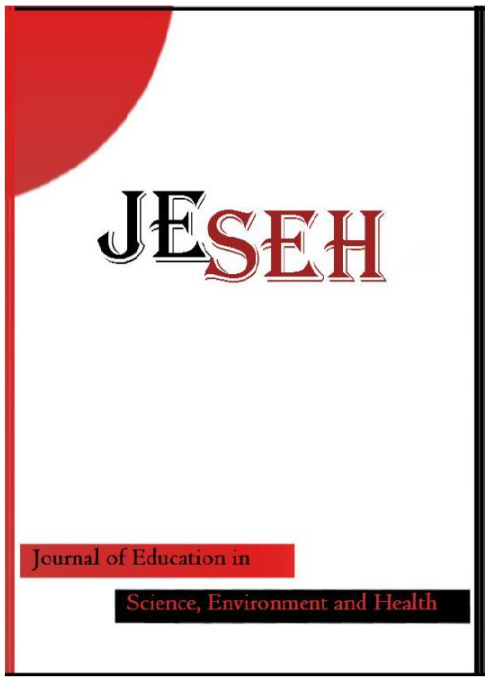

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Abstract

The aim of this study is to investigate how the use of augmented reality (AR) applications in educational environments affects students' achievement levels. The study was carried out through two dimensions; a quantitative and a qualitative aspect. The study was conducted with 7th-grade students in a public secondary school in Turkey as part of a science course. For this purpose, AR applications and activities were implemented that were suitable for the topic of Astronomy. The quasi-experimental model and one of the quantitative research methods were used for the study. As data collection instruments an achievement test and an interview form were made use of. AR activities were used for teaching in the experimental group, while the traditional method for the control group. The quantitative results of the study showed that there was a significant difference in the achievement level of learners in favor of the experimental group. The interviews with the students revealed that the AR applications used in the course were interesting, that they increased interest, desire, and motivation in class, and that they facilitated learning. However, students indicated that the cost of the AR materials was high, that they had difficulty in obtaining the materials, and that they sometimes had technical problems. Another limitation was expressed as that the excess the number of students makes it more difficult to take the advantage of AR activities. Students suggested that lowering the cost of AR materials and using them in other lessons can be more effective in learning environment.

Introduction

Information and communication technologies (ICTs) that facilitate our daily activities have gradually become an integral part of our lives and a necessity. As ICT becomes increasingly important in our daily lives, the effective use of technological tools is also getting more important in education day by day (Alkan, 1999). The use of technology improves students' interest and motivation in the course and makes it easier to memorize the subject. In addition, the information presented to students is conveyed in a simpler way through technology so that they can have concrete learning experiences (İşman et al., 2002). It is believed that technology should be used by teachers and students to improve the quality of education (Çakır & Yıldırım, 2009). This situation has led to the need for societies to follow and adopt new technological developments that play significant role in the development of the educational process (Uşun, 2003). Many countries are seriously investing in integrating technology into the education system to ensure the quality of education and train their citizens according to the needs of modern society (Topuz & Göktaş, 2015). Various technology-producing countries, especially the U.S. and EU countries, have begun to use technological developments in education. However, to get the most out of technology, it is necessary to properly understand education and training based on virtual and digital technologies.

Nowadays, there are many innovations related to the use and application of technology in education. A number of innovations, methods, and technologies can be used in education, especially in situations that are invisible, intangible, and problematic. These innovations in educational technology support and enrich education to address the shortcomings of the traditional method. One of the new technologies entering the educational environment is AR technology, which has the potential to combine virtuality and reality. The goal of this technology is to allow people to interact with both digital space and the real world. AR technologies that can be accessed via applications downloaded to vehicles, such as smartphones and tablets, are becoming increasingly popular due to their ease of use.

One indicator of the increasing influence of information and communication technologies on education is the rapid development of AR applications in recent years (Arici et al., 2019). This technology has changed and evolved over time and has come to the present in a systematic change. Although the birth of AR dates back to earlier times, this concept was first titled by Tom Caudell in 1990 (Lee, 2012). The first examples of applications of AR are cameras attached to simulators, helmets, and wearable vehicles. With the development of communication and technology, the applications have acquired various functions. These technologies became widespread through the use of pilot schemes in the 1990s. Before 2010, many applications of AR were complex and high-cost systems. One of the most important reasons for the rapid spread of AR technology and its easy accessibility is that it has moved away from expensive and complex equipment (Wu et al., 2013). Especially with the integration of AR applications to mobile devices, the number of these applications has increased in recent years. In 2012, Google Glass, which is produced based on AR technology and described as a wearable technology, was introduced by the Google Company and an important step was taken for this technology. In 2016, Microsoft developed the HoloLens, which offers its users a mixed reality experience. Also in July 2016, the game Pokémon Go was released. In addition, the use of tools and devices such as smart glasses, 3D projections, laptops, tablets, and mobile phones for AR applications is increasing day by day. Rapid development, especially in smartphones and tablet computers, has meant that applications of AR can no longer be used only in the laboratory environment, but can also be easily accessed and run on smart devices (Batdı & Talan, 2019). Therefore, these technologies have created new alternatives to improve the educational environment and become an easily accessible technology for everyone (Garzón, Pavón & Baldiris, 2019; Ozdemir et al., 2018). The annual reports of Horizon highlight that AR applications will have a significant impact on education soon (Arici et al., 2019; Cai, Wang & Chiang, 2014). The same report emphasizes that AR will be widely used in higher education in the medium term (Johnson et al., 2016). The report, published by Educause, also predicts that the use of AR applications will be popular in higher education and K-12 schools (Fidan & Tuncel, 2019; Pomerantz, 2018). The use of AR in education will have an important place in the entertaining teaching process by simplifying complex information and making abstract concepts concrete.

