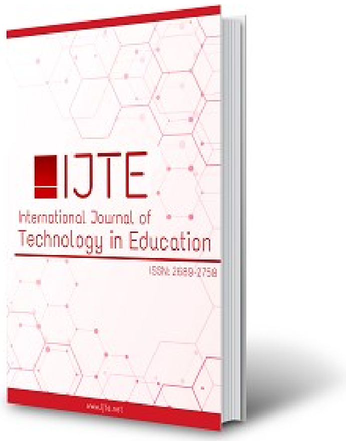

www.ijte.net

Development and Evaluation of an Augmented Reality Microscope for Science Learning: A Design-Based Research

Mustafa Serkan Abdusselam
Giresun University, Turkey

Selcan Kilis
Giresun University, Turkey

To cite this article:

Abdusselam, M. S. & Kilis, S. (2021). Development and evaluation of an augmented reality microscope for science learning: A design-based research. *International Journal of Technology in Education (IJTE), 4*(4), 708-728. https://doi.org/10.46328/ijte.88

International Journal of Technology in Education (IJTE) is affiliated with
International Society for Technology, Education, and Science (ISTES): www.istes.org

IJTE
International Journal of Technology in Education
2021, Vol. 4, No. 4, 708-728 https://doi.org/10.46328/ijte.88

Development and Evaluation of an Augmented Reality Microscope for Science Learning: A Design-Based Research

Mustafa Serkan Abdusselam, Selcan Kilis

Article Info

Article History

Received:
30 December 2020
Accepted:
21 August 2021

Keywords

Augmented reality
Design-based research
Science education
Microscope

Abstract

This study aims to develop and evaluate an augmented reality microscope, "MicrosAR", for a middle school Science course, which was aimed for use both in and out of school, and to understand the users' perceptions about it. The study adopted design-based research to iteratively develop and evaluate the MicrosAR. Learning activities and working handouts in the application were grounded upon inquiry-based learning. The initial prototype was evaluated with 99 middle school students, as well as 18 preservice and six experienced in-service science teachers. The second prototype was then evaluated with 96 different middle school students. Accordingly, design changes were applied to the second prototype to present the final product development. Participants' experiences and perceptions were gathered through a self-developed, paper-based instrument after they practiced with the MicrosAR. The findings indicated that the MicrosAR was favored by and recognized as an effective and useful tool by the participants. The study highlighted the benefits that augmented reality technology and such an application can offer for learning purposes, and that it can be practiced at any place to deliver a "real" learning experience over virtual platforms, thereby saving costs, enhancing its availability, and improved learner interest.

Introduction

There has been an increasing trend in the use of virtual reality, augmented reality, and robotics as the evolution of theories and science progresses (Plakitsi, 2013). As such, a Horizon report highlighted that augmented reality (AR) has become significant in the field of educational technology (Johnson et al., 2015). AR, especially, has taken on an important role in both classroom-based (Dunleavy & Dede, 2014) and laboratory-based learning activities (Chang & Hwang, 2018). Through the integration of AR, new applications have been developed which has seen microscopes now frequently used within digitalized learning environments (Hedvat, 2010), and technological development offering simulations in science teaching through the integration of ultra-high-resolution displays (Randell et al., 2013). Applications such as these were seen first in the healthcare field (Edwards et al. 2000), and then later in science museums (Tan et al., 2008), and mobile environments (Sueda et al., 2011).

Since AR can be employed to create a perfect combination of reality and virtuality, it can deliver real-time interaction within a three-dimensional (3D) world (Azuma, 1997). This ensures human-computer interaction is maintained at the highest level, with AR-supported learning environments providing students with enjoyable forms of learning (Huang et al., 2016). Using AR technology within a learning environment grounded on inquiry-based learning (IBL), learners can conduct various IBL activities and experiments by controlling and interacting within a 3D model using markers (Lazoudis, 2011), and as such, AR tools have become significant and supplementary tools in today's learning. Moreover, students have reported a generally positive attitude toward AR learning environments (Cai et al., 2014). When examining the literature, few examples can be found of new technological applications developed with AR, although their integration into gamified and real-world visualized learning environments is expected (Lee & Tsai, 2013). Considering this, the current study aims to design, develop, and evaluate an augmented reality microscope, "MicrosAR", for a middle school Science course grounded upon inquiry-based learning.

Literature Review

Augmented reality can have a significant effect as it creates an enhanced "reality," bridging the virtual and real worlds in a single combined environment (Bronack, 2011; Klopfer & Squire, 2008). AR can be defined as a combination of the real and the virtual, and in this way contains more real than virtual by providing additional and contextual information which augments learners' experiences of reality (Squire & Klopfer, 2007). AR can be implemented through the application of various technologies and tools such as mobile telephony devices, desktop computers, and tablet personal computers (Broll et al., 2008). In particular, AR applications that have been based especially on desktop computer environments have started to be developed focusing on Tangible User Interfaces (TUIs) (Cuendet et al., 2013).

Augmented Reality in Education

AR has recently started to be recognized within the educational process, enabling learners to attain improved learning performance, as well as increased learners' motivation and engagement (Bacca et al., 2014; Tobar-Muñoz et al., 2017). Additionally, learners are better able to visualize complex spatial associations and abstract concepts or phenomena (Arvanitis et al., 2009; Chen, 2019; Herrera et al., 2019), allowed discovering new knowledge, and to practice situations or events deemed not otherwise possible in real life (Klopfer & Squire, 2008). Moreover, AR provides an environment in which interaction with both two- and three-dimensional synthetic objects can occur within the augmented reality (Kerawalla et al., 2006). AR can enhance the boundaries of technology-based practices and applications that are deemed not otherwise possible through other technologies or tools (Squire & Jan, 2007; Squire & Klopfer, 2007).

AR can have a recognized positive effect on learning (Kozcu Cakir et al., 2021; Turan & Atila, 2021; Yuen et al., 2011), and the idea of implementing AR within an educational environment appears to be accepted by students and teachers. AR can also be suitable for constructivist orientations (Dunleavy & Dede, 2014), which have been highly stressed for learning in the 21st century. Since AR provides for synchronous and interactive practice, learners have the chance through AR to focus on their cognitive disequilibrium, as well as their critical thinking and investigative skills (Schank & Kozma, 2002).

Considering the affordances, AR is of vital importance in both today's world and the coming years (Johnson, Levine, et al., 2010; Martin et al., 2011; Wu et al., 2013). Recently, in Business Orientation classes, AR applications and games were practiced to enhance students' understanding and concluded with students' positive feedbacks (Johnson, & Westbrooks, 2021). In teaching anatomy, a mobile AR application was developed and practiced with medical faculty students (Kucuk et al., 2015). In the study, students' views toward mobile AR-based technology and learning were examined. The results of the study indicated that students' views were highly positive and their interest in the course increased. More recently, AR applications and models were practiced in medicinal chemistry courses for the students in the doctor of pharmacy (Smith & Friel, 2021). The study concluded that AR learning exercises were received positively by the students and also provided active learning opportunities.

In science education, a more recent study investigated the effects of integrating AR applications into General Biology Laboratory course studying with preservice teachers (Kozcu Cakir et al., 2021). The authors studied "dissection procedures related to the anatomy and functions of heart, brain, kidney, and eye together" (p. 98), utilizing the 5E learning model in mobile AR applications. They concluded that mobile AR applications enhanced preservice teachers' success and learning by making the course more attractive. They suggested using such kinds of applications in teaching Biology. In a chemistry experimental course, a 3D image-based AR learning environment was developed and practiced with lower secondary school students (Wojciechowski & Cellary, 2013). The study examined students' attitudes toward the aforementioned learning environment. It is found that learning in such kind of a learning environment could be attractive and evocative for younger students, and also could provide extra motivation to learn.

