

# Trends in Educational Augmented Reality Studies: A Systematic Review

Mustafa SIRAKAYA [1], Didem ALSANCAK SIRAKAYA [2]

<http://dx.doi.org/10.17220/mojet.2018.04.005>

[1] Department of Computer Technology, Vocational School of Technical Sciences, Ahi Evran University, Kırşehir, Turkey; Phone: +90386 280 4725; email: mustafasirakaya@gmail.com

[2] Department of Computer Technology, Vocational School of Technical Sciences, Ahi Evran University, Kırşehir, Turkey; Phone: +90386 280 3050; email: alsancakdidem@gmail.com

## ABSTRACT

This study aimed to identify the trends in the studies conducted on Educational Augmented Reality (AR). 105 articles found in ERIC, EBSCOhost and ScinceDirect databases were reviewed with this purpose in mind. Analyses displayed that the number of educational AR studies has increased over the years. Quantitative methods were mostly preferred in those articles and educational AR was often found to be used in science education (physics, chemistry and biology), engineering education and medical training. The reviewed articles showed that “undergraduate students” were used as samples for most of the time, the most often preferred sample size was between “31-100” and “surveys” were the most utilized data collection tools. While the majority of the articles used marker-based AR as AR type, mobile devices were utilized in many of these articles as the delivery technology. It is believed that the results obtained in this study will light the way for future research.

**Keywords:** *educational augmented reality; systematic review; trends in augmented reality*

## INTRODUCTION

Augmented Reality (AR) can be defined as the technology that allows which virtual objects to be interactively overlaid on real time images (Azuma, 1999). Through this technology, virtual objects and real time images are delivered in conjunction and synchronously (Azuma et al., 2001). In AR, virtual data are included in user’s physical environment to enable the user to interact with the virtual content (Azuma, 1997; Milgram & Kishino, 1994). That is to say, in AR, the issue is not a question of replacing the real with virtual as it is the case in virtual reality. AR enhances the real time images with synchronous virtual objects overlaid over them (Billinghurst, 2002; Kerawalla, Luckin, Seljeflot, & Woolard, 2006). Hence, the users can access more information than they would otherwise have obtained through sensory organs.

AR is a technology used in many sectors such as military, medicine, engineering, tourism and advertisement (Wu, Lee, Chang, & Liang, 2013; Yen, Tsai, & Wu, 2013). The fact that it does not require the use of specialized equipment has made it possible for AR to spread rapidly. Although it was a technology that could only be used with devices such as head-mounted-display when it was first launched, it can be easily used today with all computers or mobile devices.

Increase in the number of mobile devices (Wu et al., 2013) and easy access to these devices has made it possible for large masses to utilize AR. This prevalence has taken effect in the field of education as well and especially in recent years, the use of AR for educational purposes has become a significant topic of research (Fleck, Hachet, & Bastien, 2015; Wu et al., 2013). As a matter of fact, Horizon reports cited AR among educational technologies with significant advances (Johnson et al., 2016) which will be widely used in educational environments in a few years (Johnson, Adams, & Cummins, 2012). Review of studies in the literature shows that AR is a technology used in almost all levels of education from kindergarten (Huang, Li, & Fong, 2016), to graduate studies (Carlson & Gagnon, 2016). The studies conducted on AR report that use

of AR for educational purposes has various advantages (Table 1).

**Table 1 Advantages of AR use in educational environments**

Advantages of Educational AR	Researchers
Increases achievement	Chiang, Yang and Hwang (2014) Estapa and Nadolny (2015), Ferrer-Torregrosa, Torralba, Jimenez, Garc'ia and Barcia (2014)
Facilitates learning	Carlson and Gagnon (2016), Kamarainen et al. (2013), Yoon, Elinich, Wang, Steinmeier and Tucker (2012)
Enhances motivation	Chiang et al. (2014), Ferrer-Torregrosa et al. (2014), Solak and Cakir (2015)
Ensures permanent learning	Perez-Lopez and Contero (2013)
Increases interest towards lessons	Chen and Wang (2015), Zhang, Sung, Hou and Chang (2014)
Increases student participation in classes	Bressler and Bodzin (2013), Dunleavy, Dede and Mitchell (2009), Liu and Tsai (2013)
Develops positive attitudes	Akçayır, Akçayır, Pektaş and Ocak (2016), Hwang, Wu, Chen and Tu (2016), Lu and Liu (2015)
Enhances spatial skills	Ho, Chung and Lin (2012), Lin, Chen and Chang (2015)
Ensures cooperative learning	Bressler and Bodzin (2013), Han, Jo, Hyun and So (2015), Martín-Gutiérrez, Fabiani, Benesova, Meneses and Mora (2015)
Ensures learning by having fun	Ibáñez, Di Serio, Villarán and Kloos (2014), Yilmaz (2016)
Decreases cognitive load	Bressler and Bodzin (2013), Küçük, Kapakin and Göktaş (2016)

