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Promoting Middle School Students' Achievement and Attitude toward Science Learning through Sphere Recognition-Based AR Application

Ruixue LIU[a*], Lijun LIANG[a] & Xiaodong WEI[a]
[a]*School of Educational Technology, Northwest Normal University, China*
*isnow0211@163.com

Abstract: With the advancement of Augmented Reality (AR) technology, considerable studies have explored AR’s application in various educational fields, especially in the field of science. This paper used a sphere recognition-based identifier to develop an AR application that supports middle school students learning of science. A quasi-experimental method was adopted, using a pretest and posttest of science knowledge to measure academic performance. A questionnaire was conducted to measure students’ attitudes toward the use of AR in science lessons. The research sample included 80 middle school students and was divided into experimental and control groups. Students in the experimental group learned science lessons by using a sphere recognition-based AR application, while the control group learned the same material by using a traditional method. Results showed that students who learned science lessons in a sphere recognition-based AR application performed better in academic achievement than that in the control group. In addition, the experimental group showed a positive attitude toward the use of AR in science classes. This study provides empirical evidence to explore the use of sphere recognition-based AR in science education.

Keywords: Augmented reality, academic achievement, middle school, science learning, attitude

1. Introduction

Science learning is an important subject in the educational area. However, learners often face difficulty in learning science because it involves many complex and abstract concepts (e.g. gravity, electromagnetic phenomena, etc) (Anderson & Barnett, 2013). In this way, learners may have misunderstandings in the process of understanding and analyzing scientific phenomena due to the lack of intuitive and vivid presentation. In addition, real scientific practice faces problems such as geographical distance and security risks (Zhang & Wang, 2021). For example, previous studies have indicated that students could grasp the description of the phases of the moon, but they often misunderstand the interpretation of the moon phases and believe that the moon phases are formed by the occlusion of the sun (Lelliott & Rollnick, 2010; Wilgenbus & Lena, 2009). Therefore, many students may have difficulties in science learning, such as low interest and confidence in science curricula, and low learning achievement.

With the development of emerging technologies, various visual technologies such as virtual reality, and augmented reality can be applied in educational fields to promote student’s learning experience. Augmented reality (AR) is a technology that seamlessly connects virtual information with the real world and has the characteristics of virtual and real fusion (Azuma, 1997). It provides opportunities for learners to observe and explore 3D models and support their understanding of intellectual concepts (Xu et al., 2022). With the help of this technology, learners can place 2D or 3D virtual information in real scenes by using their devices to identify markers. Moreover, AR has the advantages of presenting abstract scientific knowledge and supporting scientific exploration. Fleck and Simon (2013) indicated that AR is a good scaffold for learning science knowledge due to its ability to enhance sensorimotor interactions, visual guides, and realistic representation. This study aims to investigate the effect of sphere recognition-based AR application on middle school students learning of science. The research questions are as follows:

- Compare to the traditional teaching methods, do students who learned science through using a sphere recognition-based AR application perform better in academic achievement?
- What are the attitudes of students toward the use of sphere recognition-based AR applications in science learning?

2. Literature Review

2.1 Science Learning

Science is a discipline concerned with the study of organisms and events in nature. It requires people to form concepts and principles by observing and generalizing things and phenomena (Karagozlu, 2021). The purpose of science education is that it requires students to form scientific concepts, master the nature of science, and improve their willingness to actively participate in scientific learning (National Research Council, 1996). One of the main challenges for science education is helping learners to develop a conceptual understanding of scientific concepts (Osborne et al., 2016). However, there is a lack of physical conditions to support learners in practicing learning tasks in a school classroom setting. To solve these problems, researchers have attempted to integrate AR and virtual reality into the science curriculum (Monita & Ikhsan, 2020). Since these technologies provide opportunities for the visualization, simulation of scientific knowledge, and science practice.