The purpose of virtual reality (VR) is to create virtual environments that allow interaction free of the real world. AR, a derivative of VR (Azuma, 1997), bridges the gap between reality and virtuality (Azuma, 1997; Cai, Wang & Chiang, 2014; Carmigniani et al., 2011). This technology enables interactive experiences by enriching the real world with virtual elements, rather than creating a completely virtual and artificial environment (Höllerer & Feiner 2004). Unlike VR, AR aims to make virtual objects more interactive by building on real images (Batdı & Talan, 2019; Cai, Wang & Chiang, 2014). Therefore, AR technology differs from VR in that users are not completely disconnected from the physical world. In other words, the most characteristic feature of AR is the use of the physical and the virtual environment for a specific purpose. This concept can be briefly defined as an interactive platform that provides a combination of reality and virtuality (Akçayır & Akçayır, 2017; Azuma, 1997; Milgram & Kishino, 1994). In other words, AR is a modern technology that makes encoded multimedia content visible by adding a digital layer (e.g. video, graphics, animation, text or sound, etc.) to real objects generated by a camera (Craig, 2013; Taskiran, 2019; Yılmaz & Batdı, 2016). Therefore, AR is also referred to the enrichment of the real world in light of technological developments through various animation, sound and multimedia tools (Bower et al., 2014; Craig, 2013; Dunleavy, Dede & Mitchell, 2009; Rabbi & Ullah, 2013; Wu et al., 2013). AR is a new tool for human-machine interaction that embeds computer-generated digital information interactively in a real environment (Ong, Yuan & Nee, 2008; Wu et al., 2013). Thanks to the renewed and advanced technology of AR, it can be used on laptops, mobile devices, and smartphones. In addition, AR technologies are widely used in social media such as Instagram and Snapchat, which have a large number of users worldwide.

The Use of AR in Education

Although AR has been used for years with the help of computers, today it is used in many different applications in mobile and portable devices due to the changes and developments in the technological field. Thanks to the development of AR technology, it has been used in all fields in recent years. AR is used in various fields such as the automotive industry, military, medicine, tourism, construction, architecture, sport, entertainment, engineering, assembly, navigation, museology, maintenance, product design, telerobotics, marketing, and advertising (Altinpulluk, 2019; Fidan & Tuncel, 2019; Ong, Yuan & Nee, 2008). After successful results in these fields, the usage areas of AR technology have increased day by day. AR is also used in education, and many researches have been conducted in this field in recent years. With the widespread use of mobile devices, the applications of AR, which are used in education, are updated and their number is rapidly increasing. AR applications are also designed to work with more and more different devices and systems as technology advances. For example, AR applications have begun to be used in wearable tech products as well as mobile

devices. With the use of AR applications in education, beneficial content is put into a fun and interesting form and presented to students. The use of AR in education is a very important development in terms of effectiveness, efficiency and accessibility in teaching and learning process.

AR is a popular technology that has added a new dimension to education and has become the focus of educational research in the last decade (Ibáñez & Delgado-Kloos, 2018; Sırakaya & Alsancak Sırakaya, 2020). A good many studies have highlighted trends, benefits, opportunities, challenges, and impacts of AR technology on education. The most important point in using AR technology in the classroom is that it is appropriate to the level of the students and the curriculum of the course, and the process is carried out regularly. Moreover, this technology provides opportunities for learning experiences and teaching processes by creating an interactive and immersive environment (Bujak et al., 2013; Dunleavy, Dede & Mitchell, 2009; Fidan & Tuncel, 2019). Unlike traditional methods and techniques, the use of technology in science education with AR applications is of great importance to schools where the laboratory environment is not accessible. Therefore, the AR technology can also be used as supplementary or evaluative material, especially in the context of laboratory or workshop studies and virtual classroom activities.

It can be stated that schools are becoming more technological every day and many new technologies are being used in the classroom to meet the age and expectations of students and enhance their learning. One of the technologies whose effectiveness in education has been widely studied in recent years is AR. Since it has been observed that more than one sense can be actively used when using this technology, it is assumed that real learning experiences can be made with this technology. Thanks to its features, AR technology has managed to attract attention of learners in all levels of education from preschool to university (Sırakaya & Alsancak Sırakaya, 2020; Talan, 2021). In fact, research shows that AR technology is suitable for all ages (López-Belmonte et al., 2020). AR can be used many different disciplines such as science, foreign language teaching, geography, mathematics, and geometry (Altinpulluk, 2019; Sırakaya & Alsancak Sırakaya, 2020; Taskiran, 2019). One of the areas where AR can be used effectively is astronomy education. Because of its relationship to the basic sciences, astronomy occupies a very important place in science education (Kurnaz & Değermenci, 2011). People who do not receive a good astronomy education are exploited with topics such as astrology, horoscopes, fortune-telling, UFOs (Unidentified Flying Objects), and aliens (Düşkün, 2011). AR is one of the immersive technologies that, thanks to its potential, it could be promising to mitigate the challenges in astronomy education.