As Table 1 displays, use of AR for educational purposes has a wide range of advantages. By taking these advantages into consideration, it can be argued that AR is a contemporary technology that can be used to obtain critical learning outcomes (Thornton, Ernst, & Clark, 2012). However, there are also some limitations in using AR for educational purposes. Technical problems experienced while using AR is the leading and most important limitation (Lu & Liu, 2015). Use of location-based AR is generally limited by technical problems experienced about GPS (Cheng & Tsai, 2013; Chiang et al., 2014; Crandall et al., 2015), use of marker-based AR is limited by technical problems experienced about perceiving the marker (Chang et al., 2014). Other limitations include teachers' lack of sufficient information to develop AR materials (Lu & Liu, 2015) and the fact that AR assisted lessons require more time compared to traditional lessons (Gavish et al., 2015).

### ***The Purpose of the Study***

Use of AR technologies in the learning-teaching process provides many conveniences and advantages (Table 1). Continuing to conduct studies related to this topic is imperative to identify affordances and characteristics of educational AR (Wu et al., 2013). Previous studies on educational AR can be used to guide future studies. Therefore, systematic reviews are crucial to present the current situation and to shed light on future studies. Reviewing previous studies assists researchers to make decisions on issues such as topic, method and sampling.

It is possible to find many systematic reviews in literature on use of technology in education (Kucuk, Aydemir, Yildirim, Arpacik, & Goktas, 2013; Pimmer, Mateescu, & Gröhbiel, 2016; Ross, Morrison, & Lowther, 2010). However, there are only a few systematic reviews that examined educational AR studies. While some of these limited number of systematic reviews only investigated the articles in specific journals (Akçayır & Akçayır, 2017; Bacca, Baldiris, Fabregat, Graf, & Kinshuk, 2014), some others examined the articles that

compared the environments with or without AR use (Radu, 2014). There are also systematic reviews in literature that focused on articles on AR related to education in a specific field (science learning) (Cheng & Tsai, 2013). It is observed in these systematic reviews that they usually focus on advantages and limitations of AR use in education. However, more comprehensive reviews are required to identify trends in educational AR studies. This study aimed to bridge the existing gap in literature by analyzing all educational AR studies found in various databases (ERIC, EBSCOhost, ScienceDirect). The study that set out to determine the trends in educational AR studies sought answers to the following questions:

1. What is the distribution of educational AR studies by years?
2. What is the distribution of educational AR studies by research methods that are used?
3. What is the change in the research methods used in educational AR studies by years?
4. What is the distribution of educational AR studies by fields of education?
5. What is the distribution of sample levels preferred in educational AR?
6. What is the distribution of the number of samples educational AR preferred in educational AR?
7. What is the distribution of data collection tools used in educational AR studies?
8. What is the distribution of AR types used in educational AR studies?
9. What is the distribution of delivery technology used in educational AR studies?

## METHOD

This study followed the 5-phase process developed by Arksey and O'Malley (2005) for systematic review studies.

### *Identifying the research questions:*

This study aimed to identify the trends in educational AR studies conducted between the years 2011 and 2016. Research questions were developed subsequent to literature review undertaken for this purpose. Research questions were provided under the heading "The Purpose of the Study".