2.2 AR in Science Learning

AR is a technology that can superimpose virtual information in the real world. It has three characteristics of the combination of reality and reality, real-time interaction, and 3D registration (Azuma, 1997). Based on AR's characteristics, it brings new opportunities in the field of education (Zhang et al., 2022). First, the combination of reality and reality can present 3D learning content for learners, which can contribute to the visualization of knowledge and solve the problems of simulating inaccessible, invisible, and dangerous scientific phenomena. Second, AR supports students' real-time interaction with virtual information in a real environment. Moreover, some studies have shown that AR plays an important role in increasing learning motivation and engagement, as well as enhancing learners' creativity and imagination (Demircioglu et al., 2022; Lorusso et al., 2018).

Previous studies have applied AR in science education. For example, Liu et al. (2023) developed an AR application for chemistry courses for middle school students level. The results showed that AR helped increase knowledge gains and improved motivation. Wang (2022) developed a game-based AR science learning system for middle school students to learn electromagnetic phenomena. Results found that the proposed system has advantages in improving interactivity, learning performance, and learning satisfaction. Tina et al. (2019) developed a real-world-oriented smartphone AR system and they found that the system is an effective learning tool and improves the interest in learning science.

Overall, previous studies have demonstrated the advantages of AR in science education. Among them, marker-based (such as image-based) AR is commonly used. Other types of AR, such as location-based and object recognition-based AR, are less implemented. In this study, we use an AR application based on sphere recognition to explore its effects on science learning.

3. Development of a Sphere Recognition-based AR Science Learning System

3.1 System Structure Overview

In this study, a sphere recognition-based AR application was developed using Unity and Vuforia engines. The process of the development of the AR application requires the use of “Scanner” software to scan spheres and then generate data files of the sphere model. Following that, upload the data file to the database of the Vuforia engine. Next, connect the corresponding Vuforia engine database in the Unity engine, and edit the sphere data in the Unity engine to form the final AR application. The AR application was eventually released as an APK and installed on students’ mobile devices. Figure 1 shows the system structure.

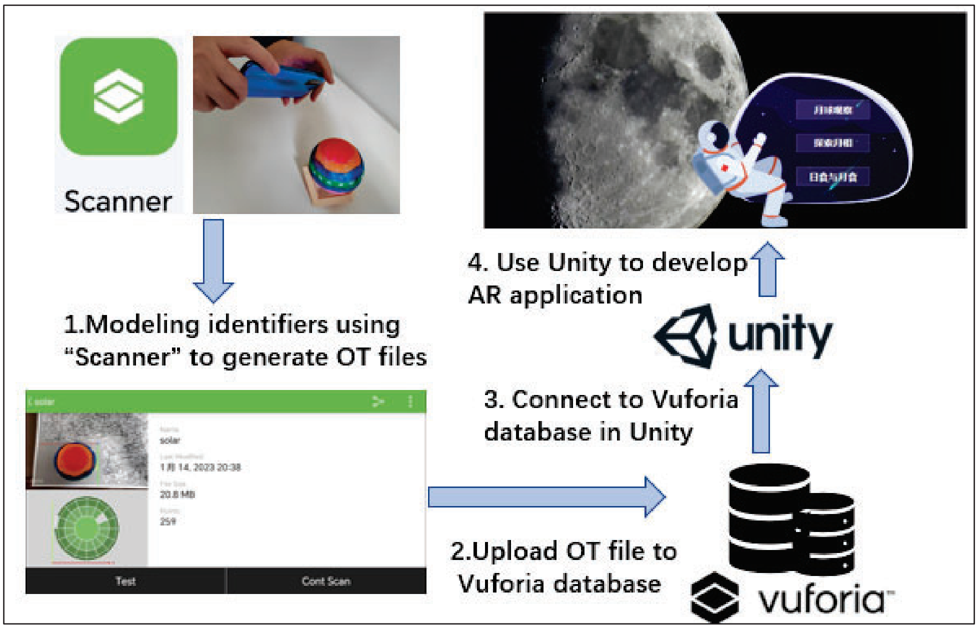

Figure 1. The System Structure of the AR Application.

3.2 Sphere Recognition-based AR Science Learning Application

The theme of the science curriculum is “Exploring the Earth-Moon System”. The AR application consists of three main parts: (a) “Moon Observation”, (b) “Exploring the Moon Phase”, and (c) “The Solar and Lunar Eclipses” module. Students can click the module selection button to enter the interface according to the learning progress on the AR application homepage (see Figure 2).

