Learning Anatomy via Mobile Augmented Reality: Effects on Achievement and Cognitive Load

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Augmented reality (AR), a new generation of technology, has attracted the attention of educators in recent years. In this study, a MagicBook was developed for a neuroanatomy topic by using mobile augmented reality (mAR) technology. This technology integrates virtual learning objects into the real world and allow users to interact with the environment using mobile devices. The purpose of this study was to determine the effects of learning anatomy via mAR on medical students' academic achievement and cognitive load. The mixed method was applied in the study. The random sample consisted of 70 second-year undergraduate medical students: 34 in an experimental group and 36 in a control group. Academic achievement test and cognitive load scale were used as data collection tool. A one-way MANOVA test was used for analysis. The experimental group, which used mAR applications, reported higher achievement and lower cognitive load. The use of mAR applications in anatomy education contributed to the formation of an effective and productive learning environment. Student cognitive load decreased as abstract information became concrete in printed books via multimedia materials in mAR applications. Additionally, students were able to access the materials in the MagicBook anytime and anywhere they wanted. The mobile learning approach helped students learn better by exerting less cognitive effort. Moreover, the sensory experience and real time interaction with environment may provide learning satisfaction and enable students to structure their knowledge to complete the learning tasks. Anat Sci Educ 9: 411–421. © 2016 American Association of Anatomists.

Key words: gross anatomy education; neuroanatomy education; undergraduate education; medical education; mobile augmented reality; MagicBook; mobile learning; learning anatomy

INTRODUCTION

Information and communication technology (ICT) is developing rapidly and these developments are influencing the field of education. A new generation of students are growing up with ICT embedded in their daily lives (Prensky, 2010). Development in ICT and changes in student profiles have led to the use of new teaching methods and technologies appropriate to the needs of modern students. Integrating complementary technologies can enhance or create new types of learning environments for students and teachers. (Barraza Castillo et al., 2015). One of the new generation technologies, augmented reality (AR), has attracted the attention of educators in recent years due its ability to merge the real and virtual world by combining human senses (e.g., sight, sound, and touch) with virtual objects (Azuma, 1997).

Augmented Reality Technology

In augmented reality technology, the real environment is used as a background and a sense of reality is created by adding texts, pictures, sounds, animations, or three-dimensional (3D) objects onto the video image of the real world (Billinghurst et al., 2001).

Additional Supporting Information may be found in the online version of this article.

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In AR applications, there are two basic image recognition techniques: marker-based and location-based (Cheng and Tsai, 2012). In marker-based applications, visual marker codes or physical objects that are recognized by the AR system are used. Augmented reality software allows for the viewing of virtual reality augmented by the data from a physical marker, which helps users to perceive the virtual image as real. In location-based applications, information is generated by computer through use of the location data identified by a Global Positioning System (GPS) or wireless Wi-Fi positioning systems overlap (Alkhamisi and Monowar, 2013; Kamphuis et al., 2014). To create create a successful augmented reality, monitoring, perceiving, imaging, and interaction operations have to be performed using specialized desktop and mobile softwares.

Devices such as computers and head-mounted systems create a sense of reality in AR, which is the most important property for users (Billinghurst et al., 2001). Recent developments in mobile technologies have made AR possible via mobile devices, bringing mobile augmented reality (mAR) applications into the spotlight. Mobile augmented reality applications integrate virtual learning objects into the real world and allow users to interact with the environment using mobile devices (Ifenthaler and Eseryel, 2013). This technology applied in various industries; for instance education, advertising, entertainment, and tourism (Jamali et al., 2013).

When the educational applications developed through AR technology are examined, it is apparent that a great deal of attention has been focused on the creation of MagicBook. The MagicBook looks like a traditional book, but there are augmented reality markers in the interface. Users turn pages, look at pictures, and read text without any additional technology. When AR displays are used, they see multimedia materials such as 3D virtual models or videos (Billinghurst et al., 2001; Ferrer-Torregrosa et al., 2015). As a result of the developments in mobile technologies in recent years, new applications are being created with mAR. In these applications, markers placed in the pages of traditional book pages through AR technology make books interactive, which serves to combine various multimedia materials with traditional printed books via mobile devices. This demonstrates the significance of multimedia materials, as instructional design is one of the most important factors influential on effective learning in mobile learning environments (Gedik et al., 2012). In the instructional design process, creating multimedia materials compatible with mobile devices is of great importance. Graphics, animations, and videos are frequently used in the learning environments designed for mobile devices. Animations and videos are among today's popular multimedia materials and are more effective than static images (Rasch and Schnotz, 2009). Since animations require both structural and temporal knowledge, they are accepted as a good learning tool to support dynamic mental models. Using animations, individuals can create mental schemas that cannot be obtained through pictures (Schwan and Riempp, 2004). In addition to videos and animations, 3D objects are also widely used in AR applications. In the present study, various multimedia materials aimed at teaching anatomy were designed within the framework of the cognitive theory of multimedia learning. MagicBook was created by combining these materials with traditional books through marker-based mAR technology.

Augmented Reality in Education

AR technology, which has gained popularity in many fields, has started to be frequently used in education in recent years. Augmented reality applications have been reported to be quite effective in facilitating meaningful learning; they transfer content and make it concrete by visualizing abstract three-dimensional (3D) structures and making complicated topics clearer (Wu et al., 2013). Providing interaction through 3D view of objects from different points of view improves students' spatial and practical skills (Kerawalla et al., 2006; Cheng and Tsai, 2012). In addition, AR technology provides instant feedback through real-time interaction, allowing students to control their own learning processes (Yuen et al., 2011; Bujak et al., 2013).

