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The Impact of the Augmented Reality Application with Inquiry-based Learning on Students' Spatial Visualization Skill and Performance

Santhira A/P Poongavanam
Faculty of Educational Sciences and Technology, Universiti Teknologi Malaysia, Malaysia, *santhira_84@yahoo.com*

Nurul Farhana Jumaat
Faculty of Educational Sciences and Technology, Universiti Teknologi Malaysia, Malaysia, *nfarhana@utm.my*

Noor Hidayah Che Lah
Faculty of Computing and Meta-Technology, Universiti Pendidikan Sultan Idris, Malaysia, *hidayah.cl@meta.upsi.edu.my*

Danakorn Nincarean A/L Eh Phon
Faculty of Computing, Universiti Malaysia Pahang Al-Sultan Abdullah, Malaysia, *danakorn@umpsa.edu.my*

Suhaizal Hashim
Faculty of Technical and Vocational Education, Universiti Tun Hussein Onn Malaysia, Malaysia, suhaizal@uthm.edu.my

Spatial visualization skills in science learning are fundamental abilities that students need to develop to ensure mastery of science performance. Therefore, this study aimed to develop an Augmented Reality (AR) application with Engage, Explore, Explain, Elaborate and Evaluate (5E) inquiry-based learning approach, named AR Learn Science App, to improve students' spatial visualization skills and performance in science. Quantitative research with a pre-experimental design of one-group pre-test and post-test was implemented in the study. Thirty Year 5 students in a Malaysian public school were selected through convenience sampling techniques. The Mental Rotation Test and Science Performance Test were used as the study instruments. The data were analyzed descriptively and inferentially using SPSS software. The findings demonstrated the effectiveness of the AR Learn Science App in enhancing students' spatial visualization skills and their performance in science learning. Notably, the findings proved that the AR application with an inquiry-based learning approach could improve students' spatial visualization skills and enhance their science learning outcomes.

Keywords: augmented reality, inquiry-based learning, spatial visualization skill, science

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INTRODUCTION

The swift progress of information technology has greatly enhanced numerous aspects of life (Zakaria et al., 2025). Most countries have focused on technology-based teaching and learning to improve their education systems and students' achievement. Accordingly, various educational methods were introduced to Malaysia's education system with the expectation that learning sessions would be more effective for students.

The emergence of new technologies, such as smartphones, has transformed the educational world by providing various opportunities for educators and students to benefit from supporting learning activities. Smartphones' extensive set of built-in sensors enables various types of applications to be used in education without limitations. For example, mobile phones and tablets have screens and cameras that make them ideal platforms for AR. A study conducted by Wahyu et al. (2020) found that Mobile AR-assisted Science, Technology, Engineering and Mathematics (STEM)-based learning in science has had a significant impact on students' scientific literacy and academic achievement.

Augmented Reality, or AR for short, is the incorporation of digital information, such as live video, into a user's actual environment in real time (Godoy, 2020). In recent years, AR applications have drawn more interest in education and become important research topics. AR is a technology that has the potential to assist students in various ways, including the abstraction of scientific concepts (Swensen, 2016).

To succeed in tomorrow's world, learners must strengthen their scientific thinking skills and gain a deeper understanding of conceptual information (Song & Wen, 2018). The application of AR in science education is strongly encouraged, particularly when it makes the unseen visible, which is crucial for science education (Martin et al., 2023). Additionally, science classes should begin by questioning natural and social phenomena as starting points for scientific inquiry and extending students' thinking (Kang & Noh, 2017). Student evaluation is facilitated by inquiry, which is the foundation of scientific teaching in elementary schools (Suduc et al., 2015).

Through Inquiry-Based Learning (IBL), students actively contribute to their education and develop concepts and theories that help explain what they observe (Şahintepe et al., 2020). AR intervention with inquiry-based learning pedagogy has become increasingly popular. AR-enabled inquiry activities can immerse students in contexts that enhance scientific investigations, enabling them to collect data outside the classroom, interact with avatars, or have face-to-face conversations with peers in more authentic settings (Wen et al., 2023).