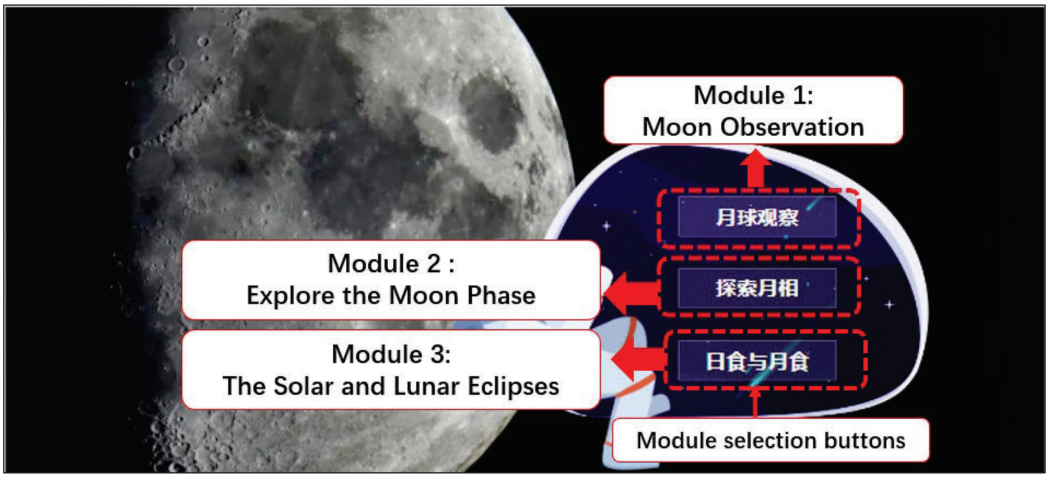

Figure 2. The Interface of the Homepage

The "Moon Observation" module includes the moon's position in the universe, the types of terrain on the moon, and the characteristics, and locations of the terrain (see Figure 3). Students scan the sphere using their mobile phones, and a 3D model of the moon appears on the page. Students can interact with the 3D model, including zooming and rotating. The surface of the 3D model is equipped with marker points, and students are guided by the marking points. When students click on the markers, text and images describing the model appear on the right side of the screen. In addition, by clicking on the buttons at the bottom of the screen, students can get an audio or video explanation of the lunar terrain.

