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Does Interactive Augmented Reality Enhance Primary Students' Geometric Understanding and Visual-Spatial Skills in Mathematics Learning?

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Abstract: Augmented reality (AR) in education has gained much attention as an innovation that promotes tangible visualization and can therefore be applied in various fields of education, especially in enhancing students' conceptual understanding and visual and spatial abilities in mathematics. Geometry often poses challenges due to its abstract nature, but AR offers interactive visualizations that make learning more engaging and accessible. This study used a quasi-experimental design on second grade forty-six students' understanding of geometric shapes. The experimental group had twenty-three students engaged in AR-enhanced learning activities, while the control group had twenty-three students who followed traditional teaching methods. Results showed that the AR group significantly improved in both geometric understanding and visual-spatial skills. These findings highlight the potential of AR to make early mathematics education more effective and engaging.

Keywords: Visual-spatial ability, primary education, shapes, mobile learning, STEM.

1. Introduction

The integration of technology into education has become increasingly popular in recent years, especially in the field of mathematics. Augmented reality (AR) is one of the instruments that has shown a remarkable level of effectiveness in improving the teaching and learning of geometry. Learning geometry helps students develop their logical reasoning ability, which includes analyzing and elaborating arguments about spatial forms, shapes, and abstract math concepts (Sudirman, Kusumah, & Martadiputra, 2022). However, geometry is often perceived as abstract, resulting in a significant number of students experiencing problems and showing poor performance (Halat, Jakubowski, & Aydin, 2008). Augmented reality (AR) is a technology that enhances the user's actual physical surroundings by overlaying virtual elements such as images, videos, and virtual items (Azuma et al., 2001). Moreover, Lisowski et al. (2023) reported AR attracts attention from students due to its interactive possibilities. AR allows users to interact in real-time with virtual elements in real-life contexts. This distinctive aspect of AR technology provides new opportunities to promote learning and allows the deployment of constructive learning environments (Lee et al., 2022). Interactive multimedia, another key element in modern education, has long been recognized for its ability to transform traditional teaching methods. Tuma (2021) found the enduring power of interactive multimedia in catering to different learning styles, emphasizing how its multi-sensory environment supports various learning methods. When combined with AR in mathematics education, interactive multimedia becomes even more impactful. As Rauschnabel et al. (2022) explained, AR technology can project 2D and 3D objects into the virtual world in real-time, giving students the chance to interact with these objects as if they were real.

The main idea behind AR is to blend virtual elements with the real world, creating an interactive and lifelike learning environment. Sutresna et al. (2020) showed that AR allows students to interact with three-dimensional objects in a way that traditional teaching methods simply can't match. With the rapid advancement of digital media, AR is becoming increasingly common in our daily lives, as Li (2024) notes. This technology doesn't just make learning more engaging; it also helps students develop visual-spatial skills, which are crucial for success in STEM fields. The ability to influence visual patterns refer to as spatial ability. It was considered an essential component of human intelligence. It has an important effect on the STEM (Science, Technology, Engineering, and Mathematics) domains and provides opportunities for reflection on and comprehension of the real world (Wai, Lubinski, & Benbow, 2009). Although spatial ability is one of the essential human abilities, it is never an effortless task to develop. Many studies indicated that childhood spatial activities were a significant predictor of adult performance in math grades (Doyle, Voyer, & Cherney, 2012). However, learning geometry usually requires students to generate and manipulate three-dimensional (3-D) mental images from two-dimensional (2-D) objects, and it may cause cognitive overload and learning difficulties for some students. (Liao, Yu, & Wu, 2015). AR, It enables students to overlay data, images, and other content onto the real world around them, providing new context and connections to enhance learning and understanding. It could serve as an effective tool to learn the spatial concepts of geometry.

This study aimed to explore how AR-based inquiry learning affects students' understanding of geometric concepts and their visual-spatial abilities. By comparing AR-enhanced inquiry-based learning with traditional teaching methods, this research seeks to determine how effective AR is in helping primary school students gain a deeper understanding of geometry.

2. Literature Review

2.1 Interactive Augmented Reality with Mathematics

AR technology represent the ability to improve the teaching of geometry through visualization and to enhance the simplicity of human-computer interaction in the real environment. AR has a chance to improve understanding of three-dimensional objects in the field of geometry. Users can view geometric structures moving realistically on mobile devices or tablets via AR (Koparan et al., 2023). Moreover, Flores-Bascuñana et al. (2020) suggested that AR could improve students' understanding of three-dimensional objects from a variety of viewpoints. Therefore, the use of AR offers a more visual representation of the learning process. However, virtual 3D objects can be used to provide calculations and solutions to mathematical problems using AR. Furthermore, applying AR to promote advanced learning may help enhance students' motivation for studying mathematics. AR is a new way of showing mathematical solutions to engage students in the subject.