Taken together, in science education, the application of AR can realize significant benefits, especially in areas such as microscopic and macroscopic investigation and the visualization of scientific phenomena. AR can be also used in the science laboratory, either to create a virtual laboratory environment or as a combination of the virtual and physical world (Chiu et al., 2015). Previous research has revealed certain benefits to students of augmented/virtual reality laboratories in science or biology education (Chiu et al., 2015; De Jong et al., 2013; Kozcu Cakir et al., 2021; Olympiou & Zacharia, 2012; Zacharia, 2007). In the current study, MicrosAR was developed solely as an augmented reality application grounded upon inquiry-based learning for a middle school science laboratory course. The aforementioned benefits and example applications from the literature are presented in the following subsection according to inquiry-based learning used to direct the development of the MicrosAR product in the current study.

Inquiry-Based Learning

Inquiry-based learning (IBL) is a form of active learning in which students learn and construct knowledge by making discoveries and inquiries from the center of the learning environment and process (Llewellyn, 2002).

Augmented reality contributes to an inquiry by providing information that is contextually relevant to the topic of investigation or question being examined (Bower et al., 2014). With regards to science education, inquiry-based learning (Ibáñez & Delgado-Kloos, 2018) has been used and preferred in both location-based (Chiang et al., 2014), and image-based (Cai et al., 2014; Wojciechowski & Cellary, 2013) AR learning environments.

The IBL 5E learning model, which sits mainly within the constructivist teaching model (Bybee et al., 2006), started to be employed following the emergence of new approaches in education (Carin & Bass, 2001). IBL 5E refers to the names of the five cycles: "engagement," "exploration," "explanation," "elaboration," and "evaluation" (Bybee et al., 2006; Carin & Bass, 2001; Trowbridge et al., 2000). It has been widely established as one of the most powerful techniques in science education since it is grounded on and promotes constructivist and active learning in the process of building or constructing knowledge or meaning (Martin, 2000). Hence, in this study, the research context indicated that the sample course prepared for middle school students of a science class and laboratory-based learning was grounded theoretically on the IBL 5E learning model and that augmented reality was used in the design and development of the application.

In the current study, a user interface for the course material of a middle school Science course was designed along with general design principles and to provide an opportunity for students to inquiry about their learning. Within the design, a platform interface was developed through which students can examine microscopic organisms, record microscopic visualizations, take notes about their learning experiences of microscopic organisms, make comparisons about microscopic visualizations, and also share their notes and/or comparisons across different web platforms through peer communication. Therefore, the MicrosAR was developed to accommodate all these features, with learning activities specifically grounded on inquiry-based learning through two experts' opinions. Students can make discoveries and inquiries to construct knowledge through the MicrosAR. On a broader level, the aforementioned 5E learning model was applied through the developed materials, the working handouts, and class activities. Further background information can be obtained from earlier research introducing a sample IBL 5E learning model lesson with the MicrosAR (Abdusselam et al., 2018).

Augmented Reality Microscopes in Science Education

When examining the literature, Tan et al. (2008) developed applications that provided a material overview for science museums in the United Kingdom to encourage a positive attitude in learners toward science. The sample application developed in their study was a web-based microscope that introduces and teaches microscopic living things and objects to users through six-times zoom microscopic visualizations recorded within the web-based system. In another study, Sueda et al. (2011) introduced a mobile-based AR integrated lens application to students' mobile devices to be used as a microscope. The application was designed by placing markers on microscopic organisms. Then, by way of connecting microscope apparatus to mobile devices, microscopic organisms could be examined. Other studies have provided learners with an interactive environment that included real interaction with microscopic creatures through a developed interface (e.g., Lee et al., 2015). This allowed learners to directly and actively interact with these microorganisms by drawing patterns based on their real-time enlarged visualizations on mobile device screens.

In another study, an accessible, low-cost educational kit was developed using Scratch programming language for biophysical modeling based on easy construction and expansion (Kim et al., 2016), and which revealed a level of educational potential and benefit. The findings of the study also indicated that microbiology could be perceived as being more tangible to learners due to such an interactive experience being incorporated into observational microscopy. In a more recent study (Hung et al., 2017), six different bacteria were studied to demonstrate their characteristics using two-dimensional graphics, as well as three-dimensional physical and virtual objects to teach fifth-grade students the respective names of each sample within 1-3 minutes.

To summarize, previous research guided the baseline for the current study. The application developed in the current study, “MicrosAR”, is similar to previous studies using microscopes, with comparable technology used in designing the application interfaced with “augmented reality”, and the primary feature of the design process of being “zoom in on” and to enlarge the visualization of microorganisms”. MicrosAR, however, differs from the previous studies as it supports mobile platforms (e.g., smartphones) and interactive smartboards, in addition to desktop applications such as seen in the study of Tan et al. (2008). Moreover, MicrosAR can be used without the need for additional hardware or software, unlike in previous studies (e.g., Kim et al., 2016; Lee et al., 2015; Sueda et al., 2011). Therefore, MicrosAR can support both in-class and out-of-class student activities at a higher level. The benefits of the developed application include the opportunity to use a microscope with AR, transforming microscopes to have mobile functionality, facilitating examination of more than one organism at a time, recording, save and share the visualizations of microscopic examinations. It also helps students to attain skills in using an optical microscope and offers the opportunity of using the required hardware and apparatus with augmented reality. In the following subsection, the MicrosAR application is introduced, along with its user interface, features, and functionality.

MicrosAR: An Augmented Reality Microscope, Its Interface, and the Features

MicrosAR is an augmented reality microscope developed for middle school students’ usage in a laboratory-based Science course. The AR application was developed on the Unity platform using the Vuforia SDK developer portal for camera and marker control. The theoretical background is founded on IBL for teaching and learning purposes. The objective of the application is for students to gain and develop microscope usage skills according to their Science course learning objectives by utilizing a technology-rich application called MicrosAR, an application that can be used both through mobile devices and interactive smartboards for educational purposes. The naming of the application, “MicrosAR”, is based on “Micros” for microscopic organisms, and “AR” for the technology employed in the development of the application.

Users can investigate microscopic organisms without physically using a microscope by using an application operated through their mobile device (e.g., smartphone), tablet, or desktop computer. In addition, they can gain skills in using a microscope to examine microscopic organisms. MicrosAR has the functionality to examine organisms such as aspergillus, rhizopus sporangia, antinomies bacteria, elodea, the mitotic division of cells in an onion root tip, paramecium, female and male blood flukes, human blood smear, fish blood smear, nerve cells, the lungs and kidneys of mice, and Golgi apparatus. Before describing the usage of MicrosAR within an educational setting, the development and systematic process need to be explained; and Figure 1 illustrates how the AR platform is organized and how the virtual objects are generated.

