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The Effects of Augmented Reality on Elementary School Students' Spatial Ability and Academic Achievement [*]

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Abstract

The purposes of this study are to investigate the effects of an augmented reality application on students' spatial ability and academic achievement, and to analyze the opinions of students and their teacher concerning augmented reality environments. To collect quantitative data, a quasi-experimental pretest-posttest with a control group design was employed, and to collect qualitative data, a case study design was used. The study was designed around the lesson topic "geometric objects and measuring volume," and 88 sixth grade students participated. While the students in the experimental group studied the lesson topic using augmented reality and real objects, the students in the control group used only real objects. The results indicate that though a significant increase was observed in the spatial ability of both groups, no significant difference was found between the post-test spatial ability mean scores of the experimental and control groups. In addition to the spatial ability results, the students' academic achievement scores in the experimental group significantly increased, but the small increase in the control group students' scores was not significant. No significant difference was found between the post-test academic achievement scores of the experimental and control groups. In addition to the quantitative data, the qualitative data gathered from the students and the teacher yielded valuable information that may assist researchers who attempt to integrate augmented reality in education.

Keywords

Augmented reality
Spatial ability
Academic achievement
Mathematics education
Elementary school students

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Introduction

Most students in all levels of education experience problems when learning math. These problems usually are related to their abstract thinking ability (Bishop, 1986; Battista & Clements, 1996; İncikabı & Kılıç, 2013). For example, students often have trouble understanding the topic "geometric objects and measuring volume" as it is taught within the context of the sixth grade mathematics curriculum in Turkey (İncikabı & Kılıç, 2013; Kurtuluş & Yolcu, 2013). One reason for these problems is

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that teachers are required to use two-dimensional drawings while explaining three-dimensional (3D) objects (or shapes). These two-dimensional drawings are not adequate to illustrate 3D objects, and students consequently experience difficulty perceiving the objects holistically (Ben-Haim, Lappan, & Houang, 1985; Battista & Clements, 1996). Another reason concerns the 3D models used for this instruction. Although these 3D models are more functional than two-dimensional drawings, beams, diagonals, and similar components – which have huge effects on students' understanding of 3D models – are not adequately presented in the models. Finally, K-12 students undergo a transition from the concrete operational stage to the formal operational stage, according to Piaget's theory of cognitive development stages. Piaget (1976) argued that when students are just beginning their abstract thinking stage, they tend to have difficulties understanding this type of topic.

To overcome such problems in mathematics classes, we suggest that instructors should improve the students' spatial abilities. Because some prior studies focused on relationship between achievements in mathematics and spatial abilities (Smith, 1964; Fennema & Sherman, 1977; Guay & McDaniel, 1977; Battista, 1980; Tracy, 1987; Lin, Chen, & Chang, 2015). These abilities involve their mental construction and maintenance of visuals, their perception of objects from different angles, and their rotation and changing of shapes in their mind (Linn & Petersen, 1985; Lohman, 1996). Though there is no precise agreement concerning the components of spatial ability, there is general agreement concerning its two main components, which are spatial visualization and mental rotation. Some studies in the literature show that spatial abilities are connected to higher-level skills such as problem-solving and reasoning (Moses, 1980), which can be developed with training (Battista, Wheatley, & Talsma, 1982; Kaufmann, Steinbügl, Dünser, & Glück, 2005). For example, activities such as use of Legos, creating engineering drawings, and finding directions positively affect the development of spatial ability. In addition, the effects of web-based environments (e.g., in games such as "Zaxxon, Space Invaders, Battlezone, Targ and Tetris") and computer-based virtual softwares (such as "Hypergami, Cubix Editor, Cabri 3D, Google Sketchup and CAD") have also been investigated (Subrahmanyam & Greenfield, 1994; Onyancha, Derov, & Kinsey, 2009; Toptaş, Çelik, & Karaca, 2012; Yurt & Sünbül, 2012; Wang, Wu, & Hsu, 2017; Weng, Hsu, & Yang, 2017).

Rafi, Anuar, Samad, Hayati, and Mahadzir (2005) conducted an experimental study over five weeks to investigate the effects of web-based virtual media on the spatial abilities of 98 pre-service undergraduate students. They found that the increases in the spatial abilities of the experimental group participants were significantly higher than those of the control group students. Kurtuluş and Uygan (2010) examined the effects of Google SketchUp (GSU) on the spatial abilities of 48 pre-service teachers and found that GSU significantly improved their spatial abilities. Toto (2011) investigated the effects of the Cabri3D software program on five components of spatial ability. A total of 50 eighth graders participated in the study. While significant increases were observed for the rotation, relation, and orientation components, no significant difference was observed for the perception and visualization components. Yurt and Sünbül (2012) investigated the effects of CubixEditor on students' spatial thinking and mental (object) rotation skills. 87 sixth grade students participated in the study. They observed significant development in the spatial thinking skills of the group of students who used concrete materials, and in the mental rotation skills of the students who used virtual objects.

Huang and Lin (2017) investigated the effects of 3D diagrams and 3D modeling-printing technologies on the students' spatial skills. Their study was conducted by 13 high school students in a single group pretest-posttest design and showed that 3D modeling-printing technologies improved both mental rotation and visualization skills while 3D diagrams only improved mental rotation skills. Katsioloudis, Jovanovic, and Jones (2014) examined the effects of two-dimensional drawing, designing 3D model and printing 3D models on students' spatial skills. Their results showed that the spatial skills of the students who printed their 3D models increased more significantly than those of the students who made two-dimensional drawings.

In the process of following the studies on 3D computer graphics and virtual environments, researches have begun on the applications of augmented reality (AR) that can be defined as more advanced forms of virtual environments (VR). AR applications can integrate sounds, videos, graphs, and GPS location information into the users' real environment. For users of these applications to perceive the combined AR and real-world images, they must use special glasses or cameras. These glasses or cameras read barcodes called markers, and in this way virtual data such as pictures, videos, 3D objects, and animations are juxtaposed with real-world data via the marker. This virtual data also can be moved within the virtual environment or viewed from different angles as the user moves the marker. Thus, without distancing oneself from the real world, observations can be made of the virtual images from every angle.

The concept of AR emerged during the 1960s. Initially, AR was used in military and health fields. Over time, it became cheaper, and began to be used in other areas – particularly in entertainment and education (Somyürek, 2014). In addition to general-purpose AR applications such as Magicbook, Zooburst, LearnAR.org, and Aurasma, discipline-specific applications developed by researchers from scientific fields also currently exist For example, AR applications developed for the Biology field (such as internal organs, bones, and animal anatomy), the Chemistry field (such as structures of atoms and molecules), the Geography field (such as solar system, planets, and the earth's layers), the Geometry field (such as solid objects), and the Physics field (such as optics and magnetism). Several studies in the literature have focused on these specific applications (Shelton & Hedley, 2002; Chen, 2006; Liu, Tan, & Chu, 2007; Dünser, Walker, Horner, & Bentall, 2012; İbili, 2013).

Aside from the mentioned studies, other studies in the literature report that AR applications facilitate the concretization of abstract concepts and thereby improve students' understanding of these concepts and processes (Shelton & Hedley, 2002); that they increase students' duration of focus and thus positively affect their academic achievement (Liu et al., 2007; Abdüsselam & Karal, 2012); that they make the class more attractive and thus draw the students' attention, increase their motivation, and make learning more fun (Liu et al., 2007; Klopfer & Squire, 2008; Sumadio & Rambli, 2010); and that they improve "21st century skills" such as critical thinking and problem-solving (Dunleavy, Dede, & Mitchell, 2009). The New Media Consortium's 2011 Horizon Report emphasized the importance of AR applications in the construction of an active learning environment because AR helps students to relate information to their real lives. In light of all these research findings, AR appears to possess great potential for enhancing educational outcomes. Its effects on learning processes should be more fully and carefully investigated.