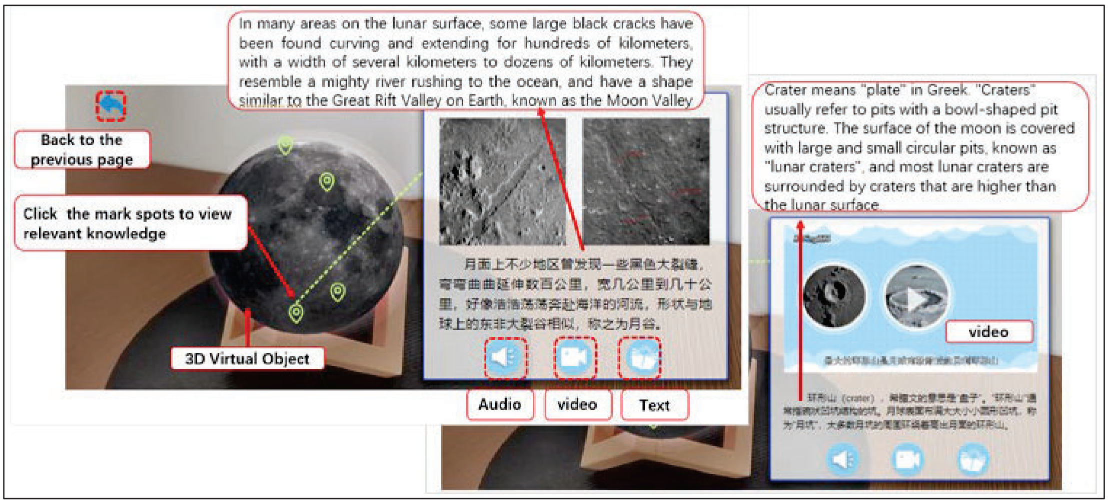

Figure 3. The Interface of the "Moon Observation" Module

The "Exploring the Moon Phases" module includes the types of moon phases, the evolution of moon phases, and reasons for the formation of moon phases (see Figure 4). Students scan the sphere using their mobile phones, and a 3D model of the Earth-Moon system appears on the page. After the student selects the date on the left side of the page, the 3D model shows the relative positions of the Earth and the Moon, and an image of the corresponding moon phase appears on the right side of the page. Students can click the buttons at the bottom of the screen to get text, audio, and video explanations of the moon phase.

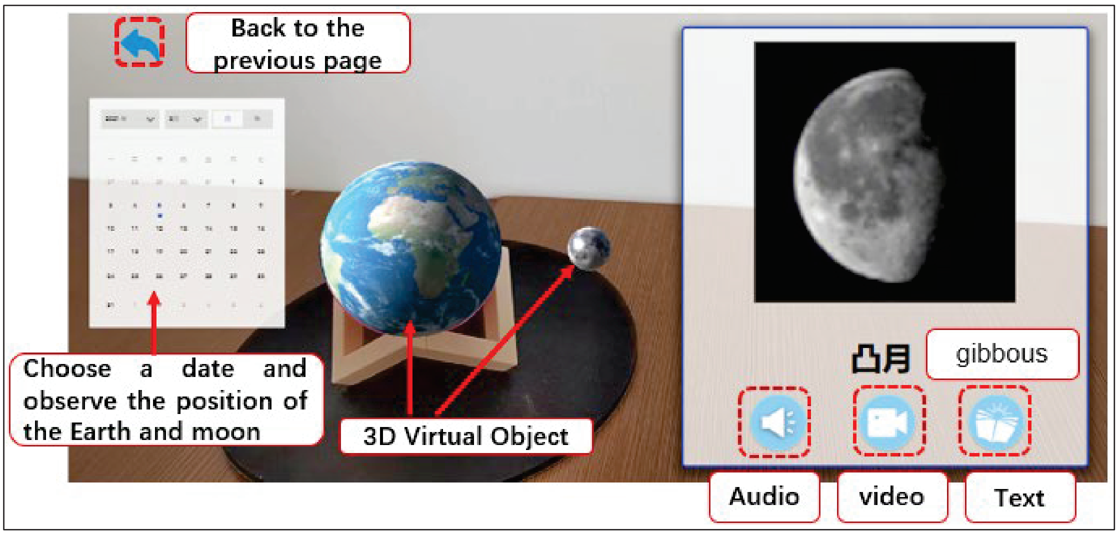

Figure 4. The Interface of the "Exploring the Moon Phases" Module

In the “The Solar and Lunar Eclipses” module (see Figure 5), students learn the types and patterns of solar and lunar eclipses and analyze the reasons for their formation. They select an option from the drop-down menu in the upper right corner of the screen. The 3D model is corresponding to the options that will be presented on the page. Students select the “Annular Solar Eclipse” option, and the 3D model on the page simulates the relative positions of the Sun, Moon, and Earth during an annular solar eclipse, as well as the light and shadow phenomena. Text and images of the annular solar eclipse are presented at the bottom of the page. Students can also use the buttons on the left side of the page to access audio and video explanations of the annular solar eclipse.