Mobile augmented reality (mAR) technology, recently increasingly common, allows students to enjoy flexible learning, or learning at times and in places they choose based on their own learning rates and styles (Bujak et al., 2013; Kamphuis et al., 2014). It provides users with an immersive sensory experience by integrating digital data into real environment (Hwang et al., 2009; Chiang et al., 2014; Ibáñez et al., 2014). A number of researchers have documented that mAR devices improve the success rate of physical interaction-related learning tasks, support memory related learning activities and enable personalized, and self-directed learning (Dunleavy et al., 2009; Chien et al., 2010; Küçük et al., 2014a; Shirazi and Behzadan, 2015)

In addition, AR technology enhances the effectiveness and attractiveness of teaching learning process by adding a new dimension to traditional educational materials like lectures and textbooks (Lee, 2012; Küçük et al., 2014b; Barraza Castillo et al., 2015). Researchers have stated that AR applications have the potential to facilitate the learning process and improve academic achievement in comparison with traditional instructions (Andújar et al., 2011; Chen et al., 2011; Chiang et al., 2014). The sensory experience and real time interaction of an AR environment can provide learning satisfaction and enable students to structure their knowledge (Dunleavy et al., 2009). As seen Table 1, AR technology used in many educational fields obtained generally effective results.

Augmented Reality in Anatomy Education

The extent to which students achieve the learning goals of the anatomy course is important for their future studies or work. In addition, as the diagnosis and treatment of diseases requires anatomy knowledge, doctors have to have good knowledge of human anatomy in medical practices (Kamphuis et al., 2014). From this perspective, the subjects covered within the scope of this course have to be taught effectively to students. In Turkey, courses in the medical school curricula are generally taught in lecture halls or through laboratory practices. The lessons given in lecture halls constitute a large part of students' learning experiences. However, both in Turkey and worldwide, attempts have been made to reduce the course hours of anatomy lessons in medical curricula and to make students start clinical experience earlier in recent years (McCuskey et al., 2005; Ganguly, 2010). That has caused lecturers to convey many subjects to students in a short amount of time. However, anatomy lessons given in medical schools are difficult in terms of content

Table 1.

A Brief Summary of Studies Using AR Technology in Education

Author/Year	Technology	Topic	Sample	Results
Kerawalla et al. (2006)	Projector, webcam	Geography	3 teachers, 133 elementary school students	Four suggested design requirements: (1) flexible content that teachers can adapt to the needs of their children, (2) guided exploration so learning opportunities can be maximized in a limited time, (3) attention to the needs of institution, and (4) curricular requirements.
Dunleavy et al. (2009)	Mobile device	Math, science, language	6 teachers, 80 secondary and high school students	Improves problem-solving skill and provides an inquiry-based learning environment
Yusoff et al. (2011)	PC, webcam	Biomedical	63 undergraduate students	Influences perceived usefulness and intention to use the most and makes students use it in the future
Borrero and Márquez (2012)	PC, 3D glasses	Electrical engineering	10 faculty members, 20 undergraduate students	Improves achievement, motivation, and interest in the lesson and makes individuals evaluate it as a useful system
Chiang et al. (2014)	Mobile device	Natural science	57 elementary school students	Improving the students' learning achievements and higher motivations
Shirazi and Behzadan (2015)	Mobile device	Engineering	166 construction and civil engineering undergraduate students	Positive impact on students' learning both in short-term and long-term. Providing interesting, helpful, and motivational approach in the classroom
Barraza Castillo et al. (2015)	Mobile device	Mathematic	59 undergraduate students	Users after the AR experience are positive, supporting the premise that AR can be, in the future, a valuable complimentary teaching tool
Jamali et al. (2015)	Mobile device	Anatomy	30 undergraduate students	Students satisfied with HuMAR in terms of its usability and features, positive impact in students' learning process
Ferrer-Torregrosa et al. (2015)	PC, webcam	Anatomy	211 undergraduate students	The results strongly suggest that the use of AR is suitable for anatomical purposes. Concretely, the results indicate how this technology is helpful for student motivation, autonomous work or spatial interpretation.

3D, three-dimensional; AR, augmented reality; HuMAR, human anatomy in mobile augmented reality; PC, personal computer.

and contain intensive knowledge. This makes it difficult for students to understand subjects and transfer the new pieces of knowledge they learn to their long-term memories (Kirschner et al., 2006; Ganguly, 2010; Deveci Topal and Ocak, 2014; Jamali et al., 2015).

The importance of anatomy education, as the basis of medical education and the aforementioned problems demand that researchers focus on solutions that will allow a more effective and productive anatomy learning. Consequently, using new methods and technologies in anatomy education is important for providing society with qualified doctors.