Today's and future students, growing up with technology, want their educational environment to be integrated with innovative approaches such as AR-based applications (Altinpulluk, 2019; Klopfer & Yoon 2004). It should also be mentioned that scientific studies on AR have gained momentum and some researchers have started to attract attention. In fact, the studies show that AR brings a different dimension to education and offers many advantages in education. For example, AR technology can increase interest, desire, attention, and motivation in the classroom by activating students (Chen & Tsai, 2012; Huang, Chen & Chou, 2016; López-Belmonte et al., 2021; Sumadio & Rambli, 2010; Wojciechowski & Celary, 2013) and creating an effective and productive learning environment (Iordache, Pribeanu & Balog, 2012; Sırakaya & Alsancak Sırakaya, 2020). In addition, AR makes abstract concepts concrete (Cheng & Tsai, 2013; Martin-Gonzalez, Chi-Poot & Uc-Cetina, 2016; Yoon et al., 2017). As a result, students learn the concepts more easily and accurately. In addition, AR enables students to learn by doing and increases student engagement in the classroom by making lessons more fun (Giasiranis & Sofos, 2017; Wojciechowski & Cellary, 2013; Yoon et al., 2012). Some studies have shown that AR applications have a positive impact on learning outcomes such as academic success, motivation, attention, attitude, and retention in the learning process (Akçayır & Akçayır, 2017; Batdı & Talan, 2019; Erbas & Demirer, 2019; Fidan & Tuncel, 2019; Talan, 2021). The common finding of various studies is that AR technologies can increase learning motivation, the learning process and effectiveness (Tzima, et al., 2019). With these aspects, it can be said that AR applications are a useful alternative to traditional teaching materials. For this reason, AR has become a topic that increasingly attracts the attention of educators and academics because of its possibilities and potential.

Although AR offers many benefits to learners and educators in education, its limited aspects hinder its widespread use. But these limited aspects do not have a significant effect on disusing AR technology, it is important to be informed in order to take precautions at some points. In the literature, excessive cognitive load in multiple and mixed tasks (Cheng & Tsai, 2013; Fidan & Tuncel, 2019; Wu et al., 2013), lack of usability (Akçayır & Akçayır, 2017), monitoring and calibration issues, and difficulties in social acceptance (Van Krevelen & Poelman 2010) are cited as limitations of AR applications (Altinpulluk, 2019; Batdı & Talan, 2019; Fidan & Tuncel, 2019). In addition, hardware and technical problems are also considered important limitations (Dunleavy & Dede, 2014). The difficulty of developing AR instructional materials (Chang, Chung & Huang,

2016) and the limited number of AR instructional materials are also barriers for the use of AR in education (Sırakaya & Alsancak Sırakaya, 2020). The fact that devices such as tablets, smartphones, computers, in which the AR technology is used, do not have sufficient hardware functions, leads to some limitations. One of the disadvantages is that content development is difficult and time-consuming. Such problems can cause significant disruption by hindering the applicability of AR technology. However, to achieve successful implementation, the applications of AR should be well designed and necessary precautions should be taken to identify such negative aspects. On the other hand, the suitability of such applications for the content of the course and the target audience (students) is very important, and the limitations on this point also affect the success of the applications.

Purpose of the Research

One of the most used and searched topics in recent times is AR applications. The use of these applications in education is important to bring innovation in education. Based on the research results, it was found that the use of AR applications in education has a positive impact on the learning environment (Batdı & Talan, 2019; Erbas & Demirer, 2019; Fidan & Tuncel, 2019; Iordache, Pribeanu & Balog, 2012; Sırakaya & Alsancak Sırakaya, 2020; Wang & Chi, 2012). Although there are many researches on this topic in the literature, it can be seen that there are still deficiencies in this topic (Eroglu, 2018; Kucuk, Kapakin & Goktas, 2016; Sahin & Yilmaz, 2020). In addition, although various scientific topics have been addressed in research on the impact of AR, the topic of astronomy has not been explored in detail. It can also be said that there is prejudice against the use of the application by teachers and even students because it is difficult to develop AR applications specifically for educational environments and these applications require knowledge.

AR is important to enrich the learning environment, provide students with a realistic environment related to the subject, and create an environment where they can learn by seeing abstract concepts more clearly. In this way, students can make a connection between the real world and virtual objects without being isolated from the real environment in which they are located. Also, it is believed that by using AR technology in astronomy lessons, the content of the subject is visualized, student participation and interest increases together with their success, attitudes and motivation towards the lesson. Thus the information they learned becomes more permanent. Similarly, in the literature, it is come out that applications such as AR enrich the written content of instruction, help students develop a different perspective, and increase learners' interest in instruction (Çakır, Solak & Tan, 2015).

