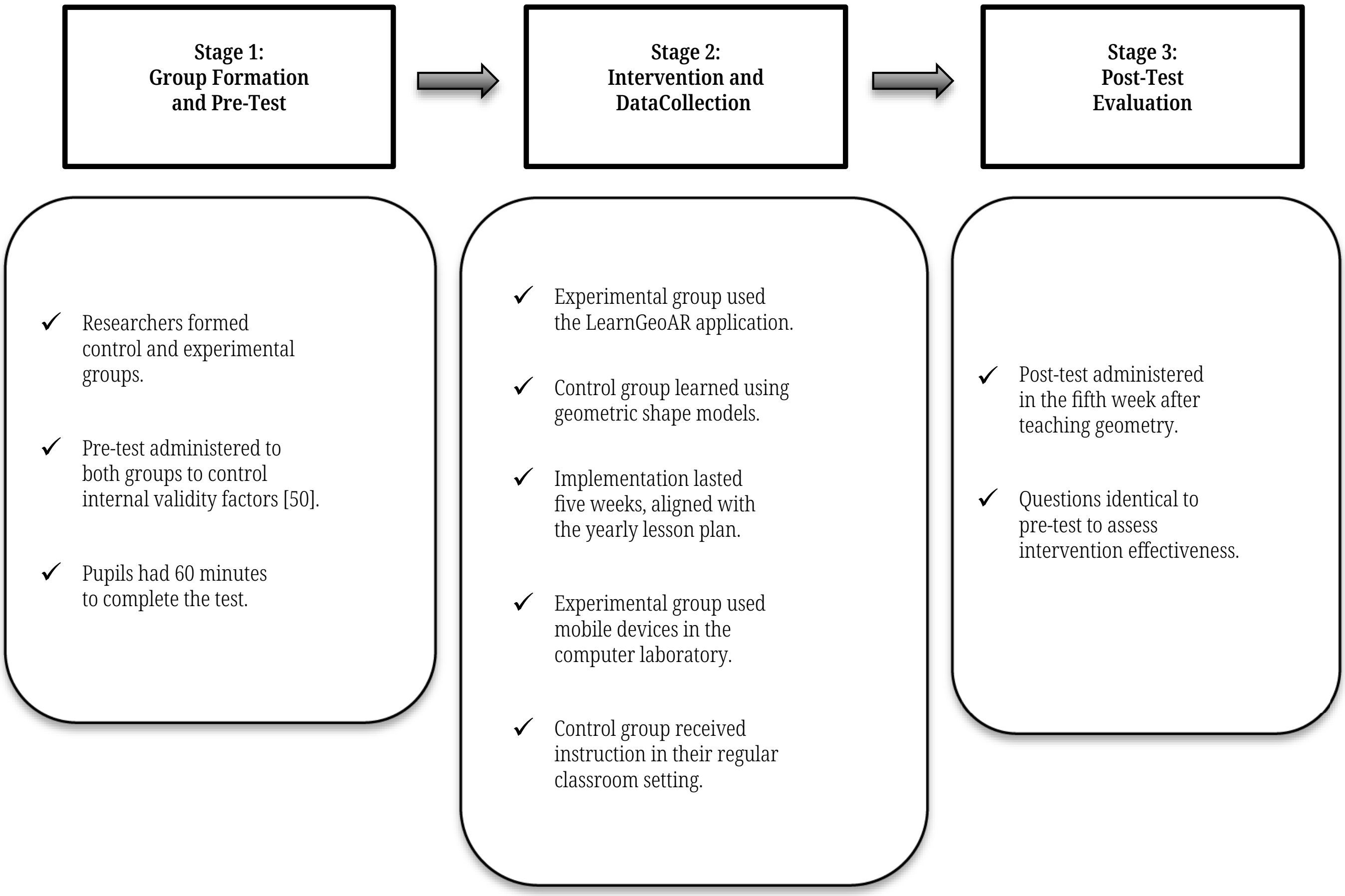
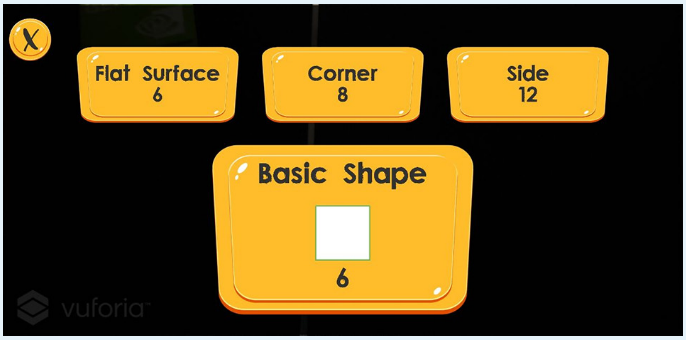
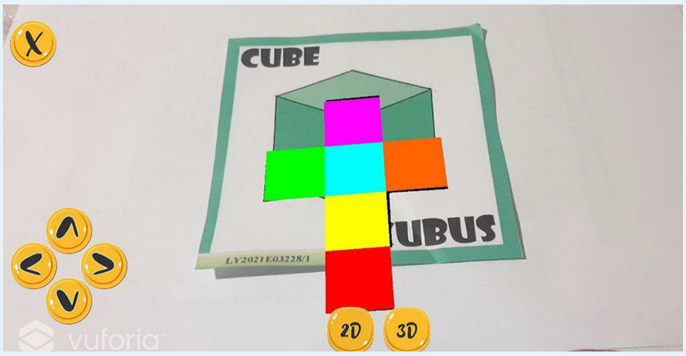
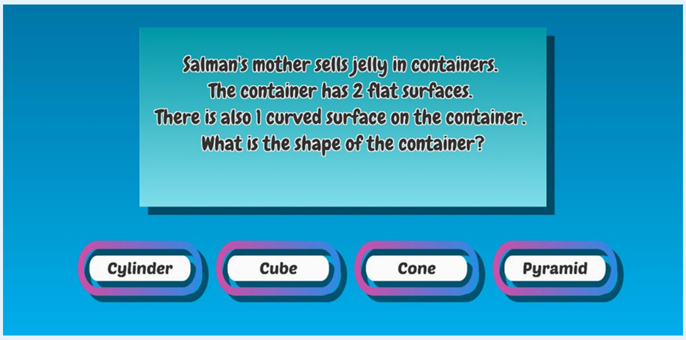