Various technologies are used for facilitating learning in anatomy education. Cadaveric teaching is one of the major teaching methods in anatomy education. In this method, the primary objective is to enable students to three-dimensionally examine the anatomical structures which they have seen in textbooks and to see the relationship among these structures in a concrete way. Though this method provides many advantages, problems may be encountered in finding and conserving cadavers as well as in ethical and public perception issues (Shaffer, 2004). A quality anatomy education should allow a maximum of six students to work on a single cadaver. Unfortunately, in Turkey, the number of students working on a cadaver is much higher. Some medical schools even have no cadavers at all in Turkey (TSACA, 2013). As stated in literature, teaching with cadavers can be troublesome, expensive, and ineffective in teaching anatomy when used alone (McLachlan et al., 2004; Winkelmann, 2007). Also, it can be difficult or impossible to understand the internal structures of some organs when standing over a cadaver (Nicholson et al., 2006; Adams and Wilson, 2011). Anatomy topics such as cross-sectional neuroanatomy require expansive knowledge, and students must be supported with well-designed multimedia materials to make their knowledge of such complex structures permanent (Waterston and Stewart, 2005; Fitzgerald et al., 2008). In comparison with cadaveric dissection, computer-based 3D models provide unlimited viewing angles and perspectives, portability, and longevity (Spitzer and Scherzinger, 2006; Adams and Wilson, 2011). For these reasons, attention should be focused on these innovative methods and technologies in anatomy education (McKeown et al., 2003; Brewer et al., 2012; Johnson et al., 2012).

The changes in anatomy curricula, inadequacy of the number of cadavers in medical schools, lack of detailed 3D models associated with each anatomical structure, and the large numbers of students, have brought the use of various innovative methods and technologies such as independent learning, computer-aided learning, and problem-based learning in anatomy education to the forefront (McKeown et al., 2003; Adams and Wilson, 2011; Johnson et al., 2012). In this regard, the use of computer-aided visualization systems for anatomy education has gained a wide currency in the course of time (Bukowski, 2002; Mangan, 2002; Khalil et al., 2005). Visualization in anatomy has turned from the use of static images into the use of animations and recently the use of interactive simulations (Khalil et al., 2005). 3D models, animations, and videos are among the multimedia materials that are frequently used for dynamically visualizing anatomical structures (Hegarty, 2004; Nicholson et al., 2006). Animations allow viewing anatomical structures in more depth and from different points of view. It is stated in the literature that the teaching of subjects involving complex knowledge, such as neuroanatomy, should be supported by two-dimensional (2D) and 3D multimedia materials (Nowinski et al., 2009). In particular, teaching the complex spatial relationships of neuroanatomy may be best supported by the use of 3D virtual materials. These materials are useful for increasing student understanding of complex 3D anatomical structures and relationships and the long-term retention of information (Gorman et al., 1999; Hallgren et al., 2002; Adams and Wilson, 2011; Brewen et al., 2012). As technology has advanced, so has the presentation of these multimedia materials that facilitate the understanding of anatomical structures to users through AR technologies come to the fore.

Although the first use of AR technology in medical education was for surgical training purposes (Bajura et al., 1992; Fuchs et al., 1998; Merten, 2007), studies on the use of AR technology in anatomy education have become more common in the recent years. These studies have focused on the development of magic mirror systems, haptic applications, and MagicBook applications for the teaching of complex anatomical structures via AR technology (Hamza-Lup et al., 2004; Blum et al., 2012; Patirupanusara, 2012; Meng et al., 2013). In these applications, AR software is generally accessed on computers (Chien et al., 2010; Thomas et al., 2010; Yeom, 2011; Patirupanusara, 2012; Kucuk and Yilmaz, 2014; Ferrer-Torregrosa et al., 2015). Chien et al. (2010) developed an interactive AR system for the teaching of the anatomical structure of the skull. In this study conducted with 30 medical students, they concluded that the system ensures faster and better learning in comparison to traditional methods and strengthens spatial memory through its interactive interface. Meng et al. (2013) developed a magic mirror system for anatomy education and concluded that the system offers a good anatomical visualization. Similarly, Blum et al. (2012) developed a magic mirror that can be used in the anatomy education of medical school students through AR technology. This system has a motion-based user interface and, among students, arouses the feeling of seeing the anatomical structures of their own bodies while they are in front of the TV screen. This system development study attracted the attention of the individuals using the system for trial purposes. Thomas et al. (2010) received the opinions of 34 medical students to determine the usefulness and usability of the AR learning system they had developed for anatomy education. The students stated that the system was quite useful for understanding the shape and placement of the ventricular system (structures in the brain). While majority of the students found the system useful and easy, some students said that they had difficulty with camera positioning settings. Yeom (2011) developed a system for the presentation of the complex anatomical structures in the abdominal region via AR system and haptic technology. Twenty-three students and one instructor were asked to use and evaluate the system. The users had positive attitudes about the system. Then, attention was focused on medical students' levels of acceptance of and the usability of the system. It was reported that the students found the system practical, easy, and useful (Yeom et al., 2013). Patirupanusara (2012) developed a MagicBook for anatomy course through marker-based AR technology. The study concluded that teaching anatomy by use of this method could be more effective than traditional teaching. Ferrer-Torregrosa et al. (2015) developed a MagicBook for the teaching of anatomy through AR technology and carried out an experimental student with 211 students. At the end of the study, they found that the experimental group was more successful than the control group and the practice was effective in providing attention, generating motivation, triggering independent study, and completing 3D tasks.