Elementary and middle school students have difficulty in understanding complex abstract concepts. For example, the abstractness of basic astronomy concepts prevents students from understanding the material and negatively affects their attitudes toward the courses (Sahin & Yilmaz, 2020). To overcome these difficulties, abstract concepts in science should be made concrete through the use of visuals in the classroom. In this way, a more meaningful learning environment can be created in which better learning outcomes can be expected. For the future of education, it is important to study the impact of the use of AR in education, to show the results in each area of education, and to reveal the negative aspects. In addition, the advantages of using AR in educational environments have a significant impact on the selection of this technology within the scope of the study. Considering the importance of the applications of AR, this study aims to investigate the effects of AR technology on secondary students' achievement in science course. In addition, students' opinions and assessments regarding the use of the AR applications were determined. It is expected that these opinions obtained from students will contribute to other studies in the field of developing and evaluating the course environments supported by AR applications. For this purpose, an experimental and a control group were created. The group taught with the AR application was referred as the experimental group while the group with the traditional face-to-face learning environment was as the control group. In accordance with the purpose of this study, answers to the following research questions are sought:

1. Is there a statistically significant difference between the academic achievement post-test mean scores of the experimental group and the control group?
2. What are the opinions of the students in the experimental group about the applications of AR?

Method

This section provides explanations of the research design, study group, experimental process, data collection instruments used in the research, and analysis of data in accordance with the research objectives.

Research Design

This research examined the effects of AR applications on students' academic achievement in a 7th-grade science course. For this purpose, the study used an explanatory design, which is one of the mixed research methods. This design consists of two phases. In the first phase, data are collected and analyzed using quantitative research techniques. Then, the quantitative data is examined in more detail by using the qualitative method (Fraenkel et al., 2012; McMillan & Schumacher, 2010).

A quasi-experimental research technique was used for the academic achievement test in the quantitative dimension of the study. Quasi-experimental studies are used in cases where subjects in the experimental and control groups are selected by measurement rather than randomly. Also, in these studies, it is randomly decided which group will be the control or experimental group (Ekiz, 2003; Fraenkel et al., 2012).

Before the experimental process, pre-tests were administered to both the experimental and control groups to determine the students' prior knowledge. Students in the experimental group implemented the content of the 7th-grade astronomy course with the AR activities. Students in the control group, on the other hand, followed the traditional curriculum. After the experimental process, a post-test was conducted to determine the learning success of both control and experimental group students. Qualitative data were collected after the experimental procedure to investigate and elaborate the quantitative data and to ensure the validity and reliability of the research. For this purpose, the opinions of the experimental group students regarding the AR activities were obtained.

Study Group

The study group of the research consisted of 7th-grade secondary school students in Turkey. The research was conducted in science course.

Table 1. Gender distribution of the experimental and control groups

Groups	Female		Male		Total	
	f	%	f	%	f	%
Experimental group	6	35	14	67	20	53
Control group	11	65	7	33	18	47
Total	17	100	21	100	38	100

As indicated in Table 1, a total of 38 students, 17 female, and 21 male, participated in the study. 20 of the participants were in the experimental group while 18 were in the control group. Experimental and control groups were randomly selected in the study.

Experimental Process

Prior to the experimental process, a course plan was prepared for teaching subject to the experimental group. While preparing the course plan, a collaboration with science teachers and filed experts was made and the content, objectives, and outcomes of the lesson were took into account. In addition, the materials, activities, and functions of AR were determined in accordance with the course plan which would be used only in the experimental group. The prepared materials were reviewed by the course instructor and three experts in the field. Based on their feedback, the necessary corrections were made. In addition, the materials were tested in a different class and researchers put a final touch on the materials and activities before applying them in the experimental group.

All the students selected for the research were informed about the purpose of the study, the requirements of the course, and the procedure of the implementations a week before the applications. Once the control and experimental groups were determined, a pre-test was used. The course instructor taught both the experimental and control groups each week according to the syllabus. But students in the experimental group participated in activities using classroom applications of AR. These applications were used for three weeks under the supervision of the course instructor. The students in the experimental group learned 3D content and videos on smartphones, tablets, and smartboards by using the AR activities in the classroom. The students in the control group, on the other hand, learned through the traditional methods like following the pictures and examples in

their textbooks, listening to the instructor and participating the activities just when questions are directed to them. Sample images for the AR application can be found in Figure 1.

Figure 1. Sample images for the application process of the experimental group

Tools such as flash cards, virtual reality glasses, smartphones, laptops, and tablets have been provided to ensure that the application runs more effectively and that there are no problems. Space 4D +, an AR application that enables spacecraft to move, was installed on these tools. AR applications were used in the course, where images of the planets were obtained by reading flash cards through tablets, phones, and computers. In addition, virtual reality glasses and the images from the tablet were provided to the students in the experimental group so that all students could see and examine well. The function in the course was systematic and orderly, the preparations were completed before the beginning of the course and the applications were conducted according to prepared specific plan regarding the curriculum. At the end of the experimental process, an achievement test (post-test) was administered to the experimental and control groups to see the effect of the AR applications. In addition, an interview was carried out with the students who volunteered in the experimental group. They were requested to express their opinions about the implementation process. The experimental process of the study was schematized and presented in Figure 2.