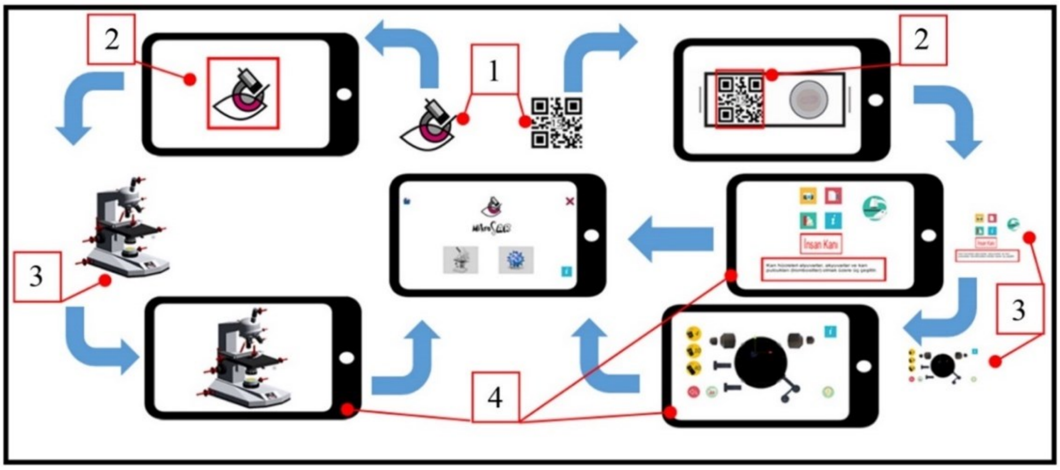

Figure 1. User Interface and Function of the MicrosAR

The cycle and process of the AR platform and how it presents microscopic organisms is illustrated in Figure 1, where “1” represents the trigger of the MicrosAR, “2” the triggering interfaces, “3” virtual objects, and “4” the AR interfaces. For all microscopic organisms, one of the most important elements of the MicrosAR process is the triggers (see Figure 2), which were prepared including lame and lamella in the microscope. The triggers also include a QR code with a number indicating the name of the organism included in the MicrosAR.

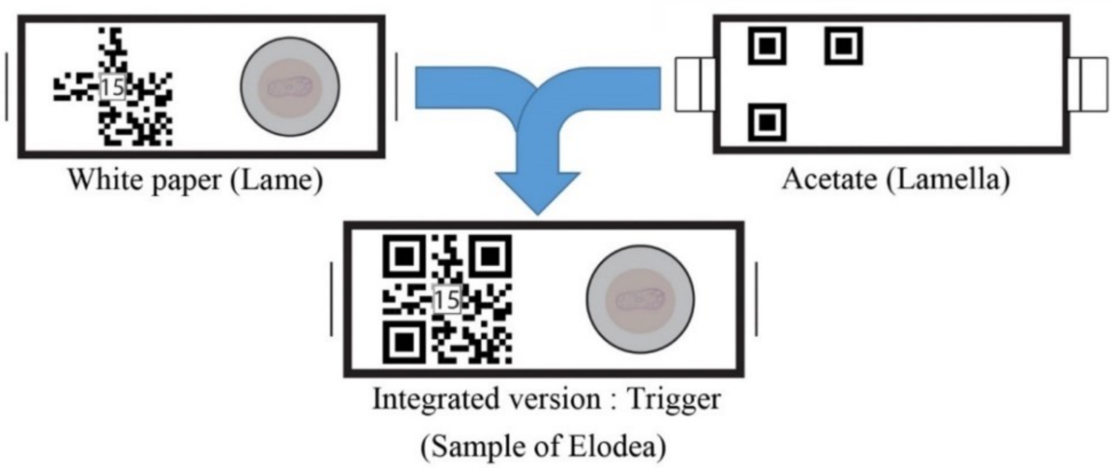

Figure 2. Sample Trigger

A sample trigger (see Figure 2) is made up of white paper (lame) and acetate (lamella). When these two parts are compiled, a QR code is then formed and the application is triggered. Then, when a user performs a microscopic examination, the appropriate visualizations are displayed. For example, an Elodea sample can be seen in Figure 3, based on different magnification levels selected by the user. With MicrosAR, learners are provided with an integrated trigger for ease of use. Triggers can be downloaded via the MicrosAR website (X) and used for training purposes.

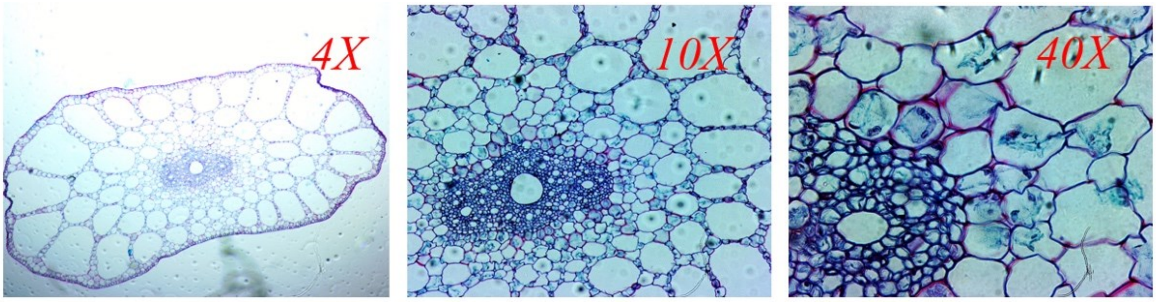

Figure 3. Microscopic Visualization of an Organism at Different Sizes: Sample of Elodea

Different interfaces were developed for the varied functionality of the MicrosAR (see Figure 1). The interface at the center of Figure 1 is the initial screen presented to users. The screen includes a Message panel button, an Exit button, the means to enter the application to undertake a microscopic examination, and to access the collection of organism images included within the application. While examining organisms, users can turn a light on if they need and, using Back, X-, Y-, and Z-coordinate buttons, users can also rotate the microscope's view. Back and Refresh buttons can be used to go navigate back or to revert the microscope's position to that before the viewpoint having been changed. Users can also examine organisms at different magnification scales (4X, 10X, and 40X), focus on a specimen using either coarse or fine focus controls, and also move the view either to the right or to the left (see Figure 4).

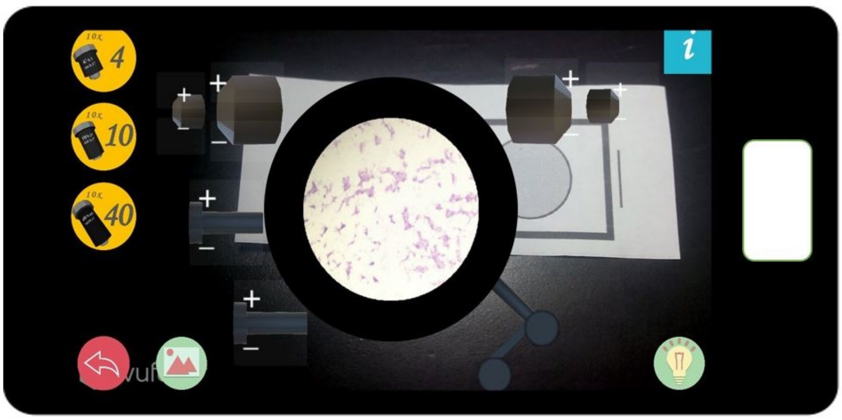

Figure 4. An Examination Screen

Users can access a collection of organisms, take notes, and also record their notes or screenshots to their library, as well as making comparisons between two samples' screenshots and notes (see Figure 5). Users can also share screenshots through social media platforms. If required, MicrosAR users can access basic information about each organism included in the application.

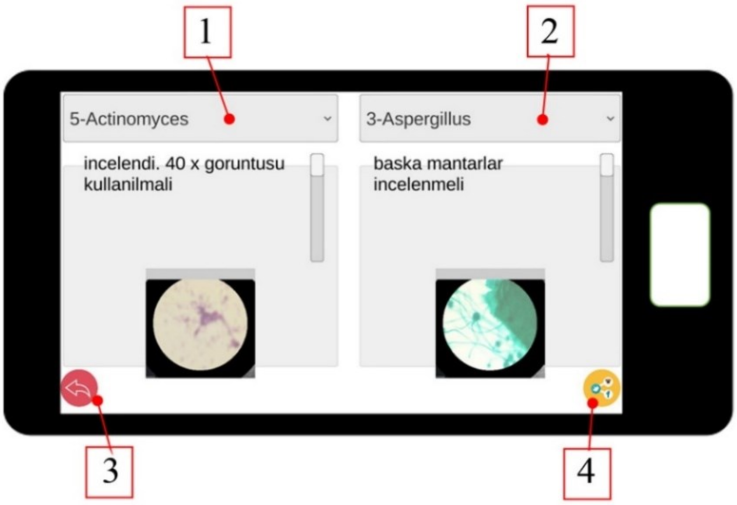

Figure 5. A Comparison Screen

In Figure 5, a comparison screen is presented in which "1" and "2" indicate organisms included within the application, "3" is the Back button, and "4" is the Share button, which can be used for sharing snapshots taken by users on social media platforms during the 3D microscopic examination of organisms. Users can practice using the MicrosAR via a web-based application on desktop or tablet computers, as well as on smartphones. The MicrosAR website includes learners' worksheets, triggers, and both Windows-based and Android-based application download links.