Interactive multimedia was a viable alternative in the initiative to transform education for a long amount of time (Tuma, 2021). Phillips (2014) suggested that interactive multimedia had the potential to accommodate a variety of learning styles and that the multisensory environment in interactive learning multimedia supported specific learning methods. Interactive multimedia could be integrated into mathematics education through the use of AR. AR was an intricate technology that can be applied as interactive multimedia. Directly or in real time, AR technology can project 2D and/or 3D objects into the virtual world (Rauschnabel et al., 2022). The main principle of AR was to present virtual components in the form of the real world. There is interaction with three-dimensional objects, that could be operated interactively and in a real manner (Sutresna et al., 2020). AR a new method of creating images using 2D and 3D images, has gradually become more prevalent in our daily lives with the development of digital media (Li, 2024). Mobile AR technologies, running on smart phones or tablets, can, in theory, support learning in situ by enabling the superimposing of layers of virtual information on the physical world (Efstathiou et al., 2017).

2.2 Visual-Spatial Ability

Visual-spatial ability is a critical cognitive skill that facilitates the processing and manipulation of visual and spatial information, and it has been linked to success in various academic and professional fields, particularly within STEM disciplines. Recent studies have explored methods to assess and enhance this ability among primary school students using innovative educational tools and strategies. Kara et al. (2022) developed the Visual-Spatial Ability Test (VSAT) to assess primary school children's ability to process information related to shape, color, texture, perspective, and rotation. Their research demonstrated the VSAT's reliability and validity, providing educators with a robust tool for evaluating and fostering these crucial skills in young learners.

In parallel, Nincarean et al. (2019) investigated the impact of augmented reality (AR) on enhancing spatial visualization abilities in elementary students using the AR-Science Magic Book Learning System (AR-SMB). Their findings revealed significant improvements in spatial abilities, highlighting AR's potential to support understanding of complex scientific concepts. Huang et al. (2022) results showed that the use of AR educational games in mathematics class could improve the spatial ability (mental rotation, spatial orientation) of primary school students, and primary school students were very willing to learn in this way. Geometry is one of the most important branches of mathematics, and spatial thinking goes hand in hand with it (Adnan et al., 2024). Geometry has always been a key and difficult part of the mathematics curriculum. Spatial intelligence is an essential skill for understanding and solving real-world problems. These visuospatial skills form the basis for three-dimensional designs or verbal explanations in learning science, technology, engineering, and mathematics (Koparan et al., 2023). Moreover, they found that students were generally able to accept using AR to learn geometry, and AR-supported teaching methods significantly improved students' learning outcomes. Therefore, researchers were interested in using AR for the conceptual understanding of shape and the development of the spatial visualization abilities of students.

3. An Example of Inquiry Learning with Interactive Augmented Reality

The researchers conducted an experiment on participants to demonstrate the application of inquiry learning with interactive AR in the mathematics classroom, with the aimed of comparing the students' conceptual understanding and visual-spatial ability. The selected topic was shapes. Technology tools are Introduced in this study:

(1) The Solid Shapes AR application: An interactive application designed to assist students in counting the faces of 3D shapes interactively. When they click on a face of the shape, the app highlights it and displays a number, such as "1" for the first face and "2" for the next, helping students visualize and understand the structure of 3D shapes more clearly. This interactive approach makes learning about geometric properties engaging and intuitive.

(2) AR from the Zapworks website: tools for creating interactive augmented reality experiences, allowing educators to develop custom content using 3D models, videos, and animations. It enhances learning by merging digital content with the real world, making lessons more engaging and accessible.

(3) Plickers: An assessment tool that lets teachers collect real-time feedback without devices. Students hold up cards that the teacher scans with a smartphone or tablet to gather responses. It’s a simple way to assess understanding, especially in classrooms with limited technology access.

Inquiry learning approach as a pedagogical tool for delivering instruction in the present study by Buck et al. (2008). Step 1: Problem/Question: The researchers used videos that showed real-world situations and then asked questions about the shapes. Step 2: Theory/Background, explained a basic understanding of shapes. Step 3: Procedures/Design, Teachers explained how to use the Solid Shapes AR application. When students scan the marker and the AR appears, they will interact with AR by clicking to answer questions on the worksheet. Students can also use the worksheets which they received as markers for scanning. Step 4: Analysis of Results, students will utilize AR from the Zapworks website to enhance their understanding of the technology for parts 1–3. Next, the students utilized the interactive Solid Shapes AR application for part 4 (as seen Figure 1). Step 5: Results communication, students will present their work, and Step 6: Conclusions, students used Plicker as a formative assessment tool to gauge their understanding. They will lift the board to answer questions, and the teacher will scan the answer to ensure that the correct answer is known in real time. They will see and discuss their friends' answers.