Data Collection Instruments

In the quantitative dimension of the study, achievement tests (pre-test and post-test) were used as instruments for data collection. The achievement test was used by the researchers to determine the effects of AR applications on students' academic achievement in science course. The achievement test was prepared by Arıcı (2013) based on the unit entitled as "Solar System and Beyond" in the 7th-grade science course. The achievement test consists of 20 questions with 4 options. The necessary calculations for the validity and reliability of the test were performed. The Cronbach's Alpha coefficient of the test was determined to be as 0.73. The value of Cronbach's alpha which is among $0.6 \leq \alpha < 0.80$ means that the scale is quite reliable.

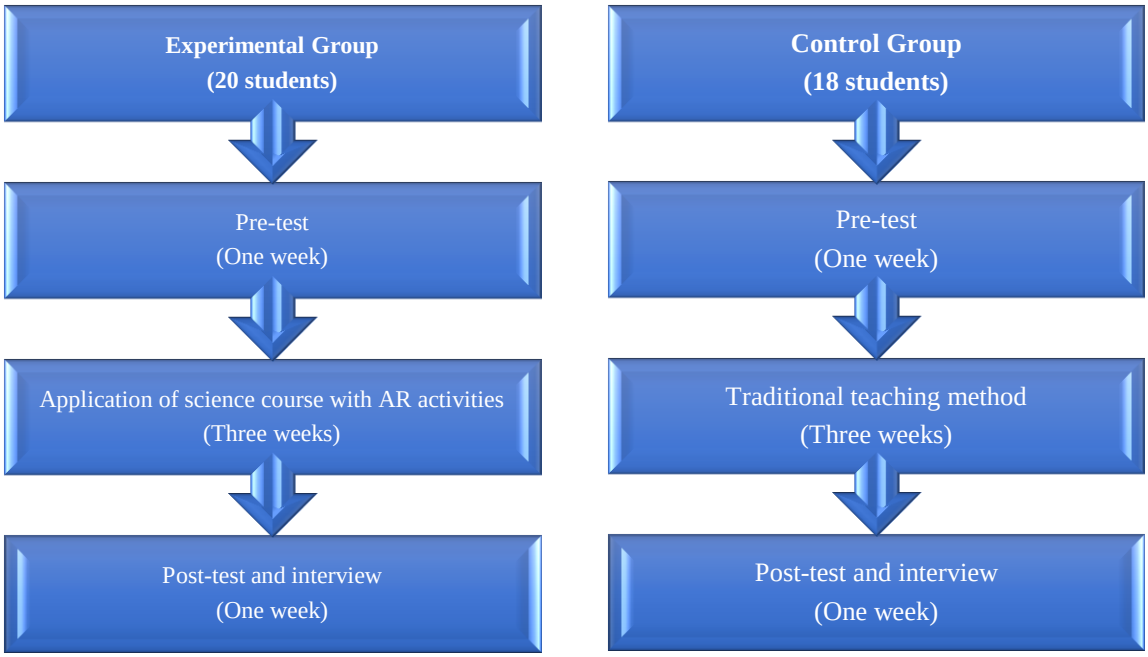

Figure 2. Experimental process

In the qualitative dimension of the research, a semi-structured interview form developed by the researchers was used. This form was prepared at the end of the research to find out the opinion of the students in the experimental group on the activities of AR. To ensure the validity and reliability of the interview form, two experts were interviewed in addition to the researchers. The necessary adjustments were made according to the experts' recommendations.

Data Analysis

In the statistical analysis of the quantitative data collected in accordance with the general aim of the study, the SPSS 18.0 Statistical Analysis Program was used. The conformity of the data to the normal distribution and the homogeneity of the variances were investigated in order to determine the appropriate statistical methods for the analysis of the data. For the assumption of normality, the Kolmogorov-Smirnov test was used, while for the determination of the homogeneity of the variances of the data, the Levene test was used. As a result of the analysis, it was decided to use parametric tests because the data set had a normal distribution ($p>.05$) and the group variances were homogeneous.

The independent sample t-test was used to analyze the data reached from the pre-test and post-test academic achievement of the experimental and control groups. Following the experimental application, a descriptive analysis of the qualitative data acquired from the interviews with the students was performed. In addition, the content analysis method was used to analyze the students' opinions. Content analysis is defined as reaching the concepts and relationships in order to explain the obtained data (Yıldırım & Şimşek, 2013). The content analysis directly quoted some of the students' opinions on each topic to ensure the validity of the study. The quotes were taken from the participants' interviews and were reproduced without any changes. Additionally, abbreviations (S1, S2, S3 …) were used to explain which student said each direct quote. To increase the reliability of the qualitative data analysis, coding was performed by two different experts apart from the researchers. In the study, the reliability formula (Miles & Huberman, 1994) was used to calculate the reliability of data analysis. As a result of the calculation, the reliability was found to be 92%. This result was accepted as reliable in the study. By the way, the MAXQDA 11 program was used to analyze and organize the qualitative data attained from the interview.