### *Identifying relevant studies:*

Use of AR in educational environments is a research topic that has recently become popular. Therefore, the review studies that examined educational AR studies are limited in number (Akçayır & Akçayır, 2017; Bacca et al., 2014; Cheng & Tsai, 2013; Radu, 2014). It was construed that the studies that were examined in these systematic reviews were generally selected based on specific journals, methods or research topics. More comprehensive systematic reviews are needed in order to determine trends in educational AR studies. Hence, it was seen fit to examine articles reviewed in different databases in the present study. ERIC, EBSCOhost and ScienceDirect databases were utilized in identifying the related studies. "Augmented reality" keywords were used in database searches in the cited databases. Searches were not filtered according to any criterion other than date (01.01.2011-31.12.2016). It was targeted to access a higher number of AR studies conducted in various fields (engineering, medicine etc.). Key word search provided a list of approximately 2.500 publications.

### *Study Selection*

Studies that were in line with the inclusion and exclusion criteria (Table 2) were selected from among the list of about 2.500 publications. 105 articles were deemed appropriate for the purpose of the study after having being assessed separately by the researchers. Article Review Form (ARF) developed by the researchers was used as data collection tool to examine the articles to be assessed. Researchers made use of the data

collection tool developed by Göktaş et.al. (2012) in developing ARF. For this purpose, the data collection tool developed by Göktaş et.al. (2012) was revised according to the research questions in the present study, ARF was adjusted to be used in this study and finalized in line with the views of 2 field experts ARF is composed of 8 sections. The first section includes copyright information of the article (title, name of author, name of journal, year of publication etc.). Other sections are method, research topic, level of sample, number of sample, data collection tools, AR type and AR delivery technology respectively.

**Table 2 Inclusion and exclusion criteria**

Inclusion	Exclusion
Articles with access to full text were included in the study	Conference proceedings, book chapters or articles with only summaries were excluded from the study.
Articles that approach AR technology for educational purposes (formal or informal) were included in the study. Literature reviews that focus on application development or discussions about educational dimensions of AR were included in the study.	AR studies with no educational dimensions were excluded from the study.
Articles in which AR technologies were used (alone or in conjunction with other environments) were included in the study.	Studies that used environments such as virtual reality etc. although the concept of AR is also mentioned were excluded from the study.

#### **Charting of Data:**

In this phase, examined articles were first coded into Microsoft Excel program with the help of ARF. It was observed that some articles included more than one sample. In such studies, each sample group was separately coded. Data were examined with the help of content analysis method. Content analysis is a method that includes text arrangement, classification of categories, comparison of categories and extraction of theoretical outcomes (Cohen, Manion, & Morrison, 2013). Frequencies and percentage calculations for related data in terms of answering the questions were presented in graphics and tables (please see Results and Discussion Section). Coding and data analysis were done by each researcher separately, in cases results differed from one another, field experts were consulted.

#### **Collating, Summarizing and reporting findings:**

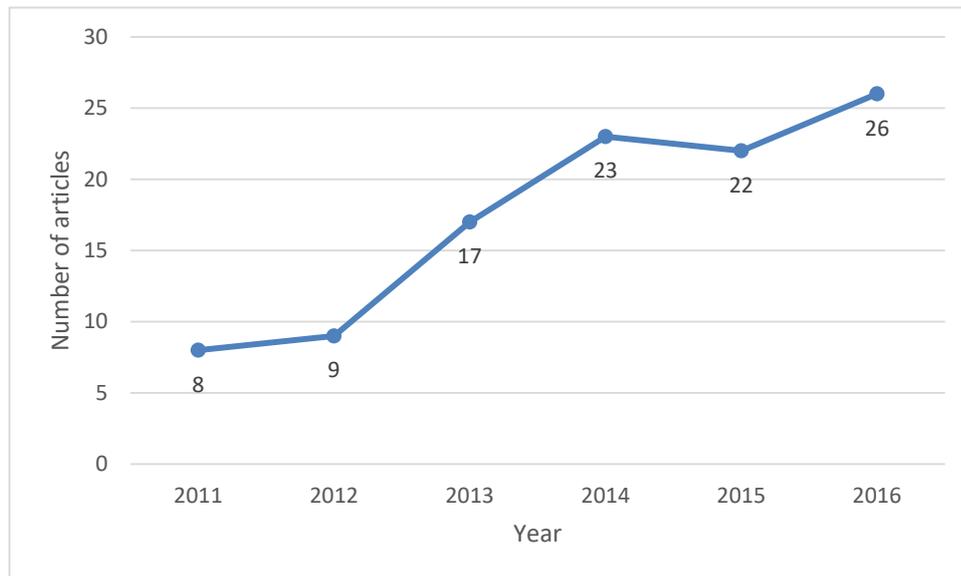
The last phase included comparison of results, summarising and reporting them. These can be found in Results and Discussion Section.