Recent developments in mobile technologies have led to AR applications for mobile devices that support anatomy learning with mAR multimedia materials (Gebril et al., 2012; von Jan et al., 2012; Alkhamisi and Monowar, 2013). Mobile device technology and AR technology are both newly developed approaches. Though they have separate uses in the field of education, efforts aimed at integrating these two technologies into one another have gained momentum in recent years. Accordingly, AR applications operating on mobile devices have been developed. However, studies in which these two technologies are used together in the field of medical education are limited in number (Billinghurst and Dünser, 2012).von Jan et al. (2012) combined these two technologies to develop a learning system for forensic medicine education through mAR technology and administered the system to medical students. Groups of four and six medical students studied for thirty minutes using the system, experimental results were compared. The researchers concluded that learning through mAR is more enjoyable, interesting, and effective in comparison to traditional book learning. Jamali et al. (2015) developed a learning tool called Human Anatomy in Mobile Augmented Reality (HuMAR) for the bones of the lower appendicular skeleton. Based on the results of the pilot test with 30 undergraduate students, it was found that students were satisfied with HuMAR in terms of its usability and features; which in turn could have a positive impact in their learning process.

As seen in literature, while the potential advantages of using AR technology in medical education have been highlighted in the literature, only a limited number of experimental studies have been conducted. The present study tested mAR applications and investigated the potential advantages of AR technology and mobile learning approaches for medical education. Anatomy lessons in medical faculties involve the transmission of a tremendous volume of knowledge that is impossible to convey in the classroom. Furthermore, conveying too much information in a short time may cause increased cognitive load among students. As cognitive load is closely associated with learning performance, it must be taken into consideration during anatomy education. Also, the concept of learner's cognitive load capacity is one area of image-coupled pedagogy that is receiving increasing attention in anatomy education. There is need to comprehensive and practical studies in this field (Wilson, 2015). In this study, it is focused on reducing cognitive load of students using cognitive theory of multimedia learning and cognitive load theory principles in designing instructional materials (Paas et al., 2003; Mayer, 2009). Conversely, a neuroanatomy subject which medical students have difficulty with was focused on in the present study. While learning this subject, it is impossible for students to see relevant anatomical structures over models and cadavers. Thus, applications making this subject concrete are needed by students (Chariker et al., 2012). In addition, the individual learning of students has to be supported on subjects of this sort with difficult, complex, and intensive content. Although there have been a variety of technological interventions in education, there has been a lack of adoption of mAR technology (Azuma et al., 2011). In addition, many of the previous studies (Chu et al., 2010; Tsai et al., 2012) state that mAR technology has been ignored in the learning environment in general, and particularly at the university level. Based on these studies, the role of mAR as part of the teaching and learning process has not been sufficiently investigated (Hwang et al., 2008; Wu et al., 2013; Jamali et al., 2015). In this regard, the current study aims to show the effects of learning anatomy via mAR on the academic achievement and cognitive load of medical students.

METHODS

This study employed a true experimental, concurrent nested mixed method design. In this design, both quantitative and qualitative data are collected simultaneously. The true experimental research method was used to determine the effects of learning anatomy via mAR on the academic achievement and cognitive load of medical students. In this experiment, subjects were randomly assigned to experimental and control groups to reduce any potential sample bias, which allows for the establishment of a clearcause and effect relationship. (Fraenkel et al., 2012). In the case of this study emphasis was given to the quantitative data. The interviews carried out with experimental group students to gain additional insights.

Participants Sample

The study group consisted of 70 students drawn from a pool of 263 second year medical students at Ataturk University in Turkey who were randomly assigned to either the experimental group or the control group. Training and education in Ataturk University Medical School consists of 6 years of medical education and one English Preparatory year. Anatomy is taught in the first 2 years of the course via an integrated systems-based approach with concurrent teaching in anatomy, histology, embryology, physiology, and radiology clinical disciplines. The anatomy course curriculum covers all aspects of human functional and clinical gross anatomy. The Human Anatomy Laboratory is a far-reaching survey of human anatomy. Each laboratory section of 80 students on four dissection tables is taught by a graduate teaching assistant (or sometimes a member of the faculty), with the aid of an undergraduate teaching assistant. Each week, students in the human anatomy laboratory participate in two four-hour laboratory sessions. An oustanding feature of this course is the use of real human cadavers, supplemented with plastic models and other materials. The cadavers are dissected by students and studied extensively, allowing for a true understanding of and valuable knowledge of the complexities of the human body. The medical school possesses an average of one cadaver per 100 students. Although the material studied in anatomy has not changed much over time, the advancements in technology and instruction have come a long way. The aim of the study was to provide exploring bodily systems in depth through augmented reality experience and understanding their interrelationships spatially—a learning experience previously only accessible in a gross anatomy laboratory to students.

Prior to the study, this study was presented to and approved by the Ataturk University Medical Faculty ethic committee. Forty students with smartphones were randomly assigned to the experimental group and forty students to the control group. In this study, random sampling method was used, in which each and every member of the population had an equal and independent chance of being selected. If the sample is large, this method is the best way to obtain a sample representative of the population of interest. In addition, statistical matching was completed according to the anatomy achievement levels of the students from the previous semester to ensure skill level equality.

The number of students who participated in all stages of the study and from whom data were collected was 34 in the experimental group (16 females and 18 males) and 36 in the control group (20 females and 16 males). All of whom had volunteered to be subjects. Before the experiment, the two groups took a pre-test to ensure that they had equal abilities in this subject. The *t*-test result showed that these two groups did not differ significant ($P = 0.821$); that is, the two groups of students had statistically equivalent abilities before learning the subject unit. Demographic informations of the groups were presented Table 2.