Results

The Results of the Academic Achievement Test in the Science Course

The difference between the post-test academic achievement results of the experimental group, in which AR applications were used, and the control group, in which traditional teaching method was used, was calculated through the independent sample t-test. In addition, the homogeneous distribution of variances was determined by using Levene test. The results of analysis were presented in Table 2.

Table 2. The results of the t-test with regard to the post-test results of the experimental and control groups

Groups	n	$\bar{X}$	sd	df	Levene		t	p
					F	P		
Experimental	20	11.92	1.87	34	2.746	0.117	2.318	0.035*
Control	18	10.19	2.93					

*p<0.05

Table 2 shows that the variances are homogeneously distributed [F=2.746; p=.117], and a statistical significance was determined between the post-test scores of the groups (t=2.318, p<.05). It was appeared that the value of significant difference was 1.75 and the difference was in favor of the experimental group ($\bar{X}_{experimental}$=11.92; $\bar{X}_{control}$=10.19). Related results show that students in the experimental group have higher academic achievement scores than students in the traditional learning method.

The Opinions of Students in the Experimental Group on AR Applications

Following the application of experimental process, students' opinions regarding the AR activities were obtained. In this context, students were primarily asked to explain their opinions about the contribution of AR applications to the learning environment. Their opinions are analyzed, turned into models and presented in Table 3.

Table 3. Contribution of AR applications to the learning environment

Providing effective learning and rich visual environments
Providing the opportunity to benefit from technology
Providing rich material opportunities
Providing research and questioning skills
Activating visual intelligence
Providing observation opportunity
Ensuring memorability
Providing easy learning
Offering the opportunity to reinforce
Permanent learning, enabling knowledge
Providing the opportunity to learn the realities of life
Providing efficient realistic and multidimensional learning opportunities
Providing detailed learning
Allowing easy learning
Arousing curiosity
Being interesting
Activating affective skills
Developing imagination
Offering the opportunity to embody
Being a remarkable application
Providing effective and productive classroom environments
Providing understandable learning

As it is presented in Table 3, students explain many opinions about the contribution of the AR applications to the learning environment. The application of AR has positive aspects such as the ability to embody something, providing rich material opportunities, being interesting, developing imagination and providing effective learning and rich visual environment. At this point, a student commented as "*I learned better because it was visual. In this way, I was able to acquire the knowledge better.*" (S5). Similarly, another student stated that "*It was so real that I felt like I was in the middle of the action. The pictures of the planets were very realistic.*" (S1) while the other one asserted that "*I was very fascinated by that. I would like to see us use this application in other lessons.*" (S9). Another student stated that "*I can say that using the AR application in the lesson makes learning more permanent. Thanks to the application, I understood the concepts more easily and my interest in the lesson increased.*" (S12). Another student said "*The application AR was fascinating for the subject. Moreover, the rich*

visual environments of the application make the lessons enjoyable and entertaining. This ensures easy learning." (S6).

On the other hand, the study comprised students' opinions on the negative aspects of the AR applications and their suggestions for solving the problems. The related opinions of the students are shown in Table 4.

Table 4. Negative aspects of the applications of AR and suggestions.

Categorty	
Negative Aspects of the AR applications	Having the student in the role of passive listener and observer
	Decreased student participation in class
	Lack of unity in the classroom
	Loss of time
	High cost
	Unavailability
	Confusing
	Everyone may not use it
	Teachers can be lagged behind
	Complicating different views
	Difficult to apply as the number of students increases
Suggestions Related to AR Applications	It can be explained by concretizing in an advanced dimension
	Suggestions should be taken at each step and continued
	Real sounds can be produced
	More realistic images should be created
	It should be more interesting
	Cost can be reduced
	It must be related to the astronomy
	It can be used in all courses
	Applicability level can be increased
	It should be projected onto the board with projection
	It should be projected somewhere in three dimensions
	Student should pretend to be in the moment
	Ensuring that experiments are carried out with an AR application

In Table 4, it is clear that problems such as the high cost, the fact that the teachers' being lagged behind, students' passive role, the difficulty to apply due to the excess number of students, unavailability, and the loss of time leapt to the eye. Considering these problems, the students put forward some suggestions such as increasing the level of application by making it more interesting, reducing the cost, and creating more realistic images and sounds. At this point, a sample expression form a student can be stated as "*It is not good that the connection and the technical problems we had in class take a lot of time.*" (S2). Another student's opinion regarding the negative aspects of AR applications can be mentioned as "*It is a very nice app, but it is not good because we do not have money to buy it and it is expensive.*" (S6). In addition, the others remarked that "*I had a hard time understanding it because it sometimes caused confusion in our class.*" (S3); "*What if I wanted to touch the sun. If we could just touch it and see what happens.*" (S14); "*In my opinion, AR is an unnecessary and time-consuming application for the course. The student observes the virtual object. I don't think it's a useful application.*" (S11); and "*I think it would be good for my brother if this was used in all courses.*" (S7). The participant students expressed their dissatisfaction concerning the use of AR and proposed some suggestions as seen in Table 4. For instance, a student put forward his/her ideas on the application as: "*The application was interesting and exciting, but more realistic sounds and images could be used during the application*." (S12). Another student commented on this issue as: "*Since these applications are costly, not every student can use them. It is important to develop low-cost applications.*" (S8).