According to Chiang et al. (2014), AR-based inquiry scenarios encompass more realistic experiments, and peer interaction activities demonstrate more knowledge construction behaviors that are typically difficult to achieve. Furthermore, by integrating Mobile Augmented Reality (MAR) apps with the 5E learning approach, students can more readily comprehend material and mentally organize it, improving their academic performance (Cakir et al., 2020).

Although AR contributes to teaching difficult subjects, demonstrating dangerous events, and presenting complex information comprehensibly, studies on AR spatial visualization are still in their early stages. The visualization obtained from AR can demonstrate virtual information and abstract ideas that text or teaching materials cannot convey (Chang & Hwang, 2018). Therefore, based on these facts, the researcher studied the effects of AR with 5E Inquiry-Based Learning on students' spatial visualization skills and science learning performance.

Research Questions

1. What is the effect of AR Learn Science towards pupils' spatial visualization skills in science learning?
2. What is the effect of AR Learn Science towards students' performance in science learning?

LITERATURE REVIEW

Augmented reality

AR can create new learning opportunities for students via various meaningful ways such as mobile applications, e-books, games, web-based apps, etc. AR also allows users to observe real-world environments through digital devices, which can be carried or integrated (Tarigan, Kuswanto & Tarigan, 2023). Research conducted in Syrian refugee schools found that AR-based learning guides significantly improved creative reading skills among primary students (AlAli & Al-Barakat, 2024). The interactive nature of AR materials helped students develop better vocabulary and comprehension skills. Case studies demonstrate that AR can visually depict complex subjects, making learning more relatable and enjoyable for students (Vashisht, 2024). Additionally, researchers (Khan et al., 2019; Karagozlu et al., 2019) stated that the integration of mobile devices with AR technology has a positive impacts on science learning, such as enhancement in motivation level, curiosity level, and information acquisition.

Many students nowadays own mobile devices for multiple purposes, such as sharing information, engaging with new technologies, developing, communicating, and so on. Currently, various technologies are being introduced by developers to fulfill people's desires. Due to developments in mobile technology and the rising use of smartphones, the application of AR for learning has become more viable (Khan et al., 2019). Although AR is increasingly popular nowadays, the use of mobile AR in primary education remains unsatisfactory. The rapid growth of AR has had major impacts on students' learning and lives. Due to that, many educators and researchers are enthusiastic to study the use of AR technology in education. It is proven that this technology could help students build a better comprehension of learning content (Eh Phon et al., 2013).

Science learning

Science education plays a key role in shaping future citizens of the world in various ways. Thus, the problems faced by teachers and students in science learning become core issues in science education. In addressing these tensions and dilemmas, this review highlights the types of problems that science education currently faces in an effort to convey quality and meaningful science knowledge to students. In certain countries such as Malaysia, the science curriculum causes many problems when students find it challenging to connect science knowledge with their daily lives. Further analysis from the Ministry of Education (MOE), based on results obtained from Programme for International Student. Assessment (PISA) and Trends in International Mathematics and Science Study (TIMSS) exams in 2013, stated that science knowledge among Malaysian students is quite limited and can only be applied to several known circumstances, meaning students face difficulties in drawing conclusions or making judgments based on simple experiments (Sumintono, 2015).

The nature of science and its understanding has changed drastically in the past 50 years (Brigham et al., 2011). During this period, science has expanded and changed its way from direct observation of causal phenomena to technology-oriented approaches to reach complex phenomena that the naked eye cannot measure. Therefore, school scientific instruction is viewed with some worry (Kaptan & Timurlenk, 2012). According to previous studies, one of the primary subjects frequently linked to an alternative scientific framework is the concept of astronomy, which has been investigated numerous times in numerous nations (Eh Phon et al., 2019). Students are unlikely to learn accurate lunar concepts if the learning activity is limited to a short duration without completing the entire observation procedure (Tarng et al., 2016).

Spatial visualization skill

Spatial visualization skills or spatial ability is a prerequisite for learning and also an integral part of human intelligence; the benefits of these skills are clearly seen in academic achievement, especially in mathematics and science (Eh Phon et al., 2019). Spatial visualization is defined as the ability to interpret three-dimensional information from two-dimensional representations, imagine different perspectives of objects, and visualize the transformation of objects during rotation (Kattner et al., 2018). Furthermore, visualization helps students learn to think visually by using visual models to improve their understanding of topics (Özkan et al., 2018).