Overall, considering the lack of similar examples in the literature, this augmented reality microscope is expected to contribute significantly to the literature. Adopting design-based research, which is accepted as the appropriate methodology for the designing of new tools and products for learning (Wang & Hannafin, 2005), the purpose of this research is to iteratively develop and evaluate an augmented reality microscope to deliver benefit in learning science. Hence, the main research question is, "What are the users' perceptions of the MicrosAR in learning science?" The following section describes the research methodology of the study.

Method

Research Design

This study adopts design-based research (DBR) approach, which is also known as educational design research. DBR was defined as "a systematic but flexible methodology aimed to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings, and leading to contextually-sensitive design principles and theories" (Wang & Hannafin, 2005, pp. 6-7). Seels and Richey (1994) referred to DBR as developmental research, defining it as "the systematic study of designing, developing and evaluating instructional programs, processes, and products that must meet the criteria of internal consistency and effectiveness" (p. 127). According to McKenney and Reeves (2012), DBR research includes a three-core process; investigation/analysis, design prototyping, and evaluation/retrospection. Based on these different statements, the DBR cycles of this study are presented in Figure 6.

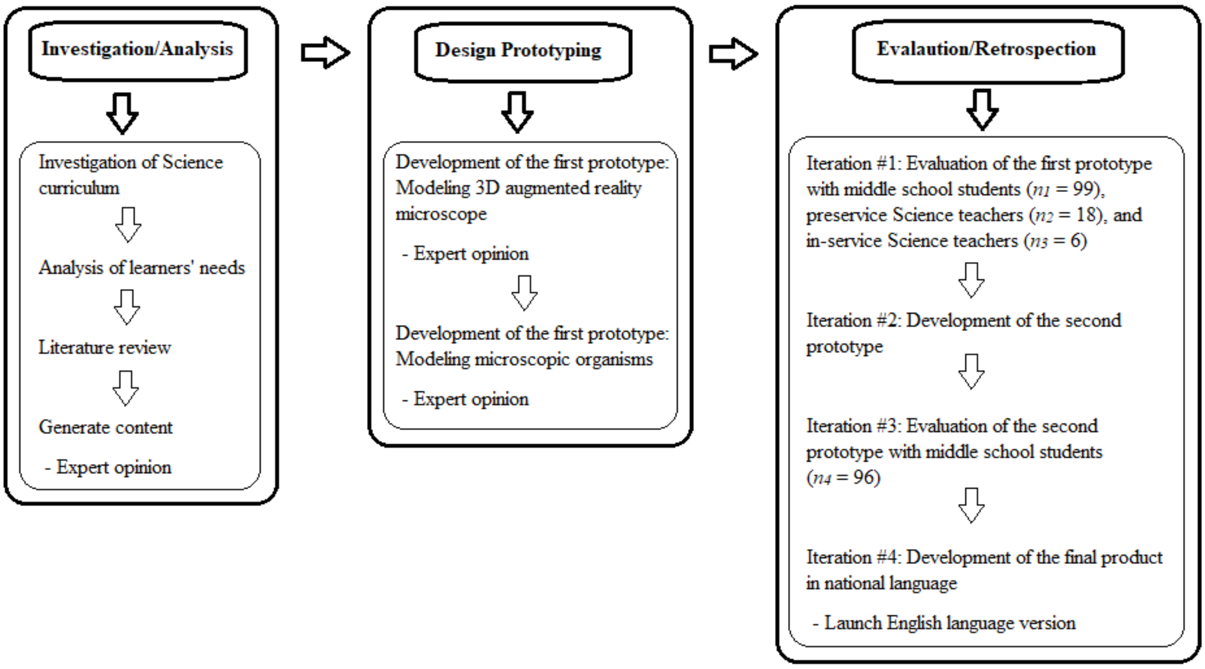

Figure 6. Design-Based Research Cycles of the Study

The iterative design steps of the current study are presented as shown in Figure 6. As can be seen, three core steps were executed in adopting a design-based research approach. The first core process of the DBR includes the investigation/analysis stages. This cycle commenced with an investigation of the Turkish Science curriculum, an analysis of the learners' needs and learning objectives, and a review of the current literature. The content was then generated and two expert opinions were taken. One expert was an in-service Science teacher with 15 years of teaching experience, who had worked in different types of schools including public and college. The other expert had a science-based doctoral degree, and 14 years of teaching experience at the higher education level.

The second core process of the DBR included the design prototyping, modeling the augmented reality microscope, and modeling the microscopic organisms included in the application. A set of lame and lamella, including 100 organisms prepared for commercial application, were included. Based on expert opinion, 16 of these organisms were selected for microscopic examination by a research center laboratorian to record the microscopic visualizations. Expert opinion was then sought with regards to the generated content, as well as regarding the principles of the microscope to be modeled, the monocular optical microscope, the location and functions of its various features, lighting within the microscope, and the design of 3D augmented reality microscopes. The microscopic organisms included in the Science course curricula were then selected by the experts, and the microscopic organisms were modeled for student users to be able to use the microscope and to make microscopic examinations using 4X, 10X, and 40X magnification lenses. The user interface was explained to the students before comparing the microscopic examinations, as well as how to discuss and share these organism examinations via different web platforms. Expert opinion was again sought before completion of the developed application and its upload to the Google Play Store.

The third and final core process of the DBR included four iterations. The first iteration included an evaluation of the initial prototype with middle school students, preservice science teachers, and in-service science teachers. According to their opinions and perceptions, the application was redesigned and updated accordingly during the second iteration to form the second prototype. In the third iteration, the second prototype was evaluated with a different set of middle school students. In the fourth iteration, the final product was developed according to the opinions and perceptions of the students who evaluated the second prototype. In the final iteration, after the final product had been launched, an English language version was also developed.

Participants

The participants were selected through convenience sampling, one of the non-probability sampling techniques. In the first stage of data collection, 99 middle school students, 18 preservice Science teachers, and six in-service Science teachers participated in the evaluation of the first prototype. In the second stage of data collection, 96 different middle school students participated by evaluating the second prototype. The primary focus was on the students' learning; hence the participants were predominantly students rather than either preservice or in-service teachers. For this reason, only the students' demographic information is provided in Table 1.

Table 1. Students' Demographic Information

	Frequency (n)		Percentage value (%)	
	First	Second	First	Second
Gender				
Female	52	53	53	55
Male	47	43	41	45
Grade level				
Grade 5	25	22	25	23
Grade 6	27	27	27	28
Grade 7	23	24	23	25
Grade 8	24	23	24	24
Age (years)				
10	7	5	7	5
11	19	22	19	23
12	35	23	35	24
13	12	19	12	20
14	26	23	26	24
15	0	1	0	1

$N_{first} = 99$, $N_{second} = 96$.