Kaufmann et al. (2005) used a medium called Construct3D, which facilitates interactive and cooperative work, to investigate AR effects on students' spatial abilities. That study was conducted with a group of students whose mean age was 17 years old. The conclusion was that AR can be used to improve this skill. In addition, the researchers stated that further research is needed in the field. Martín-Gutiérrez et al. (2010) conducted a study with the participation of 49 engineering students. They produced an AR book called AR-Deheas to develop the students' spatial abilities. This book, designed for use in technical drawing courses, contains (object) markers. Using these markers, the students can examine two-dimensional technical drawings as 3D virtual objects. Martín-Gutiérrez et al. reported significant positive effects of AR book on students' spatial abilities. Furthermore, the satisfaction questionnaire that they administered to the students revealed that the students found the AR book easy to use and attractive.

Lin et al. (2015) studied the effects of AR applications on the spatial skills of the students in their study with a participation of 76 secondary school students. The students in the experimental group used AG applications, whereas the students in the control group used traditional teaching methods. The students were divided by their mathematics achievements as high, medium and low. Their results showed that AR applications had no significant effect on the spatial ability of the high achievers, had positive but small effect on that of the medium achievers, and had significant positive effect on that of the low achievers. Carbonell Carrera and Bermejo Asensio (2017) aimed to improve the students' spatial orientation skills with 123 university students. Their study found that the students' spatial orientation skills in the experimental group who used the AR environment increased significantly compared to the students in the control group who continued their traditional lessons. Roca-González, Martin-Gutierrez, García-Dominguez, and del Carmen Mato Carrodeguas (2017) aimed to examine the effects of AR and VR applications on the spatial skills of college-level students. Their study was conducted with 31 students. The students in the experimental group were trained with AR for the first week, and second week played VR game about the maps and navigation. No training was given to the control group. Their study showed that while spatial ability scores in all subscale (spatial visualization, rotation, orientation) increased significantly in the experimental group, there was not a significant effect in the control group.

As a result, it is known that spatial ability is important and can be improved for solving the problems experienced in mathematics learning. AR can present an object's parts (such as beam, diagonal, etc.) in detailed ways that are difficult to display using other media. Moreover, AR allows the user to engage in active, spontaneous interactions via supporting features such as the ability to touch or move objects as if you were in the real world. Using these features of AR applications, users can more easily visualize 3D objects, and manipulate and study them. With its 3D displays and interaction features, AR is considered a suitable tool for enhancing spatial ability. However, to date only a few academic studies have focused on the relationship between spatial ability and AR media at elementary school level. Therefore, this study aims to investigate the effects of an AR application on elementary students' spatial ability and academic achievement by eliciting their and their teacher's opinions concerning the development and uses of AR media.

Research Questions

To investigate the effects of this AR application on the students' spatial ability and academic achievement in an educational environment, this study focused on the following research questions (RQs).

1) Is there a significant difference between the pre-test and post-test spatial ability scores of the experimental group students (working in the environment where the AR application is used)?
2) Is there a significant difference between the pre-test and post-test spatial ability scores of the control group students (working in the environment where there is no AR application)?
3) Do the students' post-test spatial ability scores vary significantly depending on whether or not they were working in the environment where the AR application was used?
4) Is there a significant difference between the pre-test and post-test academic achievement of the experimental group students?
5) Is there a significant difference between the pre-test and post-test academic achievement scores of the control group students?
6) Do the students' post-test academic achievement scores vary significantly depending on whether or not they were in the environment where the AR application was used?
7) What are the students' opinions concerning the use of the AR application in this educational environment?
8) What are the teacher's opinions concerning the use of the AR application in this educational environment?

Method

In the current study, a quasi-experimental pretest-posttest with a control group design was used to collect quantitative data, and a case study design was used to gather qualitative data to support quantitative data.

Participants

The study was conducted with the participation of sixth grade students from a state school in the city of Ankara, Turkey. Convenience sampling method was employed to assemble the sample. Students who were easy to reach were thereby included in the study group (Patton, 1987). Pre-test data were collected from 96 students. Following the completion of the study, post-test data were obtained for all of these students except 8 for spatial ability tests and 15 for the academic achievement tests. As a result (see Table 1), the final study sample consisted of 88 students for the spatial ability measures and 81 students for the academic achievement measures. Four classes from the school were randomly selected from among the overall seven available in the school; two of these four selected classes were randomly assigned to the control group and two to the experimental group.

Table 1. Number of Students in the Control and Experimental Groups

	Experimental Group		**Control Group**	
	Class 1	**Class 2**	**Class 3**	**Class 4**
Spatial ability	20	24	23	21
Total number of students	44		44	
Academic achievement	19	23	20	19
Total number of students	42		39	

Prior to the application, in order to establish equality between the groups, their spatial ability and academic achievement pre-test scores were analyzed. No significant difference was found between the groups for spatial ability (t(86)=,48, p=,633>,05) or for academic achievement (t(79)=1,19, p=,237>,05). The scores indicate that the groups were essentially equal.

The same mathematics teacher taught all four classes. When the study was first planned, the intent was to conduct the study with two different mathematics teachers. However, during the pilot application of the study, one of the teachers experienced difficulties integrating the AR application into the course, and thus, we decided to use only one teacher. This teacher was female and 28 years old; she had seven years of job experience. She was a doctorate student in mathematics education at the time of the study and had expressed positive opinions about the integration of technology into her courses. She was very excited about conducting such a study with her students and supported the researchers in every stage. Using her communication skills, she was able to create a positive learning environment for the students.

Application Process

The study was conducted within the framework of teaching the topic “geometric objects and measuring volume” in a sixth grade mathematics course. During the application process, the experimental group students used AR objects and real objects, while the control group students only used real objects. The AR materials consist of 20 3D fixed and animated objects. Prior to the actual application, piloting was conducted to give a chance for the teacher and the students to practice AR. In the light of the piloting process, AR environment was rearranged. Then the academic achievement and spatial ability pre-tests were administered to the four groups (two classes of experimental and two classes of control students). The application lasted for four weeks. In this process, the control group had their lessons in their classes, while the experimental group had their lessons in the computer lab with the AG materials. At the end of the four-week period, the post-tests and the opinions of the students and the teacher were collected. This procedure is shown in figure 1.