Moreover, spatial visualization skills help students understand processes, events, and phenomena occurring around them. These skills are considered essential in science education for imagining the surrounding and natural science environment. Previous studies indicate that visualized teaching helps students observe molecular phenomena and connect them with multiple relevant descriptions (Yang et al., 2016). Although there has been an increase in studies regarding visualization skills in education, the importance of spatial visualization skills remains unsatisfactory, especially in primary education. Therefore, these visualization skills should be embedded in learning processes at early educational stages to prepare future generations for an advanced technological world.

Vandenberg and Kuse's Mental Rotation Test (MRT) has been used in several studies to measure students' spatial visualization levels, which are considered crucial for understanding astronomical concepts. This was demonstrated by Phon et al. in 2015 and 2019, where the researchers collected visualization data from MRT to compare spatial ability levels. Thus, MRT serves as the preferred instrument for testing human spatial ability and imagination levels.

Inquiry-based learning

Inquiry-based Learning (IBL) has its roots in teaching practices that emphasize an active role in children's learning, where learners' curiosity, imagination, and desire to communicate are prioritized. A study conducted by Sasanti, Hemtasin and Thongsuk (2024) indicated that IBL approach has the potential to improve analytical thinking skills, and students generally reported positive satisfaction levels in their learning. Among many instructional approaches supporting inquiry-based science learning, the 5E IBL Model was selected for this study. The 5E Learning cycle is both an inquiry-based teaching approach and a constructivist strategy focusing on student activities such as experimenting, questioning, and investigating problems (Yonwong et al., 2024). The 5E Model comprises five phases: Engagement (curiosity about concepts), Exploration (interaction with materials and ideas), Explanation (connecting previous experience with current learning), Elaboration (drawing conclusions from evidence), and Evaluation (comparing current understanding with previous knowledge) (Yonwong et al., 2024).

METHOD

Research design

A pre-experimental one-group pre- and post-test design was used in this research. One participant group was pretested in this research design. Then, the researcher provided treatment and gathered post-test data by using the same measure (Ma et al., 2019). The treatment was deemed effective if there was a significant difference in the scores between the pre-test and post-test. The following are the measurements for the experimental design.

Figure 1
Pre-test and Post-test design

Sampling

A sample of Year 5 primary students from a Tamil school in Penang, Malaysia, was selected based on a non-probability sampling method, specifically convenience sampling. These students participate in a Dual Language Programme (DLP), with lessons conducted entirely in English. A total of 30 out of 122 Year 5 students was selected as a sample to represent the population learning Year 5 science subjects in English under the DLP. The science topic chosen was from the Earth and Universe theme, specifically Phases of the Moon. These students demonstrated characteristics including English comprehension ability and proficiency in handling mobile devices.

Research instrument and data analysis

In this study, several research instruments were used to address the research questions stated earlier. The instruments included an AR application based on 5E IBL activities, a science performance test, and an MRT instrument. All these instruments were used to examine the effects on science learning.

Mental Rotation Test (MRT)

In this research, the Mental Rotation Test (MRT), adapted from Vandenberg and Kuse 1978, was administered to assess students' visualization skill levels in science learning. The test's main focus was to evaluate students' spatial visualization skill levels in a particular science topic. MRT is a psychometric test comprising 24 items of three-dimensional drawings (Caissie et al., 2009) to identify students' visual ability levels. All the MRT test questions were designed for students aged below 12 years. This test contains 24 items with four sample stimuli, requiring students to identify two alternative answers. Marks were awarded for both correct matching figures. Figure 2 presents an example of MRT questions answered by the students.