As can be seen in Table 1, the students' grade level varied with mostly equal distribution across all four middle school grades, both at the first and the second participatory stages. Of the 99 students in the first stage, apart from three who did not respond, the majority (85%, $n = 84$) stated that they had already used a microscope, while the remainder (12%, *n* = 12) had not. They were also asked about their skills and capability in examining organisms using a microscope. A total of 96 students responded to this question, with most (71%, *n* = 71) declaring that they had an adequate capability in examining microscopic organisms under a microscope, whereas one quarter (25%, *n* = 25) did not evaluate themselves as being capable. Another question posed was regarding their usage of tablet computers and/or smartphones. Similarly, the majority of students (71%, *n* = 71) stated that they used these mobile devices, whereas 27% (*n* = 27) stated that they did not, and two students did not respond to the question.

Regarding the non-student participants in the first stage, there were in total 18 preservice teachers, 13 of whom were female and five males. Of those 18, a total of 10 were third-year students, and eight were fourth-year students at the Department of Elementary Science Education of a state university in Turkey. Their ages ranged from 19 to 26 years old. Additionally, six experienced in-service Science teachers took part in the first stage of data collection; two of whom were female and four males. Their ages were not provided. All of the in-service teachers had been working in state schools, and their levels of experience ranged from 15 to 27 years.

In the second stage of data collection, a total of 96 middle school students participated in evaluating the second prototype. Of the 96 students, 55% (*n* = 53) were female and 45% (*n* = 43) male. Their ages ranged from 10 to 15 years old, with most being 12 or 14 years old (both ages: 24%, *n* = 23), followed by those aged 11 years old (23%, *n* = 22). Of the 96 students, most (91%, *n* = 87) stated that they had already used a microscope in the past, whilst eight (8%) had not, and one student did not respond. Most students (78%, *n* = 75) declared having of capability in examining microscopic organisms under a microscope, whereas one fifth (21%, *n* = 20) did not, and one student did not respond. Similarly, the majority (66%, *n* = 63) stated that they used a tablet computer, whereas 31% (*n* = 30) did not, and three students did not respond.

Data Collection Procedure and Instrument

Considering the principles of research ethics, before collecting the data, all of the participants were informed about the study and the process to assure them that their anonymity would be protected and the data held confidentially, and their consent obtained as voluntary participants. The data were collected from test users who had practiced the MicrosAR for two weeks in practicing the first prototype, and one week in practicing the second prototype for four hours per week as part of their laboratory-based Science course at a state middle school. All of them downloaded and installed the augmented reality microscope either to their own devices or to the devices provided for their use during each course session. They were then guided by two instructors in practicing using the application throughout the course sessions. After having practiced using the MicrosAR four-hour weekly for two weeks at the first stage and one week at the second stage, in the process of data collection, the participants were administered a data collection instrument that was prepared by the researchers and revised according to two experts' opinions. The instrument included demographic questions, with four semi-structured questions (SSQ) and four structured questions (SQ) with a three-point Likert item about the developed product. The questions are about their general opinions about the MicrosAR, its advantages and disadvantages, where else they would want to use the application and the reasons, and whether they want to use such kinds of applications in science courses instead of a real microscope. They were also requested to rate the extent to that they agree/disagree with the following items: “I learned how to use the microscope and what I can do through it”, “Using microscope through MicrosAR is easier and more enjoyable”, “I don’t fear about using microscope through MicrosAR” and “Whether the application enhances their learning or not”. The instrument was conducted in the class and the data was collected using a paper-based format during the fall and spring semesters of the 2018-2019 academic year.

Data Analysis

As a requirement of evaluating the first and the second prototypes of this design-based research, both quantitative and qualitative data were collected. The data were analyzed descriptively and also inductively through content analysis. The analysis of the data was checked and additional credibility was provided through the employment of a second-rater. The findings retrieved from the data are presented in the next section.

Results

Evaluation of the First Prototype

The findings indicated that of the 99 respondents, the majority (62%, n = 62) referred to MicrosAR as a “good” and “useful tool.” For example, one student stated that “…being able to examine microscopic organisms without a microscope, thanks to this application, which is perfect!” Other statements by the students included the terms “effective” (12%, n = 12), “favor” (11%, n = 11), “easy to use” (10%, n = 10), “enjoyable” (4%, n = 4), and “informative” (3%, n = 3). On the other hand, only two students stated they did not like the application, but they had not downloaded it and thereby had not practiced with the application. Regarding additional comments and suggestions of the respondents, positive suggestions included a wish for video imaging instead of visuals, the inclusion of visuals rather than downloading, increasing the quality of the visuals, a faster working speed for the application, and the provision of additional examples. The participants also requested simplified usage, and a greater number of organisms available for them to examine using the application.

Negative feedback about the first prototype of the MicrosAR concerned Internet connectivity problems, poor quality visuals, and unsatisfactory speed of the application’s performance. They also mentioned experiencing difficulties in reading some of the application’s text displayed on the screen. Finally, some suggested that the application be made available via an online platform, rather than having to download and install it locally on a tablet computer or smartphone.

One question concerned the perceived advantages and disadvantages of the MicrosAR. In terms of the advantages, except for four non-respondents, all of the students stated that they favored the application and its affordances. Example statements from the students include, “we can examine any organism easily,” “we can learn about the cells better,” “it makes us closer and more interested in the Science course,” “if we have no (not enough) money and cannot buy a microscope, then we would use this application,” “it offers advantages for our education, it helps make conducting research easier,” and was seen as “…being a portable, practical, and informative tool."

For the disadvantages, 32% (*n* = 32) of the students stated that it presented no disadvantages, whilst 18 did not respond to the question. However, half of the students (50%, *n* = 50) stated that the MicrosAR application presented certain disadvantages. Example statements from those students included, "…works only on Android devices," "…includes only a few bacteria," "it is difficult to focus [the microscope] on a tablet computer," "[has the] possibility of making us technology-addicted," "when we turn the device in some other direction, the microscope's field of view is lost," "it performs only over triggers and does not work elsewhere," and "it does not work correctly sometimes, and should be updated."

Finally, the students were asked about where else they would want to use the application, and a total of 69 students responded. Most of them (50%, *n* = 50) stated that they would use the MicrosAR anywhere. The other responses given were to use it in the home (39%, *n* = 27), at school (17%, *n* = 12), during a Science course (16%, *n* = 11), and in a laboratory setting (4%, *n* = 3).

Regarding the 18-participant preservice and six in-service Science teachers, all of them perceived the MicrosAR as being useful in teaching the middle school Science course. Having all had prior experience in using a real microscope as well as computers or tablet computers, almost all of them declared preferring to use the MicrosAR over that of a real microscope to study in their Science course, whereas seven stated the use of both. Concerns included requiring usage of their own devices and potential problems with regards to the limited camera resolution presented by certain devices. The next subsection presents the development and evaluation of the second prototype based on the findings from the first prototype's evaluation.

Development and Evaluation of the Second Prototype

The second prototype of the MicrosAR was developed based on the feedback of students, preservice, and in-service science teachers regarding the first prototype. First, problems related to the Internet connection were addressed and an Internet network was established. Second, infrastructural problems caused by the school's network, which were limited due to regulatory matters and the Ministry of National Education's rulings such as security and protection protocols, plus certain missing security add-ons, were resolved following the appropriate permission having been received from the school's management, and then the required add-ons were installed. Third, some of the application's buttons (e.g., "light," and "share") that were inactive for the first prototype were revised and enabled for the second prototype. And finally, 13 additional microscopic organisms were prepared and included for the evaluation of the second prototype. After completing all of these revisions, the second prototype was used in practice and evaluated by the second group of middle school students.