Discussion

As abstract concepts are often used in science courses, students have difficulty in understanding the topics covered in these courses (Palmer, 1999). To overcome these difficulties, learning environments need to be turned into more concrete forms by linking them to the technologies of AR (Sahin & Yilmaz, 2020). It can be argued that the use of technologies like AR is more effective than traditional face-to-face instruction in teaching concepts that are difficult to learn and study in science courses. Thus, AR applications can increase student interest in the course and can facilitate understanding of abstract concepts by making them concrete (Arici et al.,

2019; Rehmat & Bailey, 2014). Especially in recent years, the AR applications, which are used as effective learning and teaching tools in many fields, have attracted researchers' attention. This study investigated the effects of AR applications on students' academic achievement in a science course by visualizing them on tablets, cell phones, and smartboards. By this way, the course content was illustrated through AR applications to better convey abstract concepts that were difficult to learn. Similarly, AR applications have been used as learning activities in the relevant literature, especially for visualization and concretization (Akçayır et al., 2016; Aldalalah et al., 2019; Erbas & Demirer, 2019; Estapa & Nadolny, 2015; Fidan & Tuncel, 2019; Ibanez, Castro, & Kloos, 2017; Sahin & Yilmaz, 2020).

This study found that the applications of AR had a significant impact on students' academic achievement compared to traditional learning methods. In the interviews with students, it was found that the applications of AR enabled effective and sustained learning, reinforced learning, made classes interesting and fun, and improved visual intelligence. These positive opinions of the students can be considered as the reason for the increase in their academic achievement. The fact that AR applications are a process that enables interactive and applied learning by enriching the real world with virtual elements (Höllerer & Feiner 2004) can be cited as a reason for increasing students' achievement. Also the fact that AR facilitates learning by embodying abstract concepts can result in an increase of academic achievement (Martin-Gonzalez, Chi-Poot & Uc-Cetina, 2016; Walczak, Wojciechowski & Cellary, 2006), in student motivation, interest and attention (Ab Aziz et al., 2012; López-Belmonte et al., 2021; Sumadio & Rambli, 2010; Taskiran, 2019). AR applications ensures that lessons are fun and students are active participants (Wojciechowski & Cellary, 2013; Yoon et al., 2012). In addition, the applications of AR enrich students' imagination and creativity (Yuen et al., 2011) and enable them to engage in sustained learning (Walczak, Wojciechowski & Cellary, 2006).

In examining the literature on the applications of AR in education, it was found in many studies that AR is used in many fields such as health, mathematics, geography, history, foreign languages, engineering, architecture and science courses, and improves students' academic achievement and laboratory skills development (Akçayır et al., 2016; Aldalalah et al., 2019; Estapa & Nadolny, 2015; Fidan & Tuncel, 2019; Ibáñez et al., 2020; Sahin & Yilmaz, 2020; Yen, Tsai & Wu, 2013). Meta-analyses on this topic also conclude that the applications of AR have a positive effect on students' academic achievement (Batdı & Talan, 2019; Garzón, Pavón & Baldiris, 2019). However, there are also studies in the literature stating that AR does not have a large impact on students' academic achievement (Abdusselam & Karal, 2012; Erbas & Demirer, 2019). The reason for the different results in these studies may be the application of AR activities in different ways, the type and the quality of materials used in the applications. Another reason for this difference is that the teacher who uses AR applications manages and plans the process in a different way. In addition, the process of implementing the AR applications, the attitude and motivation towards the course and technology may also lead to different results. In this direction, it can be said that the activities of AR should be created accurately and solidly according to the pattern and thus the teaching should be well planned.

It was found that the students who participated in the research explain many positive opinions about the applications of AR. In examining the students' opinions, it was found that AR applications provide visuality and flexibility in learning process by providing an interactive environment that can be adapted to the real-world environment. As a result, AR applications facilitate learning by providing a three-dimensional visualization of concepts that are difficult to visualize. In addition, students who indicate that the period of class has become more effective and productive believe that the applications of AR enable sustained learning because they reinforce what is learned. In addition, students indicated that they felt more active in class with the AR applications and that these applications contributed to better learning by improving their imagination and visual intelligence in class. In addition, the students whose opinions were queried indicated that they were more actively engaged in the learning process thanks to the applications of AR and that they were at the center of the process. In parallel with the results of this study, it was found that students in many studies thought similarly positive about the applications of AR (Cai, Chiang & Wang, 2013; Dunleavy, Dede & Mitchell, 2009; Erbas & Demirer, 2019; Höllerer & Feiner 2004; Pozo-Sánchez et al., 2021; Walczak, Wojciechowski & Cellary, 2006; Yoon et al., 2012).