Fig. 1. Stages in research procedure

Meanwhile, Table 4 provides a comprehensive summary of the study procedure, outlining the activities carried out as well as the instruments used throughout the study.

Table 4. Summary of the activities and instruments used

Week	Activities	Instruments
1	**Introduction session** – Explanation of the study for both groups. **Pupils sat for the SVAT pre-test.**	Spatial Visualisation Ability Pre-Test
2	**Learning Session 1: 3D Shapes** – Identify 3D shapes based on their characteristics. – Identify 3D basic shapes. – Identify various nets of 3D shapes.  	Geometric Shapes Model/ LearnGeoAR application Exercise (drilling)
3	**Learning Session 2: 2D Shapes** – Identify two-dimensional shapes based on descriptions. – Draw basic shapes of two-dimensional shapes.	Geometric Shapes Model/ LearnGeoAR application Exercise (drilling)
4	**Learning Session 3: Problem-Solving** – Solve problems involving daily life situations. 	Geometric Shapes Model/ LearnGeoAR application Exercise (drilling)
5	**Pupils sat for the SVAT post-test.**	Spatial Visualisation Ability Post-Test

4 FINDINGS

The effectiveness of the LearnGeoAR application was assessed to determine the difference in mean SVAT scores between the experimental and control groups. The normality of the data in each group was tested with the Shapiro-Wilk test before performing the inferential statistics. This specific test was chosen because it is considered more appropriate for assessing the normality of data, especially in smaller sample sizes (n < 50) [53]. The results of the Shapiro-Wilk tst for the SVAT score data are summarized in Table 5.