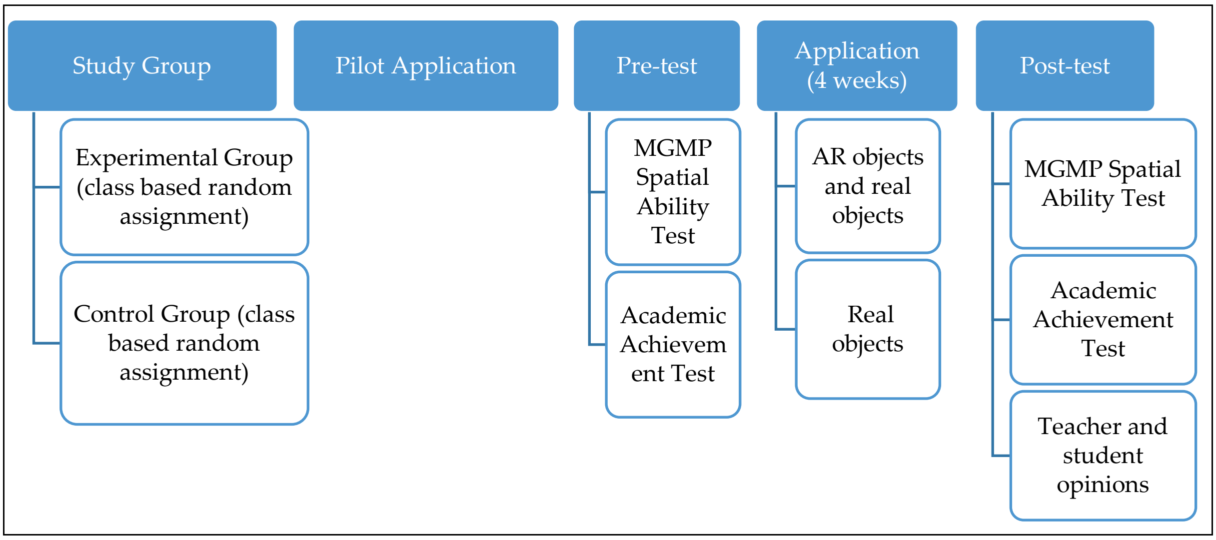


Figure 1. The Application Procedure of the Study

Pilot Application and Correction of Initial Deficiencies

Prior to the actual experimental application, a pilot AR application was conducted with the experimental group students. First, the students were informed about the application, and some instructional exercises were conducted on the use of AR. During the pilot application, 3D objects, such as a "plane" and a "doll," that were not related to the course content were used so as not to affect the pre-test results. Some problems were identified during the pilot application, such as an excessive amount of light in the environment, obscure outcomes some of the markers, and bending of the markers. These problems caused obscure perception of the markers by the video cameras. In order to correct these problems, we hanged black curtains around the environment to control the light, redrew the outcomes on the markers more boldly, and adhered harder cardboard under the marker bases. In addition, while the students were adjusting the positions of the cameras, they got distracted and experienced difficulty rotating the markers by 360°. In order to correct these problems, the angles of the cameras were fixed to obtain the best view, and sticks were pinned under the marker bases. This enabled the students to rotate the markers more easily, and thus, the students were able to examine the 3D objects from any angle. As the class seating was originally arranged in an E-shape, distances between the computers were narrow and the desks were too closely spaced. Because of this arrangement, the students were unable to move the markers easily. So the class seating arrangement was then converted to a U-shape to provide more space between the desks. After the mentioned corrections were made, the environment was more suitable to effectively conduct the AR application.

Data Collection Tools

The MGMP spatial ability test was used to measure the students' spatial ability, and an academic achievement test was used to measure their academic achievements in the mathematics course. The opinions of the teacher and students concerning the environment were collected with teacher and student opinion forms developed by the researchers.

The MGMP Spatial Visualization Test was developed by faculty from the Department of Mathematics in Michigan State University for secondary-level students (Ben-Chaim, Lappan, & Houang, 1988). Turğut (2007) translated and adapted it to the Turkish language. While adapting the test, the expert opinions of two faculty members from the Department of Elementary School Mathematics and one elementary school mathematics teacher were sought, and consequently some of the test questions were discarded as they were found to be unsuitable for this age group of students. While the original version of the test consisted of 32 questions, the adapted version (in Turkish) had 29 questions. A pilot application was conducted with 382 students; 128 were sixth graders, 150 were seventh graders, and 104 were eighth graders. The collected data were analyzed, and the final reliability coefficient of the test was 0.830. As the test measures two components of spatial ability, its name was changed to MGMP Spatial Ability Test.

In this research to conduct validity and reliability studies on the spatial ability test, data were collected from 293 students; 161 were sixth graders, and 132 were seventh graders. Using this data, item and test statistics were calculated. Five test items whose discriminatory indices were found to be lower than 0.20 were excluded from the test; then the analyses were repeated, and the final reliability value (KR-20) was calculated to be 0.81. Thus, we concluded that the test had an acceptable reliability level.

For the academic achievement test, a multiple-choice test was prepared. It consists of 20 items that assess the objectives and outcomes set by the Ministry of National Education in Turkey for the topic “geometric objects and measuring volume” in the curriculum of sixth grade mathematics courses. After eliciting the opinions of one measurement-evaluation expert, two subject-area experts, and one Turkish language expert (an academic achievement expert opinion form was used for this opinion collection), required corrections were made on the test. The revised version was administered to 172 sixth grade students from seven different classes. Item and test statistics were calculated with the collected data. Six items whose discriminatory indices were found to be lower than 0.20 were discarded from the test. On the remaining test items, the analyses were repeated, and the final reliability value (KR-20) was found to be 0.64. This value shows that the test has an acceptable level of reliability.

The teacher’s and students’ opinion forms were developed by the researchers to collect their opinions concerning the use of the AR application in mathematics education. These forms consist of open-ended questions. The forms were examined by subject-area experts and language experts. Using their feedback, required corrections were made and final versions prepared.

Course Materials

The teacher used such real objects as medicine box, eraser, and plastic cube to support the narration of 3D objects in both groups. For example, she tore off the medicine box to reveal the opening of the square prism and to present objects' diagonal she needed to the use board because she could not show diagonal onto the object directly. In the experimental group, AG materials were used in addition to the real objects. In the experimental group, AG materials were used in addition to the real objects.

Realistic models in educational environments are used to embody abstract concepts, especially in younger students who have not developed concrete thinking skills. Because individuals of this age can more easily perceive this kind of knowledge (McNeil & Uttal, 2009). Bruner (1966) states that the use of real objects is appropriate and economical for the individuals of all ages who first encounter abstract contexts. However, Kaminski, Sloutsky, and Heckler (2009) point out that the use of 3D real objects in limited numbers is not sufficient in learning abstract concepts. McNeil and Uttal (2009) emphasize that real objects cannot be effective in mathematics education without providing effective guidance to students on how to use these objects. Sarama and Clements (2009) state that the guidance students need during learning abstract concepts can be provided instantly in a computer environment by presenting the images of the concepts to students. AR is a computer environment that provides 3D support and instant communication with the users. Bruner (1966) emphasizes that many real objects must be used to teach different abstract concepts. This makes real object neither economical nor practical concerning its use in the class. Although the design of AR environments requires computers, cameras and software initially (Furio, Gonzalez-Gancedo, Juan, Seguí, & Costa, 2013), after the installation, addition of new materials will be economical and convenient. Sırakaya and Seferoğlu (2016) state that making mistakes and carrying out experiments that could be dangerous are costless and safe in AR environments. Furthermore, Di Serio, Ibáñez, and Kloos (2013) emphasize that AR is a useful and funny environment. As well as these positive effects, there are some results about the negative sides of AR if used inappropriately, such as, the difficulty of using AR environment in a crowded classroom (Yoon, Elinich, Wang, Steinmeier, & Tucker, 2012), usage problem and cognitive overload when AR environments are designed improperly (Munoz-Cristobal et al., 2015; Dunleavy et al., 2009).

In order to enhance the effectiveness of explaining 3D objects, AR materials (drawings and animations) were developed with the 3ds Max software. In accordance with the opinions of the faculty members and mathematics teachers, the materials were rearranged and converted to AR scenes using the BuildAR software. In Figure 2, we present the detailed stages of this construction process.