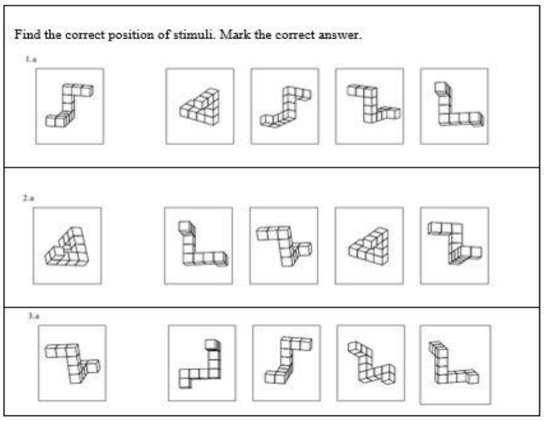


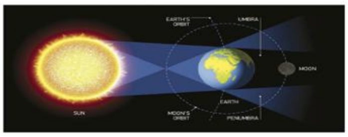
Figure 2
Example questions of mental rotation test (MRT)

Pre and Post Performance Test

Thereafter, learning activities were structured based on IBL pedagogical methods developed by Bybee and Landes (1990) to evaluate students' performance in science learning via pre- and post-tests. The main focus of this test was to analyze the effect of inquiry-based learning on students' performance in science learning through AR application. A pre-performance test was given to ascertain the students' prior knowledge before the learning process started.

In this test, students were given 20 multiple-choice questions with a total score of 20 marks. The marks will then be converted into a percentage. All the questions were based on a Year 5 textbook, which covers the topic "Phases of the Moon." The pre- and post-performance tests were considered as assessments for the students. A post-performance test was conducted to assess the learning performance of students after the activity. It also consisted of the same number of questions to assess students' knowledge of understanding phases of the moon phenomena with a perfect score of 100. The reliability for Multiple Choice Questions (MCQs) has been proposed, indicating that increasing the number of exam items can increase their reliability (Ali et al., 2016). Figure 3 shows some example questions that were in the pre- and post-performance tests.

1. Find the correct order.



A. Sun-Earth-Moon
B. Moon-Sun-Earth
C. Earth-Sun-Moon
D. Earth-Moon-Sun

2. Arrange phases of the moon in correct order.

A. 2, 1, 4, 3
B. 4, 2, 1, 3
C. 3, 2, 1, 4
D. 1, 4, 2, 3

Figure 3
Example questions of Pre-and Post-science performance test

The data were collected from students to investigate students' spatial visualization skills and performance as a result of their learning for 4 weeks. The data collection process was done with the help of school management and the science teachers from the school. A parametric t-test was used in this study. In addition, the test was used to compare two related samples from one experimental group, that is, pre- and post-test scores. Moreover, descriptive statistics were applied in this research because the data could be described using charts or graphs.

Learning activities

Students answer questions verbally using their prior knowledge. Second, the explore button is directed to an AR model that illustrates the whole phases of the moon's phenomena without time limitations. Then, students are given a video about the phenomena to discover the whole topic, and students can repeat the video for better understanding. Next, a group activity from Wordwall is given to build teamwork. Lastly, evaluation objective questions are given to check their understanding, and whoever wants to redo the evaluation is given a retry option. Figure 4 shows an illustration of the implementation of 5E inquiry-based learning with AR Learn Science App.

Figure 4
Implementation of 5E inquiry-based learning with AR Learn Science App

FINDINGS AND DISCUSSION

AR Learn Science App towards students' spatial visualization skills in Science learning

Descriptive analysis and inferential analysis were used to support these research questions. Therefore, a normality test and paired t-test were used to determine the data values between pre-MRT and post-MRT. The inferential analysis was conducted using IBM SPSS Version 27 to reach the sample conclusion. Table 1 shows the scores between pre- and post-Mental Rotation Test (MRT). Statistical data were used to ensure the reliability of the data.

Table 1
Score of pre and post mental rotation test in science learning

Respondent	Pre-MRT (%)	Post-MRT (%)	Score Difference
R1	8.00	21.00	13.00
R2	46.00	50.00	4.00
R3	21.00	42.00	21.00
R4	25.00	50.00	25.00
R5	42.00	62.00	20.00
R6	46.00	46.00	0.00
R7	17.00	33.00	16.00
R8	42.00	46.00	4.00
R9	75.00	96.00	21.00
R10	29.00	46.00	17.00
R11	62.00	96.00	34.00
R12	37.00	58.00	21.00
R13	25.00	33.00	8.00
R14	54.00	83.00	29.00
R15	37.00	87.00	50.00
R16	54.00	87.00	33.00
R17	21.00	33.00	12.00
R18	87.00	83.00	-4.00
R19	50.00	54.00	4.00
R20	58.00	71.00	13.00
R21	58.00	96.00	38.00
R22	46.00	75.00	29.00
R23	92.00	87.00	-5.00
R24	46.00	67.00	21.00
R25	46.00	67.00	21.00
R26	12.00	58.00	46.00
R27	21.00	42.00	21.00
R28	17.00	42.00	25.00
R29	17.00	37.00	20.00
R30	42.00	62.00	20.00
Average	41.10	60.30	19.20