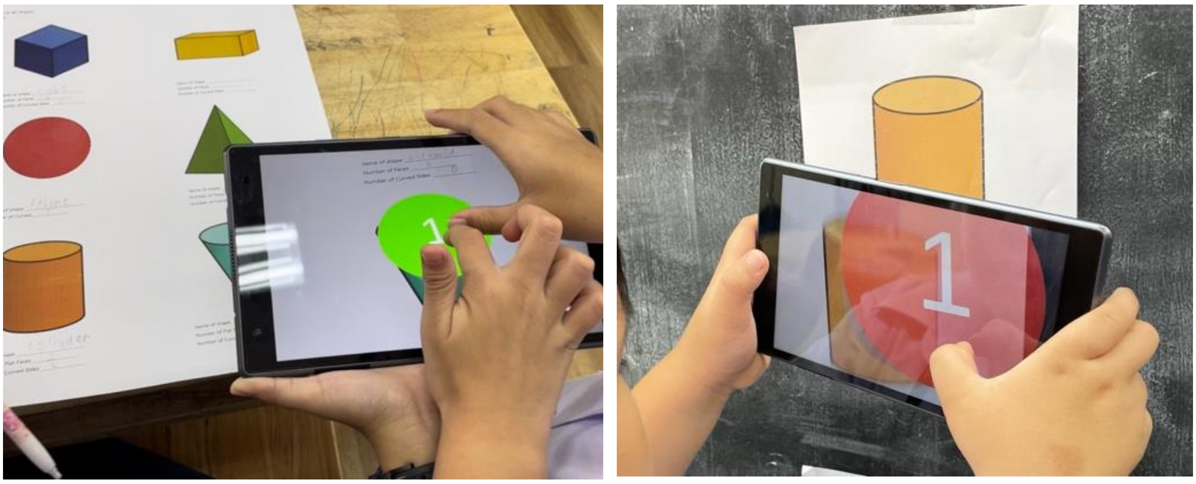

Figure 1. Experimental group with interactive AR: Solid Shapes AR application.

After completed the inquiry learning process, students apply their understanding of shapes to solve real-life problems. The researchers present a scenario involving a major earthquake, where a building remains intact despite the tremors. Students use their knowledge of 3D shapes to design a simple structure, calculate the materials, or determine the best shapes for engineering and contexts. This approach encourages students to connect abstract geometric concepts with practical applications, fostering critical thinking, problem-solving skills, and the ability to integrate science, technology, engineering, and mathematics in meaningful ways. By solving problems rooted in real-world scenarios, students see the relevance of their learning and how these skills can be used beyond the classroom as shown in Figure 2.

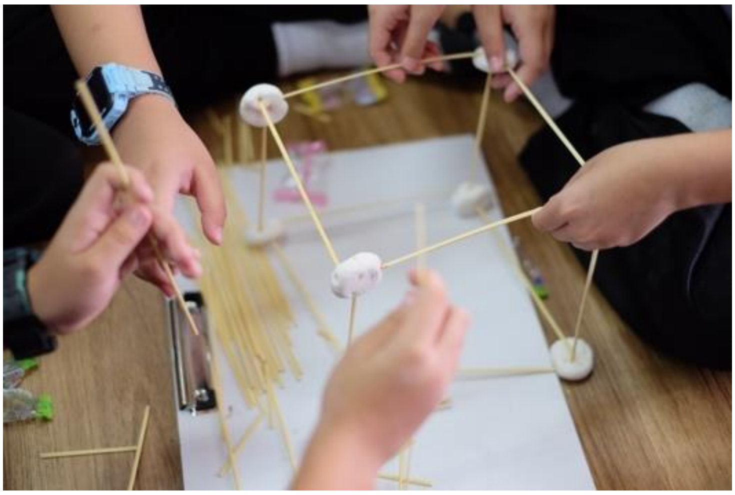

Figure 2. Experimental group with STEM activity: designed with the application of shapes.

4. Methodology

4.1 Research Design

This research is a quasi-experimental design that involved two groups of students. The design includes pre- and post-learning evaluations for all groups. An experimental group investigates the effect of inquiry-based learning combined with augmented reality (AR). The control group, using traditional learning, had the same outcomes.