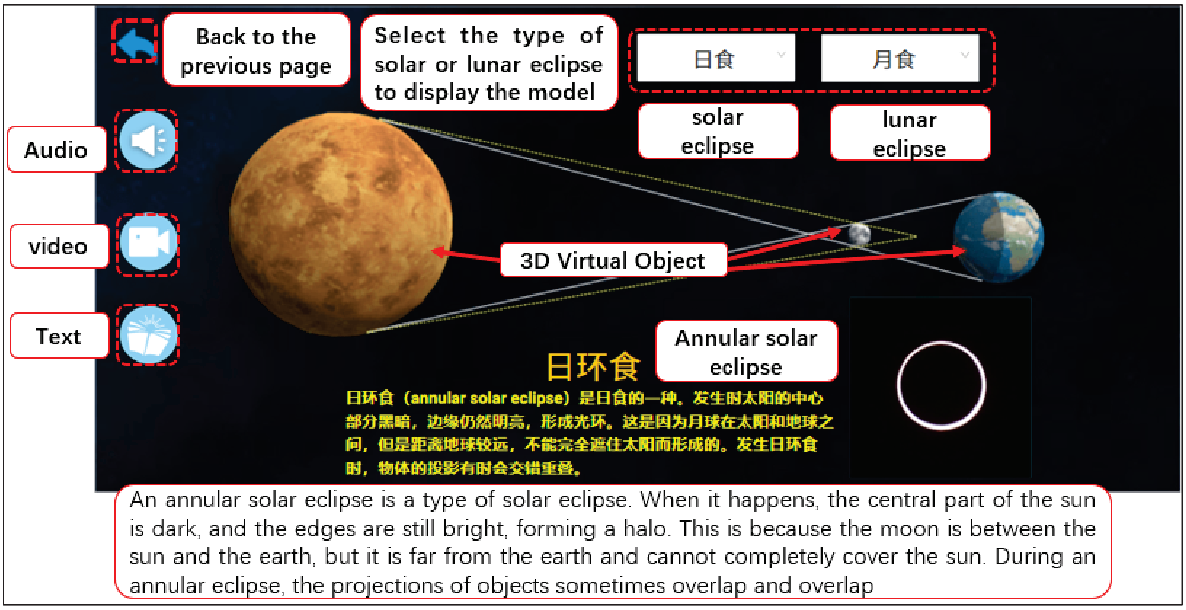

Figure 5. The Interface of the “Solar and Lunar Eclipses” Module

4. Methods

4.1 Research Design

This study used a quasi-experimental method to investigate the effect of a sphere recognition-based AR application on students’ academic performance and attitude toward science learning. The two classes participating in the experiment were divided into experimental and control groups. Before the experiment, both groups of students took a pretest to ensure that they had a similar knowledge level. Following that, students in the experimental group learned science lessons by using a sphere recognition-based AR application, while the control group learned the same content using traditional teaching methods. After finishing the experiment, a posttest and questionnaires were administered to both students.

4.2 Participants

The study was conducted in a public middle school in the Northwest region of China. A total of 80 students from two classes with an average age of 13 years old participated in this study. Among them, 40 students were in the experimental group and 40 students were in the control group. Both classes had approximately the same proportion of boys and girls. The science lessons were taught by the same teacher with more than two years of teaching experience. All students had not been exposed to AR science lessons before the experiment.

4.3 Measurement Tools

4.3.1 Pretest and Posttest

To test students' science learning effect, pretest, and posttest were used to measure students' academic achievement before and after the learning activity. Both tests were developed by research and the teacher and have a Cronbach alpha of 0.83. The pretest and posttest consist of 10 multiple-choice items (e.g., When does the lunar eclipse occur? A. new moon B. upper moon C. lower moon D. full moon), 6 true or false items (e.g., The average distance from the moon to the earth is about 3.84×10^5 km. A. True B. False), and 2 short-answer items (e.g., How many stages are there in the moon phase? What is the formation principle of the moon phase?). The perfect score on both tests is 100. An expert panel of three educators examined the validity of the tests. Both science teachers and the expert panel reviewed the final version of the tests. We modified the inappropriate items in the tests to ensure high reliability and validity.

4.3.2 Questionnaire

This study used an AR Application Attitude Scale (ARAAS) developed by Kucuk et al. (2014) to measure students' attitudes toward the use of AR applications in science lessons. The ARAAS adopts a 5-point Likert scale (*"1"= Strongly Disagree, "5"= Strongly Agree*) and consists of 14 items with three dimensions, including "using satisfaction", "using anxiety", and "using willingness", among which six positive descriptions reveal students' satisfaction with using AR application, (e.g., I enjoy the AR lessons), six negative descriptions reflect students' anxiety level in using AR applications (e.g., It is difficult to use AR applications), two positive descriptions show students' intention to use AR applications in the future (e.g., I want AR applications in other lessons). The values of Cronbach's alpha for the three dimensions were 0.86, 0.82, and 0.89, respectively. The value of Cronbach's alpha for the overall scale was 0.83, indicating that the scale is reliable.