While searching the literature, we have found that courses taught with AR applications are more student-centered (Delello, 2014). Studies have also showed that AR makes learning effective and durable by making abstract information concrete and eliminating monotony (Walczak, Wojciechowski & Cellary, 2006; Yoon et al, 2012). As indicated in the results of this study, it can be said that AR is a process that provides opportunities for interactive learning (Cai, Chiang & Wang, 2013; Dunleavy, Dede & Mitchell, 2009; Höllerer & Feiner 2004). It was also found that AR provides a flexible, fun, and exciting learning environment and is therefore popular among students (Barsom, Graafland & Schijven, 2016; Gun & Atasoy, 2017; Wojciechowski & Cellary, 2013).

The relevant literature revealed that the applications of AR provide more efficient learning environments (Arici et al., 2019; Cai, Wang & Chiang, 2014), reduce cognitive load in the learning process (Bower et al., 2014), and provide significantly more motivation, self-efficacy, and interest (Seifert & Tshuva-Albo, 2014; Taskiran, 2019).

According to the results of the research, there are also negative aspects of AR applications. When the students' opinions on the AR application were considered, it was found that the high-cost and difficulty in obtaining the materials were the most prominent. The fact that the teacher is in the background and the student is in the passive role is also mentioned as another negative aspect of the process. However, students also made several suggestions for such problems. For example, students suggest that the applications of AR should be more interesting and that their applicability should be increased by lowering their costs.

When examining the negative aspects of AR application in the relevant literature, similar problems can be encountered such as the lack of technical tools, monitoring and calibration problems, and technical limitations (Akçayır & Akçayır, 2017; Cheng & Tsai, 2013; Rabbi & Ullah, 2013; Sırakaya & Alsancak Sırakaya, 2020; Van Krevelen & Poelman 2010; Wu et al., 2013). There are also ethical issues such as confidentiality, security, and privacy (Altinpulluk, 2019; Berryman, 2012). In addition, excessive cognitive load in multiple and mixed tasks, lack of difficult design and ease of use, and difficulties in developing AR training materials are cited in the literature as limitations to its usage (Akçayır & Akçayır, 2017; Altinpulluk, 2019; Chang, Chung & Huang, 2016; Cheng & Tsai, 2013; Sırakaya & Alsancak Sırakaya, 2020; Wu et al., 2013). For an effective use of the application, in education, these negative aspects must be eliminated. In this direction, it is of great importance to bring students' access to technological tools and resources to an appropriate level. Otherwise, inadequacies in the area of technology may cause significant disruption as AR makes implementation difficult. In addition, taking into account the ability of students to use these technological tools, studies should be conducted to develop these skills. It can be said that these problems can be overcome and the effectiveness of the application will be increased if technical support is provided to students to eliminate the negative aspects.

With the development of mobile and wearable technologies, AR is attracting the attention of researchers day by day thanks to the new opportunities it offers to the world of education. This application is an important and popular technology that is used extremely effectively and efficiently in various fields such as military, health, marketing, tourism, shopping, and entertainment. With the use of AR in all fields, educators have started to benefit from this technology and use it in the learning process. Investment in this technology has increased especially in these days when the use of technology is widespread in education. In the literature, various studies have been published recently on the use of AR applications in education (Arici et al., 2019). However, it can be stated that the number is still not enough on such a popular topic. Thus, the aim of the present study was to determine the effects of AR applications on students'' achievement levels. In addition, students' opinions regarding AR applications were also investigated. The AR experiences of the students in the experimental group are limited to the Space 4D+ application provided by the researchers. Similar studies can be conducted through other teaching methods and approaches by using professional drawings. The research is limited to the subject of astronomy in the science course. Only secondary school students were included in the study. In order to make general assessments and comparisons, similar studies can be conducted by different researchers at other educational levels and/or in other courses.

The implementation period of the study (experimental procedure) was limited to three weeks. For AR applications, it may be useful to demonstrate the effects of a longer-term training program on a larger scale. Descriptive and experimental studies can be used to examine the effects of AR applications on students' motivation, concerns, and attitudes toward the course, as well as the permanence of the information learned. Future studies can further investigate the applicability and effectiveness of the AR application through using such variables. In addition, data can be analyzed using a mixed methodology that includes individual interviews or focus group interviews in AR applications. Again, studies can be conducted on the advantages and disadvantages of using AR in education. It is recommended that researchers of the future studies should arrange the classroom environment in advance and take necessary precautions to avoid problems during the application. AR applications can be developed in accordance with various course contents and contribute to the education process. With the proliferation of wearable technologies, similar studies can be conducted using technologies such as Google Glass or HoloLens in teaching and learning activities, and the impact of these technologies on the teaching process can be studied. In addition to the applications of AR, hologram or Metaverse technologies, which are relatively new applications for students, can contribute to students' cognitive and affective development by including them more in educational programs.

Scientific Ethics Declaration

We, the authors, declare that the scientific ethical and legal responsibility of this article published in the JESEH journal belongs to the authors.

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