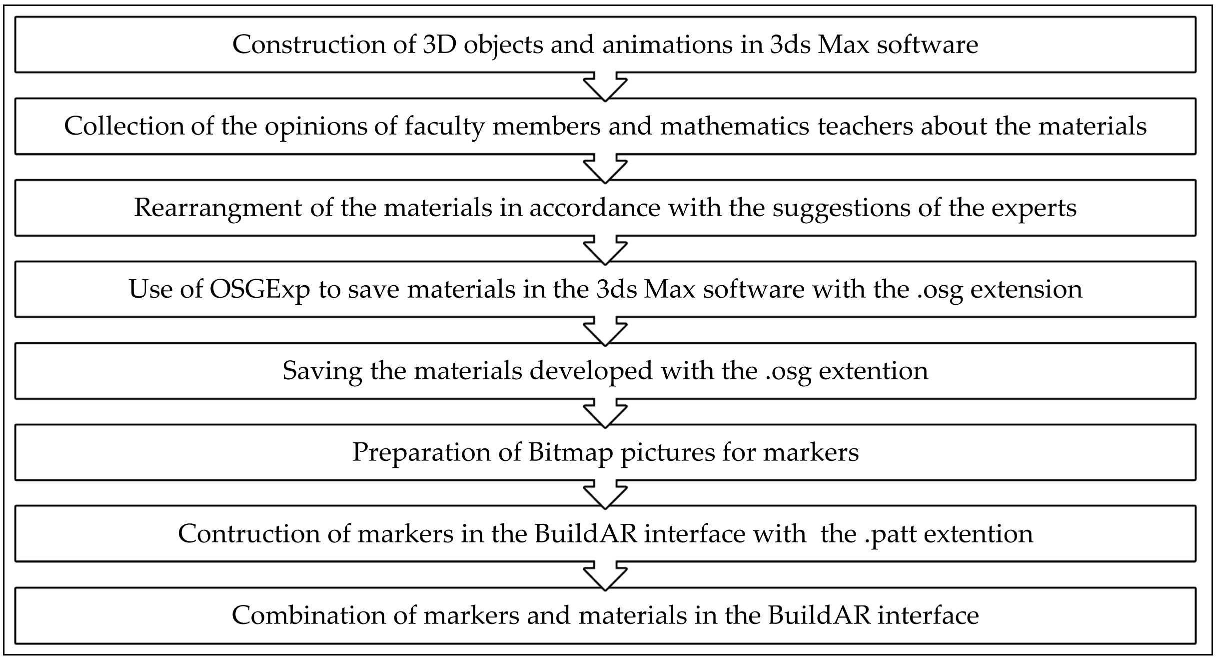
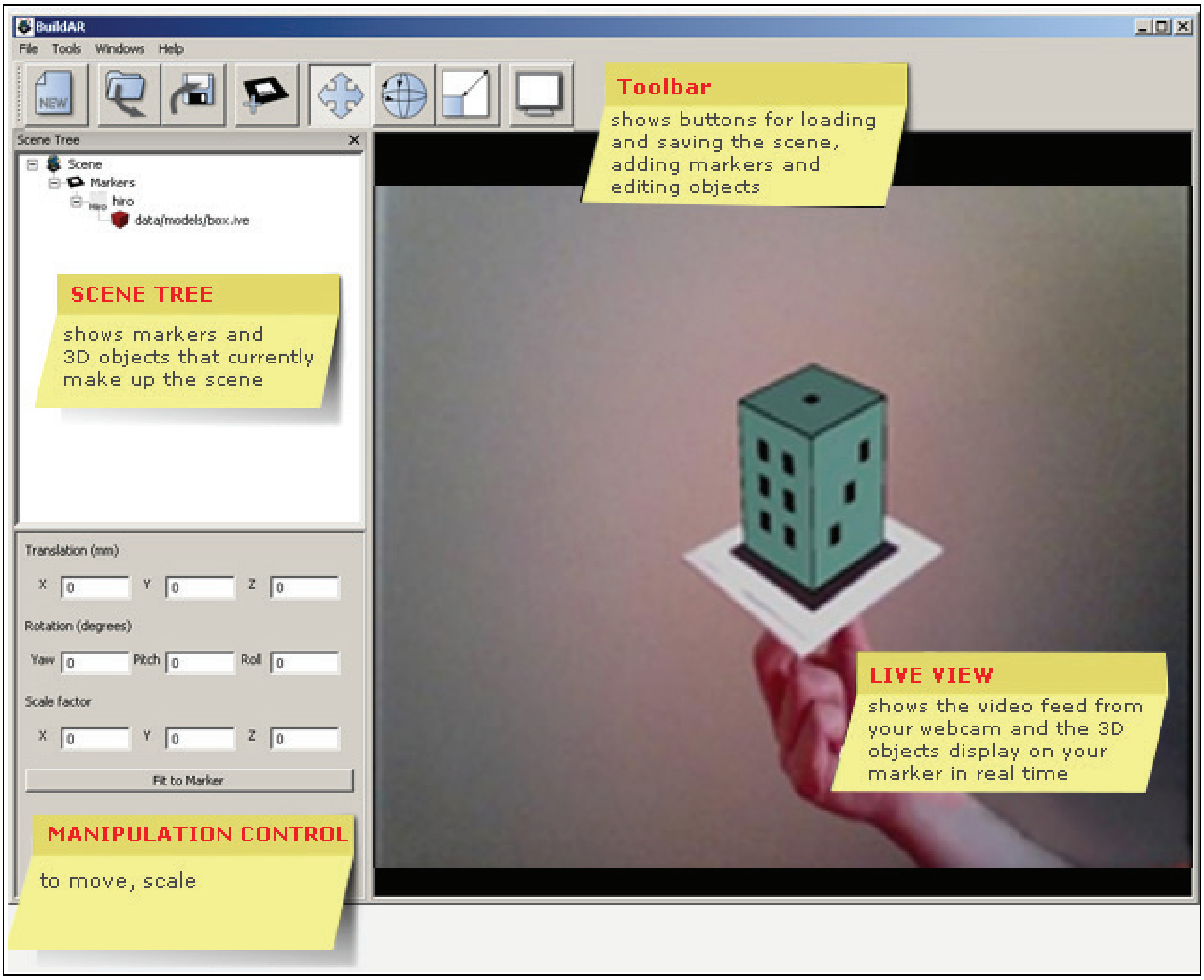


Figure 2. The Development Process of the AR Course Materials

BuildAR offers an interface that allows to combine 3D drawings with markers (Figure 3). When the interfaces of AR applications are complex, students might have difficulty using these systems (Squire & Jan, 2007). We preferred the BuildAR software because it has a quite simple and useful interface. No problems were encountered with the use of the interface during the applications.



Toolbar
shows buttons for loading and saving the scene, adding markers and editing objects

SCENE TREE
shows markers and 3D objects that currently make up the scene

Translation (mm)
X 0 Y 0 Z 0
Rotation (degrees)
Yaw 0 Pitch 0 Roll 0
Scale factor
X 0 Y 0 Z 0

LIVE VIEW
shows the video feed from your webcam and the 3D objects display on your marker in real time

MANIPULATION CONTROL
to move, scale

Figure 3. The Interface of BuildAR Software

A sample marker is shown in figure 4a. One of the objects used in the program is shown in figure 4b. These are presented together using the BuildAR interface.


Figure 4a. Sample Marker

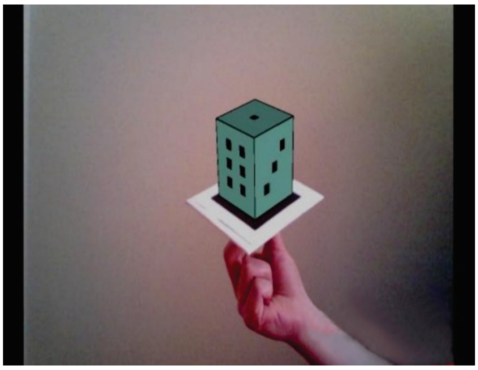


Figure 4b. One of the Objects Used

Figure 5 represents the students examining the AR materials by running the BuildAR interface full screen.

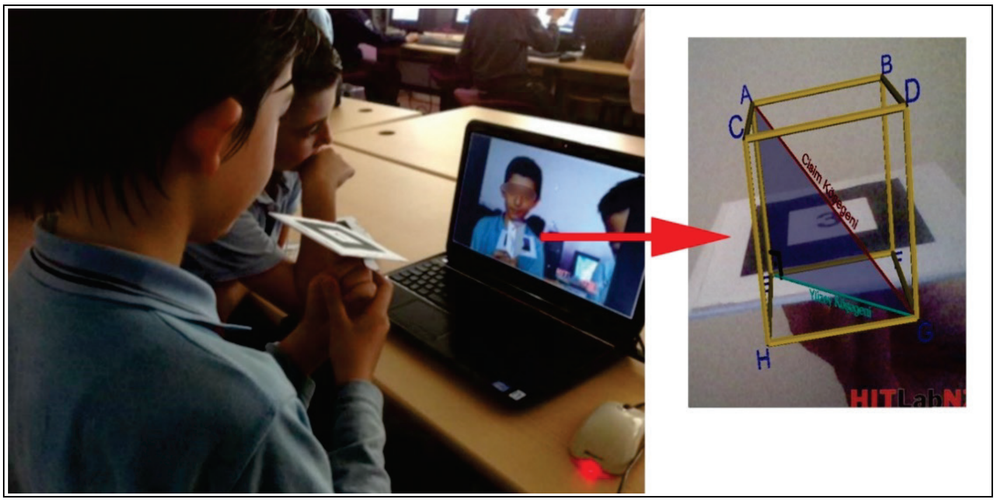


Figure 5. A Class View Using AR

AR applications are divided into optical-based and video-based applications according to the interfaces in which the virtual and the real are combined. In video-based applications, a real image is received via video cameras and then is combined with virtual images on the screen of a computer or a mobile device (Azuma, 1997). There are also other classifications, such as location-based and image-based applications; these describe the location of the information or the use of (position) markers, which are prepared in advance (Cheng & Tsai, 2013). In our educational environment, we used video-image based AR applications.