## **RESULTS AND DISCUSSION**

### ***What is the distribution of educational AR studies by years?***

There is an increase in the number of Educational Augmented Reality studies by publication year (Figure 1). While the least number of studies was found in 2011, the highest number of studies was conducted in 2016. The steady increase in the number of studies over the years can be argued to show that interest towards AR in educational environments will continue in the upcoming years as well. As a matter of fact, AR is cited in the Horizon Report among the educational technologies with significant advances (Johnson et al., 2016). Based on these findings, it can be claimed that the number of educational AR studies will continue to increase in the upcoming years. This finding is significant since it presents the value of this study to guide future studies in the field.

Figure 1 shows a significant rise especially in 2013. This striking increase may be related to the enhanced role of mobile devices in education (Martin et al., 2011). While broadband has increased in mobile communication, costs have decreased (ITU, 2016). This fact raises the ratio of owning mobile devices. Increase in the number of mobile devices is regarded as an important factor in widespread use of AR (Martin et al., 2011; Wu et al., 2013).



**Figure 1. Number of articles by year**

#### ***What is the distribution of educational AR studies by research methods that are used?***

It was observed that quantitative methods were preferred in half (50%) of the educational AR studies (Figure 2). Quantitative methods were followed by studies conducted by using literature reviews (19%) and mixed methods (18%). These were followed by other methods (7%) and qualitative methods (6%). One of the reasons why quantitative methods were often proffered may be related to the fact that the potential of AR technologies in education is recently being discovered. (Fleck et al., 2015; Vilkoniene, 2009; Wu et al., 2013). The high number of studies to identify the effect of AR use on student achievement (Chiang et al., 2014; Estapa & Nadolny, 2015; Ferrer-Torregrosa et al., 2014; Lu & Liu, 2015) or to determine student views on AR (Cai, Wang, & Chiang, 2014; Crandall et al., 2015; Di Serio, Ibáñez, & Kloos, 2013) may be the reason why quantitative methods are mostly. Similarly, studies on educational technologies also make use of quantitative methods the most (Kucuk et al., 2013; Ross et al., 2010).

Examination of Figure 2 shows that the number of studies conducted with qualitative methods is strikingly scarce. This finding points to the need for more qualitative studies. Using qualitative methods in future studies may bridge this gap. However, it would be beneficial to examine the distribution of preferred methods by year in order to better analyze distribution of methods used in educational AR studies.