The findings indicated that from the total of 96 students in the second group, 93 respondents favored the MicrosAR and referred to it as "an effective and useful tool in the learning process." For example, one student declared that "…it teaches microscope and its facilities, and how it performs; so, it is informative." Most of the students (79%, *n* = 76) declared that the product helped them during their learning, whereas 14 of them were reportedly undecided, and two did not respond. All of the students stated that they favored the MicrosAR for their learning. Some of their sample statements include, “I can examine organisms that I cannot examine under normal conditions,” “there is no fear of breakdown [of the microscope],” and “it provides ease of use and is time-saving,” etc. With regards to the perceived disadvantages, although 9% (n = 9) did not respond, 51% (n = 49) of the students stated that the application had no disadvantages, whilst 40% (n = 38) raised certain disadvantages that were similar to those reported for the first prototype, including limited camera resolution, not being real though very similar, a very simple visual display of microscope and/or organisms, difficulty in launching the application, there only being 16 example organisms, and as a risk in terms of visual (eye) health. Finally, most of the students, as in the evaluation of the first prototype, mentioned that they would be prepared to use the MicrosAR both in and out of school.

Unlike the first prototype, the structured questions were applied in this part. 76 % of the students stated that they learned how to use the microscope. Also, 74% of the participants thought that using a microscope with the MicrosAR is easier and funnier. On the other hand, 63% of the students said that they are no longer afraid of using a microscope after using the MicrosAR. 79% of the students stated their opinion that the MicrosAR is helpful for them in learning science. Based on all of these findings, the final product was developed after incorporating some elements of redesign based on the feedback received from the second prototype’s evaluation, as detailed in the following subsection.

Development of the Final Product

The final product was developed based on the students’ experiences and feedback from evaluating the second prototype of the MicrosAR and then applying certain updates accordingly. A few design issues of the application were addressed in this final stage. A new feature that enables users to point to any desired point on the image was added to the final application so that users were then able to examine all parts of the organism in detail. Second, a new version of the MicrosAR that supported 64-bit processors was developed and published for the Android market as of August 01, 2019, whereby all mobile applications required compatibility with 64-bit architectures. Thus, the development process of the final product in the Turkish language was completed. No further evaluation was conducted having already reached a point of data saturation at the previous stage (evaluation of the second prototype). Finally, an English language version was then developed and launched to the Android market and also to the MicrosAR website. For this, all content and materials were translated into the English language and context for an increased usage through wider dissemination. The following section discusses and concludes the study, as well as disclosing the study’s limitations and providing some direction for suggested future research.

Discussion and Conclusion

In this design-based research, an augmented reality microscope, MicrosAR, was designed and developed according to the requirements of a middle school Science course and was grounded upon inquiry-based learning. The developed product was evaluated at the first stage by students, preservice Science teachers, and in-service

Science teachers, and by a separate cohort of students at the second stage. The evaluations' findings indicated that the MicrosAR product was perceived to be an effective and useful tool in learning Science, helping students to perform microscopic examinations easily and without additional expenditure. In the literature, some previous studies (e.g., Lee et al., 2015; Sueda et al., 2011) had developed similar AR microscopes, but these were deemed to be simpler than the MicrosAR. The previously developed applications each required additional hardware in using the apparatus, resulting in certain financial constraints, as opposed to the MicrosAR that did not require any additional hardware or software, and was thereby proven to be more economical and available to all without additional cost. Additionally, the level of investment in the design and development process of the MicrosAR was also less than the previously developed products aforementioned reported in the literature. Moreover, the MicrosAR application was able to offer users additional features and greater convenience for learning, having been developed based on a learning-by-inquiry approach.

Lee et al. (2015) preferred to zoom and enlarge visualizations of microscopic examinations over real objects; however, zoom and enlargement were not at the microscopic level. In the current study, microscopic examinations at both the "real" and "microscopic" levels were ensured by way of using pre-prepared virtual images. Students are expected to use the microscope during their examination of certain organisms; however, the MicrosAR offers users the opportunity to use the microscope and practice with the developed application on its own before attempting to operate a real microscope.

According to Bacca et al. (2014), using AR in learning facilitates the enhancement of students' engagement, motivation, learning performance, and also the development of a (more) positive attitude toward science. Similarly, a recent study stated that using AR technology may have a potential enhancement of students' learning and attitude toward biology (Weng et al., 2020). Another more recent study concluded that mobile AR applications enhanced students' understanding and learning in Biology, making the course more attractive for them (Kozcu Cakir et al., 2021). The findings of the current study corroborate these earlier works. Additionally, Cai et al. (2014) and Hung et al. (2017) maintained that because students developed a (more) positive attitude, AR applications can be used to a greater extent and even may be preferred over conventional materials. Moreover, the current study was also found to be in line with earlier studies (Bacca et al., 2014; Hung et al., 2017; Sotiriou & Bogner, 2008) that contended AR contributing to the improvement of students' learning in line with increased active engagement, motivation, and interest, by creating a perfect combination of reality and virtuality (Bronack, 2011; Klopfer & Squire, 2008).

The MicrosAR product operates on both mobile devices and also interactive smartboards. In a recent study conducted by Onder and Aydin (2016), a recommendation for further research was offered to prepare materials appropriate for smartboards to increase efficiency, as well as to deliver certain learning gains over the use of smartboards. Since the MicrosAR can be operated in conjunction with a smartboard, it can provide for classroom learning purposes by helping to increase learners' motivation and interest. In such circumstances, MicrosAR can provide clear-cut benefits for teaching due to its availability, zero cost for users, and ease of use, and therefore presents a viable alternative for today's Science and Biology teachers. For this reason, an online seminar was arranged to introduce the MicrosAR, and to demonstrate how to use it, for 14 sciences teachers as volunteer attendees, as well as a face-to-face seminar for 30 preservice science teachers. Considering all materials available on its website and the developed product published on the Android market, interested teachers can use it in their classes.

It was reported that certain lighting and angles can lead to problems or difficulties being experienced by MicrosAR users in the image-based AR, such as recognition failures similar to that reported in the study of Chang and Hwang (2018). In addition, issues such as a preference for a more interactive, attractive, and usable interface, 3D visualization functionality, and users wanting enriched scenarios were also highlighted earlier (Sumadio & Rambli, 2010). The findings of the current study were found to be in line with these issues in that some participants declared the same issues, and could therefore form the focus of future research in this area.

Taken altogether, similar to the current research, many studies indicated that AR technology for teaching and learning is received positively by many students (Smith & Friel, 2021; Turan & Atila, 2021) and teachers, besides; providing a potential enhancement in attitude toward courses (Cai et al., 2014; Hung et al., 2017; Weng et al., 2020), interest (Kucuk et al., 2015), motivation (Wojciechowski & Cellary, 2013), success (Kozcu Cakir et al., 2021), and learning (Weng et al., 2020) for the students. It can provide and/ or enhance active learning (Smith & Friel, 2021) and inquiry-based learning. Ultimately, AR has continuously be more prevalent in many fields due to its affordances and opportunities for teaching and learning purposes.

Limitations and Recommendations

Certain potential limitations exist in this current research. MicrosAR has been developed solely for the Android and Windows platforms at the moment. It could be used to a greater extent and thereby disseminated further if a further version would be developed to include iOS platforms. With regards to microscopic organisms prepared for examination through MicrosAR, there are only 16 microscopic organisms currently, and that may be considered as another limitation. Including a greater number and wider range with more microscopic organisms for this augmented reality microscope is seen as a suggestion for a subsequent version at a later date. Regarding its improvement, generalized usage, and wider dissemination, interested researchers and science teachers are free to use it now within their classroom settings since an English language version has already been published and is available for the Android market. This may open new directions for further research and provide hints for future improvements to the product.

As a concluding remark, the use of AR in the classroom is becoming more prevalent, and as a result, more researchers will likely research in this area, as predicted by Hung et al. (2017). When the facilities and positive effects of AR's usage in education are considered, it is expected that AR will feature much more in science, technology, mathematics, and engineering (STEM) education (Ibáñez & Delgado-Kloos, 2018). Within this context, MicrosAR is expected to aid teachers, instructional designers, as well as researchers interested in STEM or AR.