Analysis

An independent samples t-test was run to determine whether differences between the achievement and spatial ability test scores of the experimental group students and the control group students were significant. Dependent sample t-test used to analyze the achievement and spatial ability test scores within the groups. The qualitative data collected from the teacher's and students' opinion forms were analyzed using descriptive statistics.

Results

Findings concerning RQ1 (Is there a significant difference between the pre-test and post-test spatial ability scores of the experimental group students)

The results of the t-test for differences between the experimental group students' pre-test and post-test spatial ability scores are presented in Table 2.

Table 2. T-Test Results for the Experimental Group's Pre-Test and Post-Test Spatial Ability Scores

	Test	**N**	**X**	**S**	**t**	**Sd**	**P**
Experimental Group	Pre-Test	44	12,00	4,88	6,02	43	,000
	Post-Test	44	15,43	5,11			

The difference between the pre-test spatial ability test scores (X=12.00) and the post-test scores (X=15.43) of the students working with the AR application are significant [t(43)=6,02, p<.01]. This shows that the AR instruction enhancement significantly increased the students' spatial abilities.

Findings concerning RQ2 (Is there a significant difference between the pre-test and post-test spatial ability scores of the control group students)

The results of the t-test on differences between the control group students' pre-test and post-test spatial ability scores are presented in Table 3.

Table 3. T-Test Results for the Control Group's Pre-Test and Post-Test Spatial Ability Scores

	Test	N	X	S	t	Sd	P
Control Group	Pre-Test	44	12,46	3,98	3,61	43	,001
	Post-Test	44	14,50	4,83			

There was a significant increase in the spatial ability scores of the students working with the AR application [t(43)=3,61, p<.01]. While the students' pre-test spatial ability mean score was *X*=12.46, their post-test spatial ability mean score was *X*=14.50. This significant increase shows that studying the topic using 3D models significantly helped to develop the spatial abilities of the students.

Findings concerning RQ3 (Do the students' post-test spatial ability scores vary significantly depending on whether or not they were working in the environment where the AR application was used?)

The t-test results for differences between the post-test spatial ability scores of the experimental and the control group students are presented in Table 4.

Table 4. T-Test Results for the Experimental and Control Group's Post-Test Spatial Ability Scores

	Grup	N	X	S	t	Sd	P
Post-Test	Experimental	44	15,43	5,12	,88	86	,382
	Control	44	14,50	4,83			

The spatial ability mean score of the control group students (X=15.43) was higher than that of the experimental group students (X=14.50). This suggests that the use of the AR application positively affected the development of the students' spatial abilities, but this difference was not statistically significant [t(86)=,88, p=,382>,05].

Findings concerning RQ4 (Is there a significant difference between the pre-test and post-test academic achievement of the experimental group students?)

The t-test results for differences between the pre-test and the post-test academic achievement mean scores of the experimental group students are presented in Table 5.

Table 5. T-Test Results for the Experimental Group's Pre-Test and Post-Test Academic Achievement Scores

	Test	N	X	S	t	Sd	P
Experimental Grubu	Pre-Test	42	5,79	2,52	4,89	41	,000
	Post-Test	42	8,31	2,67			

The difference between the pre-test academic achievement mean score (*X*=5.79) and the post-test mean score (X=8.31) of the experimental group students is statistically significant [t(41)=4,89, p<.01]. This result indicates that the use of the AR application resulted in a significant increase in the students' academic achievement.

Findings concerning RQ5 (Is there a significant difference between the pre-test and post-test academic achievement scores of the control group students?)

The T-test results for differences between the pre-test and the post-test academic achievement mean score of the control group students are presented in Table 6.

Table 6. Kontrol Grubunun Ön-Test İle Son-Test Akademik Başarı Puanlarına İlişkin T-Testi Sonuçları

	Test	N	X	S	t	Sd	P
Control Group	Pre-Test	39	6,59	3,50	1,56	41	,126
	Post-Test	39	7,33	2,53			

The difference between the pre-test and the post-test mean scores of the control group students is not statistically significant [t(41)=1.56, p>.05]. The pre-test academic achievement mean score of the control group students was (*X*=6.59), and their post-test academic achievement mean score was (*X*=7.33) – only slightly higher. Thus, the non-AR instruction conducted in the control group did not significantly increase the academic achievement of the students.

Findings concerning RQ6 (Do the students' post-test academic achievement scores vary significantly depending on whether or not they were in the environment where the AR application was used?)

The T-test results for differences between the post-test academic achievement mean scores of the experimental and the control group students are presented in Table 7.

Table 7. T-Test Results for the Experimental and the Control Group's Post-Test Academic Achievement Mean Scores

	Group	N	X	S	t	Sd	P
Post-Test	Experimental Group	42	8,31	2,67	1,69	79	,096
	Control Group	39	7,33	2,53			

The difference between the post-test academic achievement mean score of the experimental group students (X=8.31) and the score of the control group students (X=7.33) is not significant [t(79)=1.69, p=.096>.05]. However, it can be said that the AR application slightly positively affected the academic achievement of the students.

Findings concerning RQ7 (What are the students' opinions concerning the use of the AR application in this educational environment?)

The structured student form consisting of 10 questions was administered to 40 students to elicit their opinions about the usability of the AR application and its effects in the classes. These findings are provided below.

Effects of the AR application in terms of making the classes more fun. All of the students (f=40) stated that the AR application made the classes more enjoyable. Their reasons were: the application itself is fun, it is conducted in a computer environment, it facilities and accelerates learning, and the students can interact with the application using the (object) markers. Some of the students' responses for the question "Did the AR application make the classes more enjoyable?" are provided below:

> *"It was very enjoyable to view a figure from different directions by turning cards [markers]."*
>
> *"It was fun to learn by seeing the figures and by rotating them as I wished. Doing this on the computer was the most important reason that this was enjoyable."*
>
> *"Learning faster made it enjoyable."*

Effects of the AR application on comprehension of the topic. All of the students (f=40) stated that the AR application contributed to their faster and easier learning of the topic. Two of the students (12.5%) stated that the application "aided their learning a little bit" (indicating that this contribution was small). The students also stated that the opportunities provided by the AR medium for interaction and examination of the objects in a detailed manner helped them to understand the topic more easily. Furthermore, they stated that the AR application prevented misconceptions from occurring and increased retention of the learned information. Some of the students' responses to the question "Did the AR application assist with your understanding of the topic?" are provided below:

> *"Yes, because we saw the objects as three-dimensional. It was like we were holding the prisms that we saw. We could look at them from any direction we wanted."*
>
> *"Yes, I particularly gained a thorough understanding of the topics of volume and diagonal of an object. I do not confuse them anymore."*

Effects of the AR application on the visualization of objects in the mind. While a high majority of the students (f=37; 92.5%) emphasized the positive effects of the AR application on their visualization of abstract concepts in the mind, only one student (2.5%) said "No, they did not help." Two students (5%) did not provide an answer to this question. The other students stated positive opinions, mainly noting that objects viewed in the AR medium are 3D and animated. Some of the students' responses to the question "Did the AR application assist with your visualization of the abstract concepts in your mind?" are provided below:

> *"Yes. We were able to see these figures in our notebooks, but when we saw them in the computer, we were able to recall their parts in our minds, and thus we visualized them better."*
>
> *"Yes, because when we see them on the board, we can see their two-dimensional image, but on the computer, they are presented as three-dimensional, which helps us to visualize them in our minds."*

Effects of the AR application on attention to the lesson. Thirty-one students (77.5%) offered positive responses concerning the effects of the AR application on their attention to the lesson, while nine students (22.5%) stated negative opinions. Some students stated that they paid more attention to the lesson because the AR materials were interesting. Those students who stated negative opinions said that while they were examining the 3D objects, they missed the lecture about the topic. Some of the students' responses to the question "Did the AR application help to increase your attention on the lesson?" are provided below:

> *"Because I enjoyed the AR application, I paid greater attention to the lesson."*
>
> *"I paid greater attention. I did not find time to think about things not relevant to the lesson. But, sometimes I forgot to listen to the teacher while looking at the figures, and then I felt hesitant about asking questions."*