Based on the table above, the average score of the pre-MRT test is 41.1%, and the average score of the post-MRT test is 60.3%. This shows that there is a difference between pre- and post-MRT test scores, with an average score difference of 19.2%. Based on the data above, 27 students out of 30 showed improvement in the MRT test, while 1 student maintained the same score, and two students' scores dropped compared to the pre-test. However, overall, students showed very positive and satisfactory improvement in this test.

The inferential analysis was chosen to conduct a normality test on the pre- and post-MRT test scores. The normality test using 'Shapiro-Wilk' is based on the following hypothesis:

H_o: The data is normally distributed

H_1: The data is not normally distributed

According to the table below, the normality test shows that the significance data of the pre-MRT test was 0.149 (p>0.05), and the significance for the post-MRT test was 0.146 (p>0.05). It was proven that pre-MRT and post-MRT data belonged to a normal distribution.

Table 2
Normality test of pre and post MRT test

Tests of Normality			
	Shapiro-Wilk		
	Statistic	df	Sig.
Pre-MRT	.948	30	.149
Post-MRT	.948	30	.146

*. This is a lower bound of the true significance.
a. Lilliefors Significance Correction

Since the data is normally distributed, the researcher conducted a paired sample t-test as presented in table 3.

Table 3
Paired samples T-test of pre and post MRT test

	Paired Sample Test					
	Paired Differences			t	df	Sig. (2 tailed)
	Mean	Std. Deviation	Std. Error Mean			
Pre-MRT test – Post-MRT test	-19.233	13.346	2.436	-7.893	29	.001

According to the findings, the p-value from a T-Test is less than 0.05 (p<0.05). The result proved that there is a significant difference between the pre- and post-MRT test after the treatment. Therefore, the results demonstrated that AR Learn Science significantly enhanced students' spatial visualization skills, showcasing a positive and impactful achievement.

Research findings show that there is an enhancement in the average score in the post-MRT test compared to the pre-MRT test. This means AR Learn Science gives a positive impact on spatial visualization skills of Year 5 students, particularly in the topic "Phases of the Moon." Additionally, the mean is also increasing, which is parallel with the standard deviation. According to test scores, overall, 27 students showed positive changes in this test. Thus, this pair is considered statistically significant, as it shows a greater achievement value than expected. Overall, the use of AR Learn Science can help students improve their spatial visualization skills. Students' spatial skills significantly improved using AR, and it also encouraged them to be more excited about studying (Guntur et al., 2020). Moreover, this research aligns with previous studies by Eh Phon et al. (2015), which proved that AR applications can improve students' spatial visualization skills abundantly.

AR Learn Science App towards students' performance in Science learning

Descriptive analysis and inferential analysis were used to calculate averages, frequencies, percentages, and standard deviation for pre- and post-performance tests. Normality of the data was tested successfully, and a paired sample t-test was also used to determine measurements between pre- and post-tests. The inferential analysis was done using IBM SPSS Version 27. The table below shows the scores of Pre and Post performance tests of respondents in the topic 'Phases of the Moon'.