4.2 Participants

This study recruited forty-six students second-grade students from a public primary school in the northeastern region of Thailand. The experimental group had twenty-three and another twenty-three as the control group. Students have learned about shapes in the basics and know what shapes are. Furthermore, prior to their involvement in this research, the participants had experience using technology for educational purposes on a consistent basis within the classroom setting. Ethical approval for this research was granted by the Human Research Ethics Committee of Khon Kaen University under the reference number HE673356.

4.3 Research Instruments

In this study, there were two research instruments for measuring conceptual understanding and the visual-spatial ability test. The first tool is a conceptual understanding test for grade 2, It involves the conception of shapes. The conceptual understanding test is designed with open-ended questions to measure the ability to understand the topic. It consists of 35 test items that convert the concept of shapes. It has three concepts. The three concepts are Identifying 2D and 3D Shapes (10 items), Properties of 2D and 3D Shapes (20 items), and Matching 2D and 3D Shapes with Descriptions (5 items). The Visual-Spatial Ability Test has 5 questions; each question has 3 tasks. The first task requires shape transformations in terms of sides of sight. The second task entails the transformation of the shapes based on both perspective and sight by considering their colors. The third task challenges test-takers to transform their perspective by considering color and texture. A separation index over 2.0 indicates a reliability of 0.80. The value of the infit mean squares for all tasks in all target questions ranged between 1.23 and 0.86. It was also found that the value of the outfit means square (outfit MNSQ) varied between 1.91 and 0.88. These results fall into the consistency interval suggested by Linacre's (2020) Rasch Analysis Guidelines.

4.4 Data Collection

The two groups of students spent 50 minutes doing a pre-test on conceptual understanding of shapes and a pre-visual spatial ability test. The experimental group received an inquiry-learning method that integrated AR and STEM, spending 200 minutes on the instruction. During the data collection, the experimental group students were able to find the answers on the worksheet by scanning the markers. In the AR interactive section, students were able to click on the AR to help them count the sides of the 3D shapes. With the AR, the teacher demonstrated how to scan, use, and find answers. Then, the students summarized their knowledge and responded to summary questions using Plicker. After that, students applied the shapes concept to STEM activities. (See Figure 3)

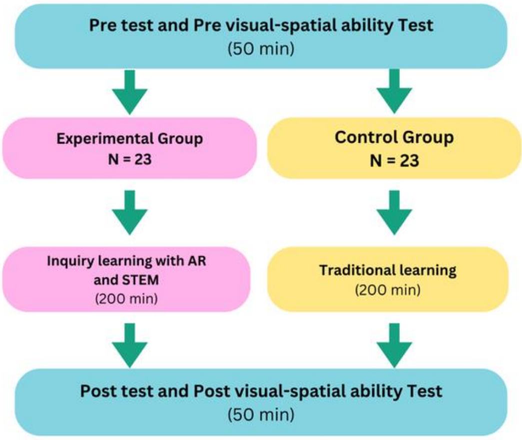

Figure 3. Data collection of learning activities.

The control group received instruction using the traditional learning method, also spending 200 minutes on the instruction. Material objects from everyday life were used during this period. Finally, all students spent 50 minutes completing a post-test on conceptual understanding test of shapes and a post-visual-spatial ability test. (See Figure 4)

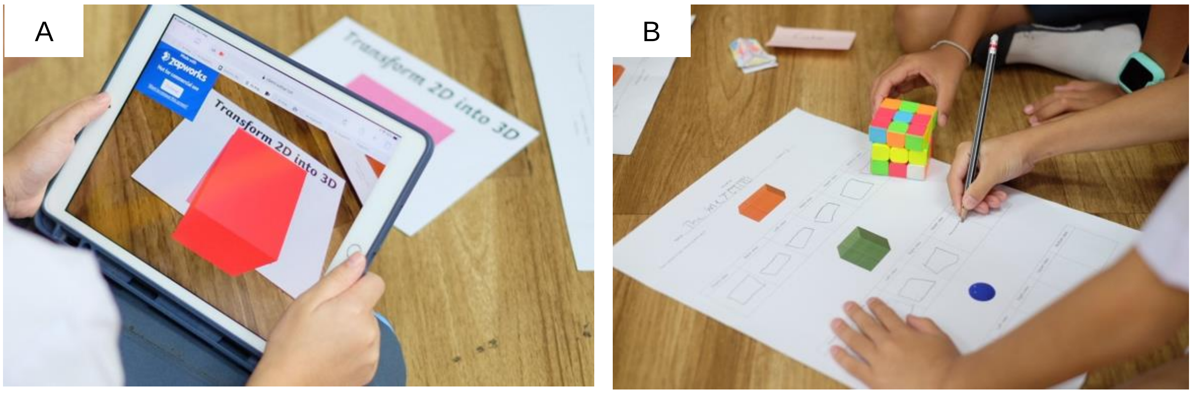

Figure 4. (A) is experimental group used AR,
(B) is control group material objects from everyday life.