Research Process

First of all, interviews were conducted with the instructor and higher grade students to choose the subject to be focused on in the study. Attention was focused on those subjects which students have difficulty with and which require the

Table 2.

Demographic Informations of Groups

Groups	Age (years)	Level	Female	Male	Total
Experimental	18-21	Second-year undergraduate medical students	16	18	34
Treatment	18-21	Second-year undergraduate medical students	20	16	36

support of multimedia materials. At the end of the interviews, Medulla Spinalis was determined to be the subject students have most difficulty with. The reason was stated to be lack of models for the subject and its abstract nature. Therefore, it was decided to focus on "Medulla Spinalis Ascending and Descending Pathways," which are included in the committee examination on the nervous system. Accordingly, mAR applications were created on the subject of neuroanatomy, specifically on ascending and descending pathways. The study's mAR multimedia materials consisted of 3D video animations (six animations lasting three to five minutes), a 3D human anatomy model, and two diagrams. These materials were prepared according to the cognitive theory of multimedia learning and cognitive load theory for reducing cognitive loads of students both experimental and treatment groups (Paas et al., 2003; Mayer, 2009; Wilson, 2015). It is suggested a triarchic model of cognitive load highlighting intrinsic, germane and extraneous cognitive processing, describing how each can separately draw on the learners' cognitive capacity. To be specific, intrinsic load is directly related to the nature of the content complexity delivered to the learners. Extraneous load can be referred to the extraneous elements designated during the instruction and germane (effective) load refers to the extra effort devoted by the learners to facilitate learning (Paas et al., 2003). It is considered pretraining, segmentation and modality principles which are highly important guide for effective presentation and visualizations to mediate intrinsic overload. The coherence, signaling, redundancy spatial, and temporal cogniguity principles were applied to reduce extraneous load. The principles of multimedia, personalization, voice and image were considered to encourage environments that facilitate german loads (Wilson, 2015).

Axiom Neuro, version 1.0 (Brainwashed Software LLC, Cleveland Heights, OH), Neuromatiq, version 1.0 (Faculty of Medicine and Pharmacy of Fes, Fes, Morocco), and Anatomy 4D (DAQRI, Los Angeles, CA) softwares were used. These multimedia materials were combined in the printed book with Aurasma application (Hewlett-Packard Development Company, L.P., Houston, TX). Aurasma is a software platform designed for high quantity operation of AR on mobile devices. Moreover, Aurasma provides the tools to create all categories of AR experience. This application is widely used for various types of product delivery in commercials, education and in other fields. Educational materials, including some 2D images to serve as visual markers, were loaded onto the Aurasma platform to create a MagicBook. Students were instructed to load the Aurasma application on their mobile devices so they could access the multimedia materials. Students then used the mobile device's screen to view the augmented or superimposed object. The flow of interaction starts with a marker, such as an image on a book page, scanned by the mobile device's camera. In this application, the image is detected as a marker by its physical dimensions, and the mobile device detects and recognizes it as an assigned marker. When the students use this application while looking pages of the book, they could see multimedia materials appearing on the mobile device scene. The study involved five course hours as well as the students' individual work on the subject. While the instructor used only traditional presentation materials (including 2D pictures, graphs and text) in lessons with the control group, the mAR multimedia materials served as supplements for the experimental group. Same instructor gave a 5 hour (2 hours + 3 hours) course for each group separately. After the lessons were completed, the experimental group studied for the examination using the MagicBook, while the control group students reviewed the traditional book, which contained the same essential knowledge. Figure 1 presents sequence diagram of mAR application used by the experimental group.

Data Collection Tools

An academic achievement test and cognitive load scale were used for data collection. The nine-point Cognitive Load Scale, developed by Paas and Van Merriënboer (1993) and translated into Turkish by Kilic and Karadeniz (2004), was used for measuring the cognitive load of the students individually studying the topic (Supplementary material - Appendix A). The reliability analyses of the scale were made by Paas and Van Merriënboer (1993), and its internal consistency coefficient was found to be 0.82. The Turkish adaptation of the scale was made by Kilic and Karadeniz (2004), and its internal consistency coefficient was found to be 0.90. Paas et al. (2003) emphasize that subjective measures were shown to be reliable and valid. In this study, cognitive load measured with subjective measurement scale. It was a nine-point symmetrical Likert scale. We asked the learner to rate his or her current level of cognitive load at points throughout the studying on a nine-point scale ranging from 1 (extremely low) to 9 (extremely high). In grading the scale; 1–4 load points was evaluated as low cognitive load, and 5–9 load points was evaluated as high cognitive load (Paas and Van Merriënboer, 1993).