Table 4
Score of pre and post-performance test in science learning

Respondent	Pre-test (%)	Post-test (%)	Score Difference
R1	85.00	90.00	5.00
R2	80.00	90.00	10.00
R3	80.00	95.00	15.00
R4	65.00	75.00	10.00
R5	35.00	75.00	40.00
R6	40.00	95.00	55.00
R7	60.00	85.00	25.00
R8	60.00	60.00	0.00
R9	65.00	95.00	30.00
R10	70.00	70.00	0.00
R11	45.00	50.00	5.00
R12	45.00	70.00	25.00
R13	30.00	85.00	55.00
R14	50.00	60.00	10.00
R15	60.00	75.00	15.00
R16	50.00	80.00	30.00
R17	80.00	85.00	5.00
R18	40.00	65.00	25.00
R19	55.00	50.00	-5.00
R20	60.00	55.00	-5.00
R21	60.00	85.00	25.00
R22	30.00	90.00	60.00
R23	50.00	70.00	20.00
R24	60.00	75.00	15.00
R25	40.00	65.00	25.00
R26	70.00	80.00	10.00
R27	30.00	80.00	50.00
R28	70.00	55.00	-15.00
R29	40.00	75.00	35.00
R30	35.00	65.00	30.00
Average	54.70	74.80	20.20

Based on Table 4, the average score of the pre-performance test is 54.7%, and the average score of the post-performance test is 74.8%. It shows that there is an improvement between pre- and post-performance tests, with an average score difference of 20.2%. According to the data above, 25 students out of 30 showed progress in the post-performance test, while two students remained with the same score, and three students' scores dropped when compared to the pre-test. However, overall, students showed improvement in the science performance test. Next, inferential analysis was tested by conducting a normality test for the pre- and post-performance tests. The 'Shapiro-Wilk' test was selected to identify the significance and normal distribution of data.

The normality test using 'Shapiro-Wilk' is based on the following hypothesis:

H_o: The data is normally distributed

H_1: The data is not normally distributed

Table 5
Normality test of pre and post performance test

Tests of Normality			
	Shapiro-Wilk		
	Statistic	df	Sig.
Pre-performance test	.951	30	.176
Post-performance test	.954	30	.218

*. This is a lower bound of the true significance.
a. Lilliefors Significance Correction

According to the Table 5, the normality test shows that the significance data of the pre-performance test was 0.176 ($p > 0.05$), and the significance for the post-performance test was 0.218 ($p > 0.05$). This proved that both tests were normally distributed. Then, the researcher conducted a paired-sample t-test analysis, as shown in Table 6.

Table 6
Paired sample T-Test of pre and post performance test

Paired Sample Test						
	Paired Differences			t	df	Sig. (2 tailed)
	Mean	Std. Deviation	Std. Error Mean			
Pre-performance Post-performance	-20.16667	18.95927	3.46147	-5.826	29	.001

Table 6 shows a paired sample t-test for the pre-performance test and post-performance test. According to the statistics, the p-value shown from a t-test is less than 0.05 ($p < 0.05$). The result proved the mean difference between the pre- and post-performance tests after the intervention. Hence, AR Learn Science significantly enhanced students' learning performance in the topic 'Phases of the Moon'.

CONCLUSION AND RECOMMENDATIONS

Overall, the AR Learn Science application gives a positive impact on the education world by creating a teaching aid that fully covers the topic "Phases of the Moon." This application not only improves spatial visualization skills but also enhances students' performance in science learning. AR Learn Science helps students with self-learning at their homes as extra teaching material. Moreover, inquiry-based learning activities help develop their science knowledge. First, students are asked general questions regarding the topic "Phases of the Moon." The AR Learn Science application is built with various activities to enhance students' science learning and spatial visualization skills. Therefore, teachers are advised to use AR Learn Science in classrooms because it is comprehensive and beneficial to students and teachers.

This study focused on 30 respondents from year 5 only. It involved students from one Tamil primary school in the Seberang Perai district. One of the subtopics from the year 5 science syllabus, called "Phases of the Moon," was selected for this study. Therefore, it is recommended that future studies widen the sample size by involving more respondents from the same school and other schools so that the findings can become more generalized.

The time taken for this study was 6 weeks, which was considered a short period because it involved primary school students who have their own schedules. Additionally, students' attendance problems due to illness, school activities, and other issues became time constraints for this study. As a suggestion, the time period for this study should be extended so that the progress becomes smoother and more flexible. Furthermore, the students can participate in this study with more interest without any inconvenience during the data collection process.

While AR has the potential to transform education, its implementation comes with several limitations, especially concerning accessibility in different educational contexts. For example, many AR applications require high-performance devices (e.g., tablets, smartphones, AR headsets), which may not be available in underfunded schools or rural areas.

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