Table 5. The Shapiro Wilk test for SVAT score

Data Set	Group	Statistic	df	Sig.
SVAT Pre-Test Score	Control (School A)	.97	31	.43
	Experimental (School B)	.94	30	.08
SVAT Post-Test Score	Control (School A)	.94	31	.06
	Experimental (School B)	.94	30	.10

The findings displayed in Table 5 indicate that the Shapiro-Wilk test showed significant results with p-values greater than.05. This indicates that the pre-test and post-test data from both the control and experimental groups are normally distributed. Thus, the independent sample t-test could be used to determine the difference in the mean score of the pre-test between both groups at a significant level of.05.

The difference in the mean score of the SVAT between the pupils who use the LearnGeoAR application and the pupils who use conventional methods

The descriptive statistics and the result of the independent sample t-test are reported in Tables 6 and 7, respectively.

Table 6. Descriptive analysis of SVAT

Test	Group	n	Mean	Standard Deviation
Pre-Test	Control (School A)	31	47.87	10.97
	Experimental (School B)	30	45.13	12.71
Post-Test	Control (School A)	31	59.35	11.20
	Experimental (School B)	30	68.30	14.10

Table 7. Independent samples T-tests findings for SVAT

	Levene's Test		Independent T-Test				
	F	Sig.	t	df	Sig. (2-Tailed)	95% Confidence Interval (CI) of the Difference	
						Lower	Upper
Pre-Test	.19	.67	.90	59	.37	–3.34	8.82
Post-Test	2.27	.14	–2.76	59	.00	–15.44	–2.45

As shown in Table 6, the mean score for the SVAT pre-test is 47.87 (SD = 10.97) and 45.13 (SD = 12.71) for the experimental and control groups, respectively. Whereas the mean post-test score of SVAT is 59.35 (SD = 11.20) for the experimental group and 68.30 (SD = 14.10) for the control group.

As reported in Table 7, the result of Levene's test showed that the homogeneity assumption of the variance was met; $F(1, 59) = .19$, $p = .67$ (>.05); $F(1, 59) = 2.27$, $p = .14$ (>.05). According to the independent sample t-test result, there was no significant difference in the pre-test score between the experimental and control groups, with $t(59) = .90$, $p = .37$ (>.05) at the 95% confidence interval, which ranged from –3.34 to 8.82. This shows that both groups had similar spatial visualization ability levels before the intervention.

At the end of the intervention, the independent sample t-test results showed a significant difference in the mean post-test score between the experimental and control groups, with $t(59) = -2.76$ and $p =.00$ (<.05) at the 95% confidence interval, which ranged from –15.44 to –2.45. In other words, compared to geometric shape models, using LearnGeoAR applications had a statistically significant effect on pupils' spatial visualization ability scores.

Next, the effect size was calculated to determine the strength of a given treatment effect [54]. By using Cohen's d formula for an independent sample t-test, the study found that the effect size ($d = .71$) exceeds Cohen's interpretation for a medium effect ($d = .50$). In other words, there is a moderate mean difference (mean difference = –8.95, 95% CI: –15.44 to –2.45) between the control group and the experimental group. In summary, the findings indicate that the use of LearnGeoAR applications had a notable impact on pupils' spatial visualization ability scores when compared to conventional methods.

5 DISCUSSION

The findings indicated that the intervention was successfully implemented and that spatial visualization abilities can be enhanced using AR. Upon conducting the pre-test and post-test, noticeable improvements were observed in the mean scores of the post-test for both the experimental and control groups. However, it is noteworthy that the mean post-test scores for the experimental group were notably higher compared to the control group, displaying a substantial difference in mean scores of 8.95. These findings strongly indicate the efficacy of AR technology in mathematics education, specifically in bolstering pupils' spatial visualization abilities.