Acknowledgments

This work was supported by Giresun University, Scientific Research Project under Grant EĞT-BAP-A-160317-57. The authors are also highly appreciative of Çiğdem Şahin Çakır, Zennure Abdüsselam, and Sencer Taşyonar for their contributions, and guidance. The authors would also like to thank Vuforia for providing free development and testing of the application.

References

Abdusselam, M. S., Kilis, S., Şahin Çakır, Ç., & Abdusselam, Z. (2018). Examining microscopic organisms under augmented reality microscope: A 5E learning model lesson. *Science Activities, 55*(1-2), 68-74.

Arvanitis, T. N., Petrou, A., Knight, J. F., Savas, S., Sotiriou, S., Gargalakos, M., & Gialouri, E. (2009). Human factors and qualitative pedagogical evaluation of a mobile augmented reality system for science education used by learners with physical disabilities. *Personal and Ubiquitous Computing*, *13*(3), 243-250. https://doi.org/10.1007/s00779-007-0187-7

Azuma, R. T. (1997). A survey of augmented reality. *Presence: Teleoperators and Virtual Environments, 6*(4), 355-385. https://doi.org/10.1162/pres.1997.6.4.355

Bacca, J., Baldiris, S., Fabregat, R., Graf, S., & Kinshuk. (2014). Augmented reality trends in education: A systematic review of research and applications. *Educational Technology & Society*, *17*(4), 133-149. http://repositorio.minedu.gob.pe/handle/123456789/5029

Bower, M., Howe, C., McCredie, N., Robinson, A., & Grover, D. (2014). Augmented reality in education–cases, places and potentials. *Educational Media International*, *51*(1), 1-15. https://doi.org/10.1080/09523987.2014.889400

Broll, W., Lindt, I., Herbst, I., Ohlenburg, J., Braun, A. K., & Wetzel, R. (2008). Toward next-gen mobile AR games. *IEEE Computer Graphics and Applications*, *28*(4), 40-48. https://doi.org/10.1109/MCG.2008.85

Bronack, S. C. (2011). The role of immersive media in online education. *Journal of Continuing Higher Education, 59*(2), 113-117. https://doi.org/10.1080/07377363.2011.583186

Bybee, R. W., Taylor, J. A., Gardner, A., Van Scotter, P., Powell, J. C., Westbrook, A., & Landes, N. (2006). *The BSCS 5E instructional model: Origins, effectiveness and applications*. Colorado Springs, CO: BSCS. http://www.fremonths.org/ourpages/auto/2008/5/11/1210522036057/bscs5efullreport2006.pdf

Cai, S., Wang, X., & Chiang, F. K. (2014). A case study of augmented reality simulation system application in a chemistry course. *Computers in Human Behavior, 37*, 31-40. https://doi.org/10.1016/j.chb.2014.04.018

Carin, A. A., & Bass, J. E. (2001). *Teaching science as inquiry*. Upper Saddle River, NJ: Prentice Hall.

Chang, S.-C., & Hwang, G.-J. (2018). Impacts of an augmented reality-based flipped learning guiding approach on students' scientific project performance and perceptions. *Computers & Education*, *125*, 226-239. https://doi.org/10.1016/j.compedu.2018.06.007

Chen, Y. (2019). Effect of mobile augmented reality on learning performance, motivation, and math anxiety in a math course. *Journal of Educational Computing Research*, *57*(7), 1695–1722. https://doi.org/10.1177%2F0735633119854036

Chiang, T. H. C., Yang, S. J. H., & Hwang, G.-J. (2014). Students' online interactive patterns in augmented reality-based inquiry activities. *Computers & Education*, *78*, 97-108. https://doi.org/10.1016/j.compedu.2014.05.006

Chiu, J. L., DeJaegher, C. J., & Chao, J. (2015). The effects of augmented virtual science laboratories on middle school students' understanding of gas properties. *Computers & Education*, *85*, 59-73. https://doi.org/10.1016/j.compedu.2015.02.007

Cuendet, S., Bonnard, Q., Do-Lenh, S., & Dillenbourg, P. (2013). Designing augmented reality for the classroom. *Computers & Education*, *68*, 557-569. https://doi.org/10.1016/j.compedu.2013.02.015

De Jong, T., Linn, M. C., & Zacharia, Z. C. (2013). Physical and virtual laboratories in science and engineering education. *Science, 340*(6130), 305-308. https://science.sciencemag.org/content/340/6130/305/tab-pdf

Dunleavy, M., & Dede, C. (2014). Augmented reality teaching and learning. In M. J. Bishop & J. Elen (Eds.), *Handbook of research on educational communications and technology* (4th ed., pp. 735-745). New York, NY: Springer. https://doi.org/10.1007/978-1-4614-3185-5_59

Edwards, P. J., King, A. P., Maurer, C. R., De Cunha, D. A., Hawkes, D. J., Hill, D. L. G., Gaston, R. P., Fenlon, M. R., Jusczyzck, A., Strong, A. J., Chandler, C. L., & Gleeson, M. J. (2000). Design and evaluation of a system for microscope-assisted guided interventions (MAGI). *IEEE Transactions on Medical Imaging*, *19*(11), 1082-1093. https://doi.org/10.1109/42.896784

Hedvat, C. V. (2010). Digital microscopy: Past, present, and future. *Archives of Pathology and Laboratory Medicine*, *134*(11), 1666-1670. https://doi.org/10.1043/2009-0579-RAR1.1

Herrera, L. M., Pérez, J. C., & Ordóñez, S. J. (2019). Developing spatial mathematical skills through 3D tools: Augmented reality, virtual environments and 3D printing. *International Journal on Interactive Design and Manufacturing (IJIDeM)*, 13(4), 1385-1399. https://doi.org/10.1007/s12008-019-00595-2

Huang, T. C., Chen, C. C., & Chou, Y. W. (2016). Animating eco-education: To see, feel, and discover in an augmented reality-based experiential learning environment. *Computers & Education*, 96, 72-82. https://doi.org/10.1016/j.compedu.2016.02.008

Hung, Y.-H., Chen, C.-H., & Huang, S.-W. (2017). Applying augmented reality to enhance learning: A study of different teaching materials. *Journal of Computer Assisted Learning*, *33*(3), 252-266. https://doi.org/10.1111/jcal.12173

Ibáñez, M.-B., & Delgado-Kloos, C. (2018). Augmented reality for STEM learning: A systematic review. *Computers & Education*, *123*, 109-123. https://doi.org/10.1016/j.compedu.2018.05.002

Johnson, K. L., & Westbrooks, K. (2021). Quelling the boredom with alternative instruction: Augmented reality, escape kits, and scavenger hunts. *International Journal on Social and Education Sciences (IJonSES), 3*(1), 180-196. https://doi.org/10.46328/ijonses.65

Johnson, L., Adams Becker, S., Estrada, V., & Freeman, A. (2015). *NMC Horizon report: 2015 K-12 Edition*. Austin, TX: The New Media Consortium. https://www.learntechlib.org/d/182009

Johnson, L. F., Levine, A., Smith, R. S., & Haywood, K. (2010). Key emerging technologies for middle and secondary education. *Education Digest, 76*(1), 36-40.

Kerawalla, L., Luckin, R., Seljeflot, S., & Woolard, A. (2006). "Making it real": Exploring the potential of augmented reality for teaching primary school science. *Virtual Reality, 10*(3), 163-174. https://doi.org/10.1007/s10055-006-0036-4

Kim, H., Gerber, L. C., Chiu, D., Lee, S. A., Cira, N. J., Xia, S. Y., & Riedel-Kruse, I. H. (2016). LudusScope:

Accessible interactive smartphone microscopy for life-science education. *PLOS ONE*, *11*(10), 1-16. https://doi.org/10.1371/journal.pone.0162602

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. http://www.jstor.org/stable/25619918

Kucuk, S., Kapakin, S., & Goktas, Y. (2015). Medical faculty students' views on anatomy learning via mobile augmented reality technology. *Journal of Higher Education & Science, 5*(3), 316-323.