5. Result and Discussion

5.1 Student's Conceptual Understanding in Shapes

An independent sample t-test was performed to explore the conceptual understanding; the results are shown in Table 1. The pre-test on both groups showed no significant difference, which means that the students had a similar basic knowledge of shape. The post-test in the experimental group ($\bar{X}$ = 29.13, S.D. = 5.53) obtained higher scores on conceptual understanding than the control group ($\bar{X}$ = 25.58, S.D. = 5.42). There was a significant difference in conceptual understanding between the two groups ($t = -2.19$, $p < .05$). As a result, this finding revealed that the inquiry learning approach with augmented reality was more effective in conceptual understanding than the traditional learning approach.

Table 1. Independent t-test results of Student's Conceptual Understanding.

	Experimental group		Control group		t-score	*p*-value
	$\bar{X}$	*S.D.*	$\bar{X}$	*S.D.*		
Pre-test	22.34	6.28	20.26	7.04	-1.06	0.29
Post-test	29.13	5.53	25.58	5.42	-2.19	0.03*

*p < .05

The results related to the study Efstathiou et al. (2017) conducted a study that utilized an inquiry-based augmented reality mobile learning method to enhance the historical reasoning skills of primary school students in non-formal environments. The results showed that students' conceptual understanding increased from pre-to-post for both conditions. There were statistically significant differences between the AR and the traditional methods.

5.2 Student's Visual-spatial ability

In this section, an independent sample t-test was performed to assess visual-spatial ability. The experimental group ($\bar{X}$ = 14.57, S.D. = 0.84) demonstrated higher scores in visual-spatial ability compared to the control group ($\bar{X}$ = 13.57, S.D. = 2.04). The analysis revealed a statistically significant difference in visual-spatial ability between the two groups (t = -2.17, $p < .05$). These findings suggest that the inquiry-based learning approach enhanced with augmented reality was more effective in improving visual-spatial ability than the traditional learning method. The detailed results were presented in table 2.

Table 2. *Independent t-test results of Student's Visual-spatial ability.*

	Experimental group		Control group		t-score	*p*-value
	$\bar{X}$	*S.D.*	$\bar{X}$	*S.D.*		
Pre-test	13.65	1.26	12.09	3.10	-2.24	0.03*
Post-test	14.57	0.84	13.57	2.04	-2.17	0.03*

*p < .05

The study focused on students' visual-spatial ability. The results showed that using inquiry-based learning with AR for teaching shapes to grade 2 students was effective. The interactive AR kept students excited and interested, leading to more focus and participation. Students enjoyed using the AR features and engaged with them actively. The Plickers app also helped by showing students their classmates' responses during discussions. In the meantime, Nincarean et al. (2019) examined the effect of augmented reality on the spatial visualization ability of elementary school students. As a result, this study has significant implications for understanding AR's effect on improving spatial visualization ability among primary school students.

6. Conclusion

The research findings suggest that incorporating augmented reality into inquiry learning can enhance students' conceptual understanding of shapes in grade 2. Furthermore, interactive AR can help students visualize and increase their comprehension. Additionally, students interact through the Solid Shapes AR application, which could develop their visual-spatial ability. The application can help students view 3D images clearly, rotate and click, and count sides without confusion. In addition, students summarize and answer questions in the Plicker application, which allows them to exchange ideas with classmates immediately and discuss them in class. Research suggests that augmented reality inquiry learning enhances students' conceptual understanding and visual-spatial skills in the mathematics classroom. Moreover, students can apply AR to various mathematical subjects, like determining the area of different shapes. Additionally, AR can create games to gain both knowledge and enjoyment.

7. Limitation

Although the above-mentioned study provides a positive result on using AR in primary school mathematics learning, some limitations still exist in the current study. Firstly, the study restricted its experimental sample to primary school students. Future studies should consider taking other age levels into account and increasing the sample size to obtain more comprehensive and accurate data. Furthermore, this study used an interactive AR application with inquiry learning to investigate the students' conceptual understanding of shapes. Future research can examine the effect of using interactive AR applications with other learning methods and conduct comparative studies to determine which method best supports students' learning. It is also necessary to consider the long-term effects of using AR applications in primary school mathematics education.

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