4.4 Procedure

As shown in Figure 6, the experiment lasted for 5 weeks. In the first week, students in both groups took a pretest. From the second to the fourth week, the students participated in science lessons. Each week, both groups of students took a 45-minute science lesson. An example of a 45-minute class is shown in Table 1. During the lesson, students in the experimental group learned science lessons using a sphere recognition-based AR application. the teacher first conducts the lesson by introducing the topic. After that, the teacher introduces the use of AR and guides the students to use it. When finished, students use the AR application for science learning. In the end, the teacher guides the students to summarize and share the knowledge learned in the lesson. The control group followed the same teaching process and used traditional teaching methods. In the fifth week, both groups took the posttest. Meanwhile, students in the experimental group were also required to complete the questionnaire.

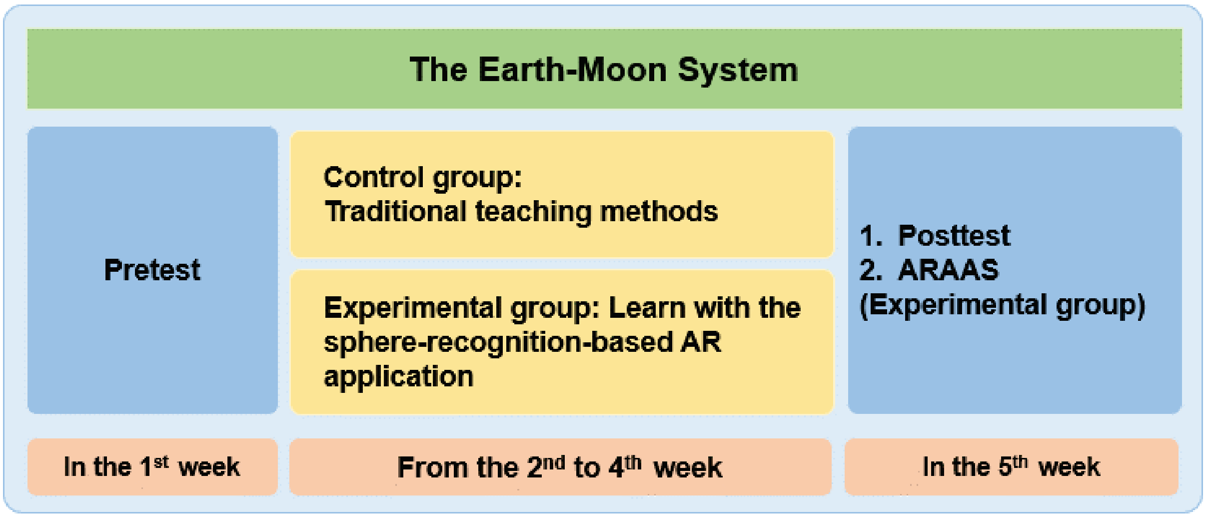

Figure 6. Procedure

Table 1. *An Example of a 45-minute Class*

Step	Activity (T for Teacher, S for Students)	Time
1	T introduces the content and topics learned in this lesson or guides S to review	10min
2	T introduces and demonstrates the use of AR application and guides S to scan identifiers	5min
3	S use AR applications to learn	20min
4	T guides S to summarize the learning content and invites S to share what have learned today	10min

4.5 Data Analysis

In this study, data were analyzed using SPSS software. Descriptive analyses and *t*-tests were used to analyze the student's academic achievement. In terms of attitudes toward AR technology use, descriptive analysis was used to analyze data from students' ARAAS questionnaires.

5. Results

5.1 Academic Achievement

The results of the pretest scores are given in Table 2. The Mean values of the pretest scores were 47.75 for the experimental group and 47.50 for the control group respectively. The *t*-test results (t = 0.27, p > 0.05) showed no significant difference between the two groups, indicating that both groups had a similar level of a priori knowledge before the learning activity.