Kozcu Cakir, N., Guven, G., & Celik, C. (2021). Integration of mobile augmented reality (MAR) applications into the 5E learning model in Biology teaching. *International Journal of Technology in Education (IJTE), 4*(1), 93-112. https://doi.org/10.46328/ijte.82

Lazoudis, A. (2011). The "Science Center to Go" project. In A. Lazoudis, H. Salmi, & S. Sotiriou (Eds.), In *Proceedings of the "Science Center To Go" Workshops EDEN - 2011 Open Classroom Conference* (pp 27-29). Athens, Greece: llinogermaniki Agogi.

Lee, S. A., Chung, A. M., Cira, N., & Riedel-Kruse, I. H. (2015). Tangible interactive microbiology for informal science education. In *Proceedings of the Ninth International Conference on Tangible, Embedded, and Embodied Interaction* (pp. 273-280). New York, NY: ACM. https://doi.org/10.1145/2677199.2680561

Lee, S.-W.-Y., & Tsai, C.-C. (2013). Technology-supported learning in secondary and undergraduate biological education: Observations from literature review. *Journal of Science Education and Technology*, *22*(2), 226-233. https://doi.org/10.1007/s10956-012-9388-6

Llewellyn, D. (2002). *Inquiry within: Implementing inquiry-based science standards*. Thousand Oaks, CA: Corwin.

Martin, D. J. (2000). *Elementary science methods: A constructivist approach*. Belmont, CA: Wadsworth, Cengage Learning.

Martin, S., Diaz, G., Sancristobal, E., Gil, R., Castro, M., & Peire, J. (2011). New technology trends in education: Seven years of forecasts and convergence. *Computers & Education, 57*(3), 1893-1906. https://doi.org/10.1016/j.compedu.2011.04.003

McKenney, S., & Reeves, T. C. (2012). *Conducting educational design research*. London: United Kingdom, Routledge.

Olympiou, G., & Zacharia, Z. (2012). Blending physical and virtual manipulatives: An effort to improve students' conceptual understanding through science laboratory experimentation. *Science Education, 96*(1), 21-47. https://doi.org/10.1002/sce.20463

Onder, R., & Aydin, H. (2016). Students' views towards the usage of smart board in Biology lessons. *Journal on School Educational Technology, 11*(3), 18-28. https://doi.org/10.26634/jsch.11.3.4787.

Plakitsi, K. (2013). Rethinking the role of information and communication technologies (ICT) in science education. In K. Plakitsi (Ed.), *Activity theory in formal and informal science education* (pp. 57-81). Rotterdam: Netherlands: Sense.

Randell, R., Ruddle, R. A., Mello-Thoms, C., Thomas, R. G., Quirke, P., & Treanor, D. (2013). Virtual reality microscope versus conventional microscope regarding time to diagnosis: An experimental study. *Histopathology*, *62*(2), 351-358. https://doi.org/10.1111/j.1365-2559.2012.04323.x

Schank, P., & Kozma, R. (2002). Learning chemistry through the use of a representation-based knowledge building environment. *Journal of Computers in Mathematics and Science Teaching*, *21*(3), 253-279. https://www.learntechlib.org/primary/d/9262

Seels, B. B., & Richey, R. C. (1994). *Instructional technology: The definition and domains of the field.* Washington, DC: Association for Educational Communications and Technology.

Smith, C., & Friel, C. J. (2021). Development and use of augmented reality models to teach medicinal chemistry. *Currents in Pharmacy Teaching and Learning, 13*, 1010-1017.

Sotiriou, S., & Bogner, F. X. (2008). Visualizing the invisible: Augmented reality as an innovative science education scheme. *Advanced Science Letters, 1*(1), 114-122. https://doi.org/10.1166/asl.2008.012

Squire, K., & 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. https://www.learntechlib.org/p/76265/

Squire, K., & Klopfer, E. (2007). Augmented reality simulations on handheld computers. *Journal of the Learning Sciences, 16*(3), 371-413. https://doi.org/10.1080/10508400701413435

Sueda, K., Gu, J., Kitazawa, S., & Duh, H. B. L. (2011). Micro AR for education: Using metaphors for familiar actions. In *SIGGRAPH Asia 2011 Emerging Technologies*. New York, NY: ACM.

Sumadio, D. D., & Rambli, D. R. A. (2010). Preliminary evaluation on user acceptance of the augmented reality use for education. In *Proceedings 2010 Second International Conference on Computer Engineering and Applications*, *Balli Island*, (Vol. 2, pp. 461-465). Los Alamitos, CA; IEEE. https://doi.org/10.1109/ICCEA.2010.239

Tan K., Lewis, E., Avis, N., & Withers, P. (2008). Using augmented reality to promote an understanding of materials science to school children. In *Proceedings of ACM SIGGRAPH ASIA 2008 Educators Programme, Singapore, 2,* 1-8. New York, NY: ACM. https://doi.org/10.1145/1507713.1507716

Tobar-Muñoz, H., Baldiris, S., & Fabregat, R. (2017). Augmented reality game-based learning: Enriching students' experience during reading comprehension activities. *Journal of Educational Computing Research*, *55*(7), 901–936. https://doi.org/10.1177%2F0735633116689789

Trowbridge, L. W., Bybee, R. W., & Powell, J. C. (2000). *Teaching secondary school science: Strategies for developing scientific literacy*. Upper Saddle River, NJ: Prentice Hall.

Turan, Z., & Atila, G. (2021). Augmented reality technology in science education for students with specific learning difficulties: its effect on students' learning and views. *Research in Science & Technological Education*, 1-19. https://doi.org/10.1080/02635143.2021.1901682

Wang, F., & Hannafin, M. J. (2005). Design-based research and technology-enhanced learning environments. *Educational Technology Research and Development*, *53*(4), 5-23. https://doi.org/10.1007/BF02504682

Weng, C., Otanga, S., Christianto, S. M., & Chu, R. J.-C. (2020). Enhancing students' biology learning by using augmented reality as a learning supplement. *Journal of Educational Computing Research*, *58*(4), 747–770. https://doi.org/10.1177%2F0735633119884213

Wojciechowski, R., & Cellary, W. (2013). Evaluation of learners' attitude toward learning in ARIES augmented reality environments. *Computers & Education, 68*, 570-585.

Wu, H.-K., Lee, S.-W.-Y., Chang, H.-Y., & Liang, J.-C. (2013). Current status, opportunities and challenges of augmented reality in education. *Computers & Education*, *62*, 41-49. https://doi.org/10.1016/j.compedu.2012.10.024

Yuen, S.-C.-Y., Yaoyuneyong, G., & Johnson, E. (2011). Augmented reality: An overview and five directions for AR in education. *Journal of Educational Technology Development and Exchange*, *4*(1), 119-140. https://aquila.usm.edu/jetde/vol4/iss1/11

Zacharia, Z. C. (2007). Comparing and combining real and virtual experimentation: An effort to enhance students' conceptual understanding of electric circuits. *Journal of Computer Assisted Learning*, *23*(2), 120-132. https://doi.org/10.1111/j.1365-2729.2006.00215.x

Author Information

Mustafa Serkan Abdusselam
https://orcid.org/0000-0002-3253-7932
Giresun University
Giresun
Turkey
Contact e-mail: *mustafa.serkan@giresun.edu.tr*

Selcan Kilis
https://orcid.org/0000-0001-5751-2363
Giresun University
Giresun
Turkey