Effect of the AR application on opinions concerning the mathematics course. While 77.5% (f=31) of the students stated that the AR application positively affected their opinions concerning the mathematics course, 22.5% (f=9) stated that their opinions did not change. Some students stated that their opinions changed in a positive direction because the AR applications facilitated their understanding of the topic and made the process more enjoyable. On the other hand, other students stated that the AR application had no effect because they already liked the course. Some of the students' responses to the question "Did the AR application change your opinion concerning the mathematics course in a positive or negative direction?" are provided below:

> *"Because I understood it better, it was more enjoyable. The AR made me love the course."*
>
> *"Though in general I do not like mathematics much, there are some topics I like. If such applications are added for the topics I do not like, I may also like them. "*
>
> *"I had already liked the mathematics course with this teacher. But this way, I liked it better."*

Effects of peer-cooperation on understanding the topic while using the AR application. During the application, while some of the students worked alone on the computer, others worked in pairs. Twenty-nine (72.5%) of the students stated that working with their peers positively affected their learning, while 11 (27.5%) stated that it negatively affected their learning. The students who stated positive opinions about pair-work said that they examined the objects together and asked questions of their peers about issues that they did not understand. Those students who did not like working with others complained about the obligation to talk with others during the lesson; they were unable to agree concerning the objects they were examining and did not understand activities which they could not perform on their own. Some of the students' responses to the question "How did working together with a friend while using the AR application affect your understanding of the topic? Positive/Negative?" are provided below:

> *"It affected me positively because we shared our ideas and opinions, and thus reached a better understanding."*
>
> *"It affected me negatively. While my friend was using one of the cards, I used the other. I only understood my part. I did not understand what my friend did."*

Difficulties involved when using AR. While 30 (75%) of the students stated that they did not encounter any problems using the materials, ten students (25%) stated that they faced various difficulties. All of the students who stated that they experienced problems specified difficulties related to the perception of the (object) markers. Because of an excessive amount of light in the environment, the surfaces of the markers glittered, and this caused some problems in the pilot study. Another difficulty experienced by the students relates to their unfamiliarity with the AR materials. Some of their responses to the question "Did you encounter any difficulties while using the AR? If yes, what are these difficulties?" are provided below:

> *"I had difficulty seeing the objects because the cards glittered."*
>
> *"Because I was sitting by the window, the cards glittered too much. I had to look at my friend's cards next to me."*

Willingness to use the AR application in different courses. Only 19 (47.5%) of the 40 students responded to the question "Do you want to use AR applications in different courses? In which courses or topics can they be used?" Their responses indicate that the students thought AR applications can be useful in science and technology, social studies, and English courses. Three of the students wanted AR applications to be used for teaching topics such as the "skeleton and muscle system," the "granular structure of the matter," "support and movement," and "our body."

Suggestions for changes to the AR application. Only five (8%) of the students responded to the question "What kinds of changes would you like to be made to the AR application?" Their suggestions were to include different topics, better lighting and video recordings, and to increase the number of virtual objects – especially the number of animations.

The students' other opinions concerning the AR application. Only two students (5%) answered the question "Do you have anything else to say about the AR application? If yes, then tell us." These two students stated that they would like to use AR applications in other courses in the coming years.

Findings Related to the Eighth Research Question that "What are the teacher's opinions concerning the use of the AR application in this educational environment?"

The teacher's opinions on the AR application in her classes were positive. Her overall comments about the effects of AR on the instructional process have been grouped into three thematic categories.

First, she stated that the AR increased the students' excitement and interest in the course. According to the teacher, the reason for this is that students love computers, and the AR application was a novel technology for them. The teacher also stated that throughout the application, when the students were entering the laboratory, they asked "which figures are we going to see this week?" Thus, they indicated their interest in each class, and they maintained their interest until the end of the class. As a result, the students paid greater attention and were less distracted. Overall, this also decreased disciplinary problems normally experienced in the class.

Second, the AR application helped the students to concretize abstract concepts. By means of the AR medium, the students were able to observe the objects from different angles, and they were able to feel as if they were moving the objects in their hands. In this way, common difficulties experienced by students who are visualizing figures in their minds when this topic is taught through traditional methods can be reduced.

Third, the AR application requires less time and effort compared to traditional methods. This is because in non-AR lessons the construction and readying of 3D real models are very time-consuming preparatory procedures.

Aside from the advantages that the AR application added to the instructional process, the teacher also pointed out some difficulties stemming from the application process. She stated that in the first week, because the students placed the (object) markers too close to the screen and moved them very quickly, they experienced some problems; but these initial difficulties were solved during the pilot application. She also stated that while working in pairs, some of the students talked to each other, and thus they could not follow the teacher and had some disagreements about who would conduct the activities.

Finally, the teacher made some suggestions about the use of the AR application in classes. She emphasized that for teachers to be able to use AR in their classes, they first must be willing to use this technology. For AR applications that might be developed in the future, in addition to rotation and zooming, different functions such as dividing objects, and changing their sizes, colors, and textures can be added.

Discussion and Conclusion

Effects of the AR Application on the Students' Spatial Abilities

There was a significant difference between the pre-test and post-test spatial ability mean scores for both the experimental and the control group students. This shows that both the AR application and the use of 3D real objects in the educational environment positively affected the spatial abilities of the students. In the literature, some studies have reported similar results (Shelton & Hedley, 2002; Kaufmann et al., 2005; Martín-Gutiérrez et al., 2010; Lin et al., 2015). When the groups were compared to each other in terms of their spatial ability scores, we found that the spatial ability mean score of the experimental group increased more than that of the control group. AR enhances the featured real objects by providing extra information about the objects without isolating them from their environment. Due to this feature, AR applications can assist in the processes of visualization and rearrangement of 3D objects in the mind in a more effective manner than real objects alone.

When the experimental and control groups' spatial ability post-test mean scores were compared, the mean score of the experimental group was higher than that of the control group. However, contrary to our expectation, the difference was statistically insignificant. This finding is contradictory to the findings reported in some studies on the effects of AR on spatial ability in the literature. In these studies (Shelton & Hedley, 2002; Kaufmann et al., 2005; Martín-Gutiérrez et al., 2010; Lin et al., 2015) the samples consisted of high school and university students. We believe that our difference in this result might be due to the different age groups in the samples. The students in the current study were at a different stage of cognitive development, according to Piaget's theory of cognitive developmental periods. Piaget (1976) argued that, though some individual differences can be observed, students who are in the age group of 7-13 years old are in the developmental period of concrete operations, and students aged 12 or older are in the developmental period of abstract operations. The mean age of the participants in the current study was 11.92. Thus, these students were in that critical process of transition to the period of abstract operations. The participants in the other some studies were already within their period of abstract operations. Therefore, the reason for not finding a significant difference between the post-test spatial ability mean scores of the groups in the current study might be because the participants were in this transitional period.

Effects of the AR Application on the Students' Academic Achievement

The difference between the pre-test academic achievement mean score of the experimental group students and their post-test score was significant. This shows that the use of AR materials in the educational environment increased the students' academic achievement. The studies conducted by, Liu et al. (2007), Abdüsselam and Karal (2012), and Lin et al. (2015) support this finding. An increase was also observed from the pre-test academic achievement mean score of the control group to their post-test score, but that difference was not statistically significant. The between-groups difference is likely because the AR medium enriches the real objects by providing features that are not possessed by concrete objects alone. These elements in this case included visuals and animations related to volume, diagonals and the forms of objects.

The difference between the post-test academic achievement mean scores of the experimental and control groups was not significant. The spatial ability test was similar to the academic achievement test for this subject topic. While the spatial ability test includes questions related to the rotation and rearrangement of cubes, the academic achievement test includes questions related to the rotation of cubes and volume calculations. Therefore, it is not surprising that the effects of the AR application on academic achievement were the same as their effect on spatial ability. İbili (2013) conducted a study in two different schools to investigate the effects of AR on academic achievement. In that study, the same conditions were provided for both groups. İbili found a significant difference for one of the groups, but not the other and stated that the reason for this difference might be the different teachers teaching the groups. In the current study, though the same teacher taught all of the classes, no significant difference was found in academic achievement. Estapa and Nadolny (2015) also investigated the effects of an AR application on academic achievement; their findings do not concur with the findings of the current study. In Estapa and Nadolny (2015) the target population was high school students. Therefore, their results might have been different from the results of the current study due to the difference in the participants' ages.