Table 2. *T-test Result of Pretest and Posttest Scores*

	Group	N	M	SD	*t*	*p*
Pretest	Experimental	40	47.75	4.14	0.27	0.79
	Control	40	47.50	4.23		
Posttest	Experimental	40	83.70	4.50	9.34	0.00*
	Control	40	72.33	6.25		

*p < 0.01.

At the end of the learning activities, both groups of students took a posttest. The Mean values of post-test scores were 83.70 for the experimental group and 72.33 for the control group. The *t*-test results ($t = 9.34$, $p < 0.01$) showed a significant difference between the two groups. It can be concluded that the students who use AR applications for science learning had better learning performance.

5.2 Attitude Towards AR Applications

As shown in Table 3, the Mean values and SD of the overall attitudes for the experimental group were 3.95 and 0.27, indicating that students in the experimental group gave high attitudes toward the use of AR applications in science classes. Moreover, the Mean values and SD of satisfaction for the experimental group were 3.91 and 0.38, and the willingness for the experimental group was 3.86 and 0.57. In addition, the Mean values and SD of anxiety for the experimental group were 1.99 and 0.29. The results showed that students were satisfied with using AR applications in their courses, with a low level of anxiety and they generally showed their intention to continue using AR applications in the course. It can be concluded that students in the experimental group have positive attitudes toward using AR applications in science courses.

Table 3. *Descriptive Data of ARAAS*

Dimension	N	Min	Max	M	SD
Satisfaction	40	3.17	5.00	3.91	0.38
Anxiety	40	1.00	2.50	1.99	0.29
Willingness	40	3.00	5.00	3.86	0.57
General ARAAS	40	3.50	5.00	3.95	0.27

6. Discussion and Conclusion

In this study, we explored the effects of a sphere recognition-based AR application on middle school students' academic performance and their attitudes toward science learning. The results showed that students who used a sphere recognition-based AR application for science learning had significantly higher academic achievement than that of the control group. In addition, students in the experimental group gave positive attitudes regarding the satisfaction and willingness to use AR applications in a science curriculum.

In terms of academic achievement, the results of the current study are consistent with previous studies (Kalemkus & Kalemkus, 2022; Wang, 2022). In this study, the reasons for such an effect may be as follows. First, AR helps visualize scientific knowledge. Although middle school students have certain abilities of cognitive and abstract, they are prone to misunderstand complex scientific phenomena such as the moon phase. AR presents complex and abstract scientific phenomena in the form of 3D models in the real world, and students can observe intuitively through real-time interaction to facilitate understanding and learning. Second, this study uses spheres as identified objects because the external shapes of the Earth, Moon, and Sun are spherical. Compared with 2D images, the 3D model has a better sensory effect in the way of sphere recognition. The fun and manipulability of the learning process motivate students to maintain a high level of motivation and interest in learning, which provides the possibility for learning more knowledge and finally effectively improves their academic performance.

Moreover, students showed positive attitudes toward the use of AR applications, which confirmed other studies' similar results (Celik & Ersanli, 2022; Fidan & Tuncel, 2019; Kaya & Bicen, 2019; Karagozlu et al., 2019). They were satisfied with the use of AR application in science lessons. Visual observation displayed by the AR helps students understand and learn from the knowledge. They also looked forward to using AR in future science lessons.

7. Limitations and Future Research

Although the above-mentioned study provides a positive result on using AR in middle school science learning, some limitations still exist in the current study. First, students were first exposed to AR learning activities in this study. Therefore, the novelty of AR learning activities may be a reason for the positive effects. In future research, pre-experiments should be performed on this issue to eliminate the influence of this factor on experimental results. Second, the experimental sample was limited to middle school students. Future studies should consider taking other age levels into account and increasing the sample size to obtain more comprehensive and accurate data. Moreover, this study used a sphere recognition-based AR application to investigate the students' learning effect in science lessons. In future research, the effect of using AR applications of other recognition methods can be examined, and comparative research can be conducted to see which recognition method has a better effect in supporting students' learning. It is also necessary to consider the long-term effects of the use of sphere recognition-based AR applications in middle school science learning.

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