An academic achievement test consisting of 30 multiple choice (five-choice) questions was used to measure the academic achievement levels of the students. This test was developed by the second author of this study, an expert in the field, and the questions were selected from the medical faculty question database. This database was used to ensure valid and reliable questions. In addition, the selected questions were checked by two other experts to confirm their content and face validity and necessary corrections were made based on their feedback. Attention was paid to ensure that the academic achievement test involved the learning

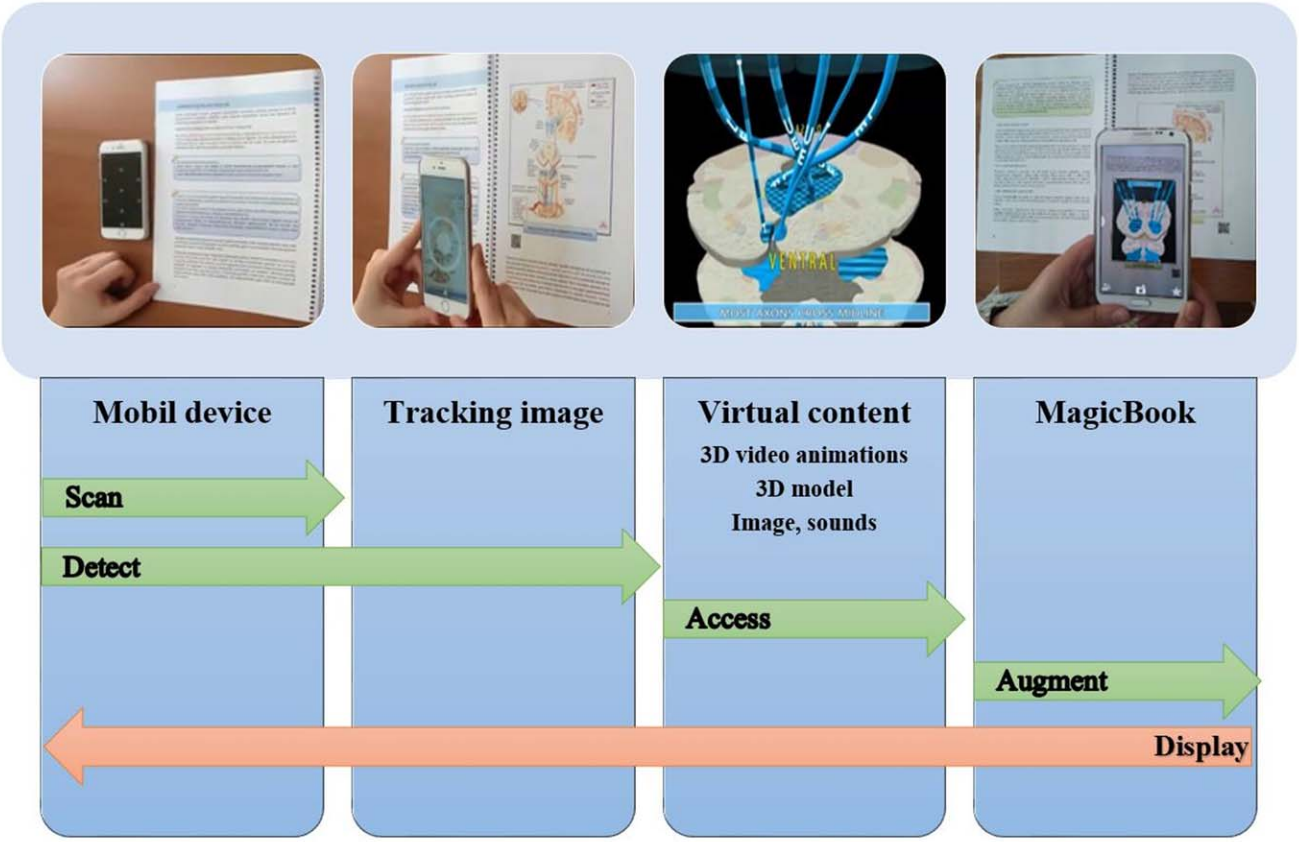

Figure 1.

Sequence diagram of mAR application.

objectives of the entire subject, and a table of specifications was formed to assess content validity. The academic achievement test is presented in the Supplementary material - Appendix B. After the implementation, the Cronbach α reliability test was found to be $\alpha = 0.77$.

After studying the learning materials, students independently filled out the cognitive load scale test and completed the academic achievement test at the same time and in the same monitored environment.

Data Analysis

The data obtained in the study were analyzed via SPSS statistical package, version 18.0 (IBM Corp., Armonk, NY). To compare the results statistically, the *P*-value test was conducted. The *P*-value test is a statistical significance testing method which calculates the probability of obtaining a test statistic result at least as extreme as the one that was actually observed, with the assumption that the null hypothesis is true (Mendenhall and Sincich, 1995). In this experiment, the null hypothesis was that both groups performed similarly. A one-way MANOVA test was implemented to determine the effects of learning via mAR on academic achievement and cognitive load. In this study, MANOVA test was used because it incorporates two or more dependent variables in the same analysis, thus permitting a more powerful test of differences among means. It is justified only when the researcher has reason to believe correlations exist among the dependent variables (Field, 2009; McMillan, 2010). All assumptions of the MANOVA were satisfied; namely, the sample size, normality/outliers, linearity, equality of variances, collinearity, and singularity (Pallant, 2007; Field, 2009). These assumptions are as follows:

- Sample size: You need to have more cases in each cell than you have dependent variables. The two variables in this study were academic achievement and cognitive load. The minumum required number of cases in each cell in this example is three. In this study, there were many more than the required number of cases per cell.
- Normality and outliers: Dependent variables are normally distributed and there were no outliers in the dataset.
- Linearity: This assumption refers to the presence of a straight-line relationship between each pair of dependent variables. Scatterplots graphs between each pair of variables demonstrate that the assumption of linearity is satisfied.
- Homogenity of variance-covariance matrices: Box's M and Levene's tests' results examined for academic achievement and cognitive load; Box's M test result ($P = 0.50$) Levene's test result ($P_{\text{academic achievement}} = 0.24$, $P_{\text{cognitive load}} = 0.19$).