Lin et al. (2015) conducted a study to investigate the effects of AR applications on junior high school students' academic achievements. Their research findings showed a small effect on students with average and low academic achievement between control and experimental group, while the effect was insignificant on students with high academic achievement. In our study, we did not classify students according to their academic achievement level, and they were attending primary school. For this reason, the results show similarities and differences.

AR technology can be customized to suit a particular need. In AR applications generally, wearable, portable, interactive, and location-based tools and equipment can be used (Van Krevelen & Poelman, 2010). In the current study, a video and picture-based AR medium was developed to suit the purpose of the instruction. Some research studies have examined on the effects of AR on academic achievement (Shelton & Hedley, 2002; Liu et al., 2007; Abdüsselam & Karal, 2012; Dünser et al., 2012), but no study findings to date have suggested which AR technologies would be the most suitable to use for this purpose at this particular grade level. This led us to wonder, "If we used a different AR technology, would we have different results related to academic achievement?"

The Teacher's and Students' Opinions Concerning the AR Application

The students who used the AR application in their lessons stated that it was enjoyable and that it helped them to visualize abstract concepts in their minds. The AR helped them to learn and increased their interest in the course. In the literature, these findings are echoed in several other studies (Liu et al., 2007; Klopfer & Squire, 2008; Di Serio et al., 2013; Lin et al., 2015). The teacher's opinions were similar to the students' opinions. The teacher stated that problems experienced in prior, traditional lessons on this topic were diminished by the AR application. She also argued that this application helped the students to visualize the objects in their minds, and that it helped them to learn. Moreover, the teacher stated that the students came to the AR classes with more curiosity and interest, and it was easier to keep their attention on the topic. Compared to teaching the topic using 3D real objects created by the teacher, the AR applications saved time. Some of the students who had to work on one computer in pairs stated that working with a peer was useful because they could help each other to reach a better understanding. Yet, some students were not happy about experiencing the AR application with peers. Most of the students already had a positive opinion concerning the mathematics course; these students liked their teacher. But they also stated that the AR application helped them to enjoy the course even more. Some students had a negative opinion of the course initially, but developed a more positive attitude due to the AR application. Some of the students stated that use of similar AR applications in different courses would be helpful. Two problems were noted by the teacher and the students. These related to the lighting in the laboratory, and obscure imaging due to the video camera. These two problems made perception of the (object) markers more difficult, and limited the effectiveness of the application. İbili (2013) reported similar problems. Closely spaced students' desks also made it more difficult for the students to manipulate the (object) markers.

Suggestions

Suggestions for Further Development of the AR Application

In our AR environment, some of virtual objects were contain animations, and some of them were fixed. Virtual objects, which have contain animation, attracted a great amount of attention. Therefore, objects in AR applications should include animations to increase the students' interest in the medium.

Suggestions for the Organization of the Environment

When excessive light was not reduced, the (object) markers glittered and perception of these images became more difficult. Therefore, while arranging the laboratory, the amount of light in the class environment should be carefully controlled.

During the pilot application, the close seating arrangement made it difficult for the students to move the (object) markers easily. For optimal AR effectiveness, proper student seating arrangements are needed to allow full access to the markers.

Suggestions for Future Research

The students' opinions revealed that some preferred to work individually, while others preferred to work in groups. Future research may focus on which factors lead to these different preferences. Another investigation could focus on the most suitable designs for the learning environments of particular AR applications.

During the pilot application, one of the teachers experienced problems using the AR application in the classrooms. That teacher withdrew from the study. Thus, future research could explore which teacher competencies would be required to successfully integrate AR applications into their classes.

While a great deal of prior general research has focused on developing spatial ability, few studies focus on the relationship between AR and spatial ability. There is a need for further research to collect data on this topic from different age groups, and particularly from the K-12 level using larger samples.

By using various methods, technologies, and tools, different types of AR can be constructed. In this regard, future research may be focused on which AR applications would be the most suitable for particularly targeted student groups.

References

Abdüsselam, M. S., & Karal, H. (2012). The effect of mixed reality environments on the students' academic achievement in physics education: 11th grade magnetism topic example. *Journal of Research in Education and Teaching*, *1*(4), 170-181.

Azuma, R. T. (1997). A survey of augmented reality. *Presence: Teleoperators and Virtual Environments*, *6*(4), 355-385.

Battista, M. (1980). Interrelationships between problem solving ability, right hemisphere processing facility, and mathematics learning. *Focus on Learning Problems in Mathematics*, *2*(1), 53-60.

Battista, M. T., & Clements, D. H. (1996). Students' understanding of three-dimensional rectangular arrays of cubes. *Journal for Research in Mathematics Education*, *23*(7), 258-292.

Battista, M. T., Wheatley, G. H., & Talsma, G. (1982). The importance of spatial visualization and cognitive development for geometry learning in preservice elementary teachers. *Journal for Research in Mathematics Education*, *13*(5), 332-340.

Ben-Chaim, D., Lappan, G., & Houang, R. T. (1988). The effect of instruction on spatial visualization skills of middle school boys and girls. *American Educational Research Journal*, *25*(1), 51-71.

Ben-Haim, D., Lappan, G., & Houang, R. T. (1985). Visualizing rectangular solids made of small cubes: Analyzing and effecting students' performance. *Educational Studies in Mathematics*, *16*(4), 389-409.

Bishop, A. J. (1986). What are some obstacles to learning geometry. *Studies in Mathematics Education*, *5*, 141-159.

Bruner, J. S. (1966). *Toward a theory of instruction*. Cambridge, MA: Harvard University Press.

Carbonell Carrera, C., & Bermejo Asensio, L. A. (2017). Landscape interpretation with augmented reality and maps to improve spatial orientation skill. *Journal of Geography in Higher Education*, *41*(1), 119-133.

Chen, Y. C. (2006). A study of comparing the use of augmented reality and physical models in chemistry education. In *Proceedings of the 2006 ACM International Conference on Virtual Reality Continuum and Its Applications* (pp. 369-372). Hong Kong, China.

Cheng, K. H., & Tsai, C. C. (2013). Affordances of augmented reality in science learning: Suggestions for future research. *Journal of Science Education and Technology*, *22*(4), 449-462.

Di Serio, Á., Ibáñez, M. B., & Kloos, C. D. (2013). Impact of an augmented reality system on students' motivation for a visual art course. *Computers & Education*, *68*, 586-596.

Dunleavy, M., Dede, C., & Mitchell, R. (2009). Affordances and limitations of immersive participatory augmented reality simulations for teaching and learning. *Journal of Science Education and Technology*, *18*(1), 7-22.

Dünser, A., Walker, L., Horner, H., & Bentall, D. (2012). Creating interactive physics education books with augmented reality. In *Proceedings of the 2012 OzCHI 24th Australian Computer-Human Interaction Conference* (pp. 107-114). Melbourne, Australia.

Estapa, A., & Nadolny, L. (2015). The effect of an augmented reality enhanced mathematics lesson on student achievement and motivation. *Journal of STEM Education: Innovations and Research*, *16*(3), 40-48.

Fennema, E., & Sherman, J. (1977). Sex-related differences in mathematics achievement, spatial visualization and affective factors. *American Educational Research Journal*, *14*(1), 51-71.

Furio, D., Gonzalez-Gancedo, S., Juan, M. C., Seguí, I., & Costa, M. (2013). The effects of the size and weight of a mobile device on an educational game. *Computers & Education*, *64*, 24-41.

Guay, R. B., & McDaniel, E. D. (1977). The relationship between mathematics achievement and spatial abilities among elementary school children. *Journal for Research in Mathematics Education*, *8*(3), 211-215.

Huang, T. C., & Lin, C. Y. (2017). From 3D modeling to 3D printing: Development of a differentiated spatial ability teaching model. *Telematics and Informatics*, *34*(2), 604-613.

İbili, E. (2013). *Development, implementation and assessment of the effect augmented reality on geometry teaching materials for geometry classes* (Unpublished doctoral dissertation). Gazi University, Ankara, Turkey.