Specifically, the pupils have shown improvement in thinking, imagining, and viewing geometric shapes from various perspectives after receiving the LearnGeoAR application in this study. The findings are consistent with previous study demonstrated that AR technology helped improve spatial visualization skills [41], [55]. Nevertheless, the SVAT instrument used by [55] was focused on the topographic map for engineering pupils in universities instead of our study focused on geometry within primary school-aged pupils. Meanwhile, several spatial ability tests used by [41] investigated the relationships between mathematics and spatial abilities in children aged five to seven.

One of the strengths of our study lies in the development of a spatial visualization ability test (SVAT) tailored to the geometry topic, considering the age group of the participants and grounded in Van Hiele's theory of geometric thinking. This approach aligns with [38], which suggests that spatial ability can be segmented into three phases: (i) beginning with 2D images, (ii) progressing to 3D objects, and (iii) discovering the relationship between 2D and 3D objects. This tailored test enabled a more targeted evaluation of spatial visualization abilities specifically relevant to geometry and age-appropriate cognitive development.

Besides, the findings show that AR technology enhances spatial visualization skills, according to a study by [56]. Notably, the implementation of AR applications appears to have a more substantial effect compared to using 3D models. This superiority stems from AR's capability to allow pupils the freedom to manipulate virtual objects from various perspectives using smartphones. This interactive approach enables pupils to use their hands to interact with and examine shapes more flexibly [57].

Furthermore, AR technology has the potential to bridge the gap between abstract geometric concepts and real-world applications. By superimposing virtual objects onto the physical environment, AR enables pupils to witness the practical implications of geometric concepts [58]. For instance, they can observe how geometric transformations, such as rotations and translations, influence objects within their surroundings. This connection between abstract concepts and tangible experiences aids pupils in cultivating a deeper comprehension of geometry and its relevance in their daily lives. Such hands-on experiences facilitate a more profound understanding of geometric principles by linking them to concrete, real-life scenarios.

Despite the numerous benefits, integrating AR technology to enhance pupils' spatial visualization abilities presents several challenges. One primary obstacle is the availability of suitable AR devices and applications, impacting the widespread implementation of AR-enhanced learning experiences. Moreover, utilizing AR technology effectively demands a certain level of technical proficiency among educators, which might hinder its widespread adoption in educational settings.

Additionally, ensuring effective instructional design and seamless integration of AR experiences into the curriculum is crucial. Aligning AR applications with educational objectives and ensuring they contribute to meaningful learning experiences can be complex. Teachers need to design and implement AR activities that serve educational goals effectively, which may require additional training and resources.

6 CONCLUSION

The study discovered that AR technology could improve pupils' spatial visualization abilities, evident through the significant difference in the SVAT mean scores during the pre-test and post-test. In this regard, this intervention effectively contributed to enhancing their spatial visualization skills. Consequently, these study outcomes provide valuable insights for teachers, advocating for the incorporation of AR learning into teaching instructions. This integration enables pupils to comprehend the rotation and transformation of shapes more effectively. AR's unique capability to seamlessly merge virtual objects with the real world, providing immersive and collaborative learning experiences, fosters the development of spatial thinking skills.

While the study focused on lower-grade primary school pupils, it is recommended to extend the use of AR applications to upper-grade pupils, especially for topics involving abstract concepts such as perimeter, area, and volume of shapes. AR-enhanced learning experiences can significantly benefit the visualization and manipulation of 3D objects inherent in these topics, enhancing students' comprehension of complex mathematical concepts.

Considering the duration of experimental study is crucial, allowing sufficient time for an in-depth exploration and analysis of AR technology's impact on pupils' spatial visualization abilities. This extended study duration can offer a better understanding of the long-term effectiveness and sustained benefits of AR-integrated learning environments on pupils' spatial thinking skills and academic performance.

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