There is between-group homogeneity of variance ($P > 0.05$).

- Multicollinearity and singularity: MANOVA works best when the dependent variables are only moderately correlated. With low correlations, separate univariate analysis of variance for various dependent variables should be run. When the dependent variables are highly correlated, this is referred to as multicollinearity. Correlations up around 0.8 or 0.9 are reason for concern. In this study, correlation between the dependent variables: experimental group ($r = -0.4$), treatment group ($r = -0.17$).

RESULTS

Effects of Learning via Mobile Augmented Reality on Academic Achievement and Cognitive Load

The Academic Achievement Test (AAT) and the Cognitive Load Scale (CLS) were administered to both the experimental and control group students as a post-test. A one-way MANOVA test was used to determine the effects of learning via mAR on academic achievement and cognitive load. The MANOVA test indicated a significant difference between the experimental group and the control group (Pillai's Trace $= 0.149$, $F_{(2,68)} = 5.87$, $P < 0.05$). As to the impact factor, 15% of the variance in the dependent variables was explained by the group variable.

Since a significant result was obtained on the multivariate test, it was required to check univariate analysis ANOVA to understand the effect of instruction on AAT and CLS scores. The univariate ANOVAs for AAT and CLS scores were both significant. The experimental group students who studied anatomy via mAR (78.14 ±16.19) were found to be statistically significant ($F_{(1.68)} = 7.92$, $P < 0.05$) more successful than the control group students (68.34 ±12.83). Moreover, the experimental group students (3.88 ±1.71) were found to have statistically significant ($F_{(1.68)} = 5.22$, $P < 0.05$) lower cognitive loads in comparison to the control group students (4.86 ±1.85).

The Students' Opinions about the Effects of Learning through Mobile Augmented Reality on Their Academic Achievement and Cognitive Loads

The opinions of the students about the effects of learning anatomy through mAR on their academic achievement and cognitive load were recorded in the study. In response to the question about whether or not learning through MAR facilitated learning the subject, twenty-six of the students (79%) said, "Yes" while eight students (21%) said, "Partially." No student gave the answer, "No" to this question. In the interviews, the students generally stated that their achievement was high though the subject was difficult and the application enhanced their achievement. Moreover, the students said that more permanent learning was achieved in a shorter time. In response to the question whether or not the application reduced their cognitive load, twenty-seven of the students (77%) said, "Yes" while six students (24%) said, "Partially." Conversely, one student (3%) gave the answer, "No" to this question. During the interviews, the students stated that although the subject contained intensive knowledge, they were able to learn the subject without exerting much cognitive effort and the application reduced cognitive load by making the subject concrete.

Some student opinions about the effects of learning via MAR on their academic achievement and cognitive load are as follows;

> "*I think it has improved my achievement. I got 87 points. This is a very high score for me. I normally get 70 to 71. I got 87 points on such a difficult subject. This is very good*" (S3).
>
> "*I absolutely think it has improved my achievement…it was a topic requiring hard work for a long time. It is not an easy subject, but it stuck in my mind easily though I studied a lot*" (S5).
>
> "*…this application has both reduced our study time and made the subject more permanent*" (S8).
>
> "*It has reduced cognitive load to a considerable extent. Normally, it is very difficult to read and repeat lecture notes for a long time. Picturing a subject is very difficult. You have to picture what you read and put it in an appropriate place in your mind. Seeing something which has already been pictured allows faster learning*" (S9).

DISCUSSION

In this study, experimental group students who learned anatomy via mAR applications were more successful than the control group when studying anatomy. Moreover, the experimental group students were satisfied with mAR based anatomy learning. The higher academic achievement of the experimental group students may have resulted from the ability of of AR applications to make content concrete by visualizing abstract structures in 3D and clarifying complex topics (Yuen et al., 2011; Bujak et al., 2013; Wu et al., 2013). Augmented reality technology enhances the effectiveness and attractiveness of teaching learning process by adding new values to traditional books (Lee, 2012; Albrecht et al., 2013a,b; Barraza Castillo et al., 2015). Researchers have stated that AR applications have potential to facilitate learning process and contribute to improving academic achievement in comparison with traditional instructions, which is consistent with the results of the present study. (Chien et al., 2010; Andújar et al., 2011; Chen et al., 2011; von Jan et al., 2012; Ferrer-Torregrosa et al., 2015). The sensory experience and real time environmental interaction can provide learning satisfaction and enable students to structure their knowledge and complete the learning tasks (Dunleavy et al., 2009; Dalgarno and Lee, 2010; Chiang et al., 2014).

The present study involved a mobile learning application. Mobile learning activities provide a flexibility that allows students to learn anytime and anywhere they want (Kamphuis et al., 2014). This flexibility also supports the learning of students based on their own paces and styles (Bujak et al., 2013). The positive effect of learning via mAR on the academic achievement of students may be associated with these potentials of mobile learning. Mobile augmented reality provides users with an immersive sensory experience by integrating digital data into real environment (Hwang et al., 2008; Hwang et al., 2009; Chiang et al., 2014). A number of researchers have documented that mAR devices improve the success rate of physical interaction-related learning tasks, support memory related learning activities and enable personalized and self-directed learning (Dunleavy et al., 2009; Looia et al., 2009; Chien et al., 2010; Shirazi and Behzadan, 2015). In this study, AR technology was presented using mobile devices to increase interest and engagement in the learning process and thus provide higher academic achievement and lower cognitive load. The mAR technology mobilizes the learning environment irrespective of location and time, allowing for flexibility of learning in higher education (Jamali et al., 2015).