İncikabı, L., & Kılıç, Ç. (2013). An analysis of primary school students' conceptual knowledge of geometric solids. *Journal of Theoretical Educational Science*, *6*(3), 343-358.

Kaminski, J. A., Sloutsky, V. M., & Heckler, A. (2009). Transfer of mathematical knowledge: The portability of generic instantiations. *Child Development Perspectives*, *3*, 151-155.

Katsioloudis, P., Jovanovic, V., & Jones, M. (2014). A comparative analysis of spatial visualization ability and drafting models for industrial and technology education students. *Journal of Technology Education*, *26*(1), 88-101.

Kaufmann, H., Steinbügl, K., Dünser, A., & Glück, J. (2005). General training of spatial abilities by geometry education in augmented reality. *Annual Review of CyberTherapy and Telemedicine: A Decade of VR*, *3*, 65-76.

Klopfer, E., & Squire, K. (2008). Environmental detectives- the development of an augmented reality platform for environmental simulations. *Educational Technology Research and Development*, *56*(2), 203-228.

Kurtuluş, A., & Uygan, C. (2010). The effects of Google Sketchup based geometry activities and projects on spatial visualization ability of student mathematics teachers. *Procedia-Social and Behavioral Sciences*, *9*, 384-389.

Kurtuluş, A., & Yolcu, B. (2013). A study on sixth-grade Turkish students; spatial visualization ability. *The Mathematics Educator*, *22*(2), 82-117.

Lin, H. C. K., Chen, M. C., & Chang, C. K. (2015). Assessing the effectiveness of learning solid geometry by using an augmented reality-assisted learning system. *Interactive Learning Environments*, *23*(6), 799-810.

Linn, M. C., & Petersen, A. C. (1985). Emergence and characterization of sex differences in spatial ability: A meta-analysis. *Child Development*, *56*(6), 1479-1498.

Liu, T. Y., Tan, T. H., & Chu, Y. L. (2007). 2D barcode and augmented reality supported english learning system. In *Processings of the 2007 ICIS 6th International Conference on Computer and Information Science* (pp. 5-10). Melbourne, Australia.

Lohman, D. F. (1996). Spatial ability and g. In I. Dennis, & P. Tapsfield (Eds.), *Human abilities: Their nature and measurement* (pp. 97-116). Hillsdale, NJ: Lawrence Erlbaum Associates.

Martín-Gutiérrez, J., Saorín, J. L., Contero, M., Alcañiz, M., Pérez-López, D. C., & Ortega, M. (2010). Design and validation of an augmented book for spatial abilities development in engineering students. *Computers & Graphics*, *34*(1), 77-91.

McNeil, N. M., & Uttal, D. H. (2009). Rethinking the use of concrete materials in learning: Perspectives from development and education. *Child Development Perspectives*, *3*(3), 137-139.

Moses, B. E. (1980). *The relationship between visual thinking tasks and problem-solving performance*. Paper presented at the 64th annual meeting of the American Educational Research Association, Boston, MA.

Munoz-Cristobal, J. A., Jorrin-Abellan, I. M., Asensio-Perez, J. I., Martinez-Mones, A., Prieto, L. P., & Dimitriadis, Y. (2015). Supporting teacher orchestration in ubiquitous learning environments: A study in primary education. *Learning Technologies, IEEE Transactions on Learning*, *8*(1), 83-97.

Onyancha, R. M., Derov, M., & Kinsey, B. L. (2009). Improvements in spatial ability as a result of targeted training and computer-aided design software use: Analyses of object geometries and rotation types. *Journal of Engineering Education*, *98*(2), 157-167.

Patton, M. Q. (1987). *How to use qualitative methods in evaluation*. California: Sage.

Piaget, J. (1976). Piaget's theory. In B. Inhelder, H. H. Chipman, & C. Zwingmann (Eds.), *Piaget and his school: A reader in developmental psychology* (pp. 11-23). New York: Springer-Verlag.

Rafi, A., Anuar, K., Samad, A., Hayati, M., & Mahadzir, M. (2005). Improving spatial ability using a Web-based Virtual Environment (WbVE). *Automation in Construction*, *14*(6), 707-715.

Roca-González, C., Martin-Gutierrez, J., García-Dominguez, M., & del Carmen Mato Carrodeguas, M. (2017). Virtual technologies to develop visual-spatial ability in engineering students. *Eurasia Journal of Mathematics, Science & Technology Education*, *13*(2), 441-468.

Sarama, J., & Clements, D. H. (2009). "Concrete" computer manipulatives in mathematics education. *Child Development Perspectives*, *3*, 145-150.

Shelton, B. E., & Hedley, N. R. (2002). *Using augmented reality for teaching earth-sun relationships to undergraduate geography students.* Paper presented at The First IEEE International Augmented Reality Toolkit Workshop, Darmstadt, Germany.

Sırakaya, M., & Seferoğlu, S. (2016). Öğrenme ortamlarında yeni bir araç: Bir eğlence uygulaması olarak artırılmış gerçeklik. In A. İşman, H. F. Odabaşı, & B. Akkoyunlu (Eds.), *Eğitim teknolojileri okumaları 2016* (pp. 417-438). Ankara: Salmat Basım Yayıncılık

Smith, I. M. (1964). *Spatial ability*. San Diego: Knapp.

Somyürek, S. (2014). Gaining the attention of generation Z in learning process: Augmented reality. *Educational Technology Theory and Practice*, *4*(1), 63-80.

Squire, K. D., & Jan, M. (2007). Mad City Mystery: Developing scientific argumentation skills with a place-based augmented reality game on handheld computers. *Journal of Science Education and Technology*, *16*(1), 5-29.

Subrahmanyam, K., & Greenfield, P. M. (1994). Effect of video game practice on spatial skills in girls and boys. *Journal of Applied Developmental Psychology*, *15*(1), 13-32.

Sumadio, D. D., & Rambli, D. R. A. (2010). Preliminary evaluation on user acceptance of the augmented reality use for education. In *Proceedings of the 2010 ICCEA 2nd international conference on computer engineering and applications* (pp. 461-465). Bali Island, Indonesia.

Toptaş, V., Çelik, S., & Karaca, E. T. (2012). Improving 8th grades spatial thinking abilities through a 3D modeling program. *TOJET: The Turkish Online Journal of Educational Technology*, *11*(2), 128-134.

Toto, S. (2011). The use of Cabri 3D software as virtual manipulation tool in 3-dimension geometry learning to improve junior high school students' spatial ability. In *Proceedings international seminar and the fourth national conference on mathematics education* (pp. 609-618). Yogyakarta, Indonesia.

Tracy, D. M. (1987). Toys, spatial ability, and science and mathematics achievement: Are they related?. *Sex Roles*, *17*(3-4), 115-138.

Turğut, M. (2007). *Investigation of 6, 7 and 8 grade students' spatial ability* (Unpublished master's thesis). Dokuz Eylül University, İzmir, Turkey.

Van Krevelen, D. W. F., & Poelman, R. (2010). A survey of augmented reality technologies, applications and limitations. *International Journal of Virtual Reality*, *9*(2), 1-20.

Wang, J. Y., Wu, H. K., & Hsu, Y. S. (2017). Using mobile applications for learning: Effects of simulation design, visual-motor integration, and spatial ability on high school students' conceptual understanding. *Computers in Human Behavior*, *66*, 103-113.

Weng, T. S., Hsu, M. H., & Yang, D. C. (2017). A Study investigating the use of 3D computer animations of trigonometric functions to enhance spatial perception ability. *International Journal of Information and Education Technology*, *7*(1), 23-26.

Yoon, S. A., Elinich, K., Wang, J., Steinmeier, C., & Tucker, S. (2012). Using augmented reality and knowledge-building scaffolds to improve learning in a science museum. *International Journal of Computer-Supported Collaborative Learning*, *7*(4), 519-541.

Yurt, E., & Sünbül, A. M. (2012). Effect of modeling-based activities developed using virtual environments and concrete objects on spatial thinking and mental rotation skills. *Educational Sciences: Theory and Practice*, *12*(3), 1987-1992.