The data obtained in the present study indicate that cognitive load was significant lower for the experimental group students who learned via mAR than for the control group students. Evidence indicates that there is a considerable cognitive effort required to assimilate anatomical structures and their relationships (Garg et al., 2002; Seixas-Mikelus et al., 2010; Moxham et al., 2011). Such a positive result can be explained by spatial and temporal continuity principles of the cognitive theory of multimedia leaning (Mayer, 2009; Wilson, 2015). Namely, learning from systems that present relevant materials (e.g., images, texts, videos) in a well integrated and organized form can avoid incidental cognitive load and benefit students by improving their learning performance (Chiang et al., 2014). Findings in the literature have also reported that when AR applications are well designed, better learning can be achieved with less cognitive effort (Di Serio et al., 2012; Iordache et al., 2012).

To better understand cognitive load measurement findings, we should focus on three kinds of cognitive processing that can contribute to cognitive load; intrinsic, extraneous, and germane load. As learning environment design is directly related the way extraneous and germane cognitive loads are formed in the mind, how materials such as images, graphs, and animations are used in multimedia applications must be considered to make learning more effective (Brünken et al., 2003; Paas et al., 2003: Anglin et al., 2004; Wilson, 2015). The topic of the present study, neuroanatomy, may have increased the intrinsic cognitive load of students because it is complex and difficult. However, cognitive load may also have been affected because measures were taken with the mAR applications to reduce extraneous cognitive load, which is directly related to instructional design. The cognitive load of students may have reduced because they saw the abstract information made concrete through the 3D animations of the mAR applications. In the study, MagicBook allowed the information to be received via verbal and visual senses, which transferred information from sensory to working memory and helped students integrate it with their prior knowledge and it to their long-term memory (Shirazi and Behzadan, 2015). Moreover, the MagicBook and mAR applications allowed the students to access information instantly while their minds were engaged with the topic, thus requiring less cognitive effort. Today's medical students are becoming increasingly proficient in using computer resources throughout their education. Moreover, they are growing up with technological tools embedded in their daily lives. Thus, it is necessary to integrate complementary technologies that can be exploited to enhance or create new types of learning environments for students and teachers (Barraza Castillo et al., 2015).

Study Limitation

The present study involved the use of mAR applications to enrich anatomy learning. Although the mAR based anatomy learning benefited the students in this study, there are some limitations to be noted. The study was limited to 5 course hours in which "Medulla Spinalis Ascending and Descending Pathways" was covered in the class and out-of-class time when the students engaged in MagicBook involving mAR applications. The necessity of internet connection for the operation of mAR applications limited the access of some students to the materials. What is more, some students had difficulty in operating some mAR software because of the inadequacy of the technical features of their smart phones. Cognitive load is extremely ductile and changes with environment, which can be a further limitation for study. In addition, it is unknown how much time students were spending with the study materials, which could potentially impact their achievement and cognitive load levels.

CONCLUSIONS

All in all, the medical students who learned via mAR had higher academic achievements and lower cognitive loads. That is, less "cognitive load" yielded more "learning" (Wilson, 2015). In the present study, mAR applications were integrated with printed textbooks. Similar integrations should be investigated with models and anatomy atlases used in anatomy laboratories. Since mAR technology is new, its integration into education will be influenced by different variables (e.g., students, teachers, administration, and universities). Future research could consider the comprehensive process of integrating this technology into medical faculties. In this study, mAR applications allowed for more effective learning in a shorter period. Future research may examine more details of the variables of retention and engagement in the learning process. The present study mostly focused on individual student learning via mobile applications. Future research may focus on the integration of mAR applications with different learning approaches (e.g., problem-based learning, game-based learning, and collaborative learning). Future research may include collaboration among several universities to assess the benefits of mAR in multiple courses using larger and more diverse student populations. Moreover, different learning devices, such as Google Glass (Google Inc., Mountain View, CA) could be used to develop AR applications in anatomy education. Mobile augmented reality applications can easily be implemented in the classroom at no additional cost, as most students can use their own mobile devices (Shirazi and Behzadan, 2015). However, one of the main obstacles to integrating AR technology in classrooms is the development of 3D multimedia content (Wasko, 2013; Barraza Castillo et al., 2015). This technology is still underutilized because there are not enough experts available to develop content for their subjects. Instructors do not have the required level of skill needed to develop 3D modelling, programming knowledge and a detailed understanding of the subject for content development (Jamali et al., 2013). In the near future, an AR materials library (e.g., of 3D models, animations, videos, sounds) may be developed for anatomy topics. Instructors would be able to easily find necessary materials for creating AR applications. In general, researchers in educational technology are in agreement that more motivation studies of mAR as a learning method are needed (Lee, 2012; Tarng and Ou, 2012). The students' intrinsic and extrinsic motivations should also be taken into account. The use of this technology could be very effective in motivating students' learning and nurturing their ability to become passionately involved in their own learning process.

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