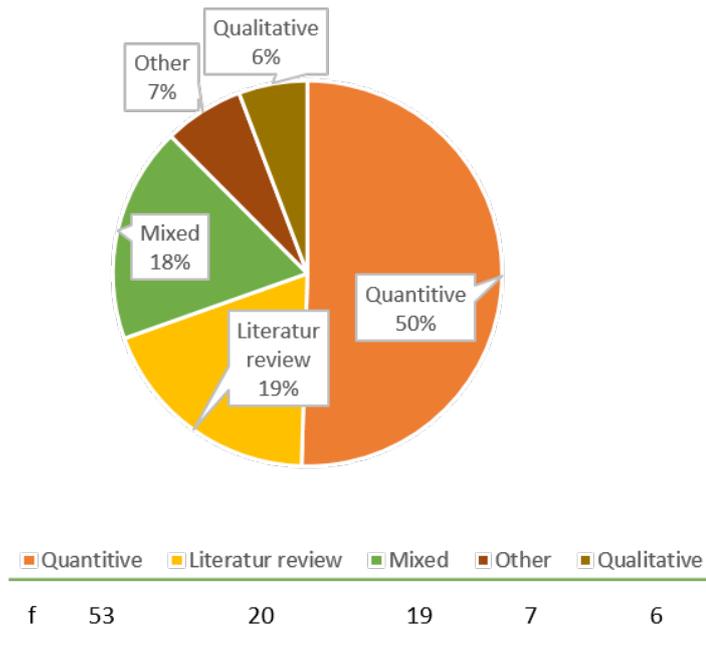


Figure 2. Distribution of methods used in educational AR studies

**What is the change in the research methods used in educational AR studies by years?**

Examination of the distribution of research methods by years (Figure 3) shows rises and falls generally for all methods. It can be claimed that quantitative methods generally increased until 2016. Especially in 2015, the number of studies that utilized quantitative methods was on the rise. While the use of qualitative methods decreased by 2016; the use of mixed, other and qualitative methods increased. It may be claimed that quantitative methods lost their impact by 2016 in educational AR studies whereas other methods have started to gain importance. There is an increase in the number of qualitative methods used in educational AR studies since 2013. However, qualitative methods still have the lowest ratio among all methods (Figure 2) and there is a dire need for studies that will be conducted with qualitative methods.

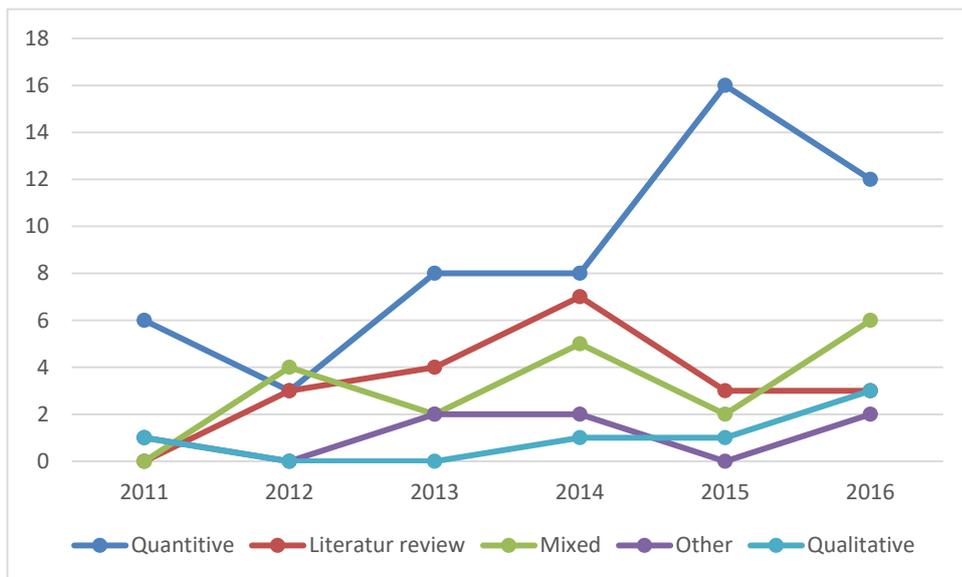


Figure 3. Change in research methods by year

### ***What is the distribution of educational AR studies by fields of education?***

According to Table 3 AR technologies are used in many educational fields. Biology is the leading field in this regard (19,8%). Taken into consideration along with physics (7%) and chemistry education (5,8%), it can be claimed that AR is a tool that is often employed in science education (physics, chemistry and biology). This finding may be related to the fact that science topics include a multitude of concrete concepts (Kara! & Abdüsselam, 2015). AR presents appropriate environments to facilitate the comprehension of science concepts with the help of 3D models. Therefore, students have the opportunity to directly observe concrete concepts rather than visualizing them (Furió, González-Gancedo, Juan, Seguí, & Costa, 2013). As a matter of fact, literature includes many AR studies conducted on different science topics such as ecology (Hsiao, Chen, & Huang, 2012), electrostatic (Echeverría et al., 2012), electromagnetic (Ibáñez et al., 2014), molecules (Cai et al., 2014), elastic collision (Wang, Duh, Li, Lin, & Tsai, 2014) and momentum (Lin, Duh, Li, Wang, & Tsai, 2013). It is also observed that AR technology is utilized in laboratory training (Akçayır et al., 2016; Enyedy, Danish, Delacruz, & Kumar, 2012; Lin et al., 2013).

AR is often used in engineering (12,8%) and medical training (11,6%). In addition to formal education, AR is also employed for informal purpose such as museum education (Chang et al., 2014), library education (Chen & Tsai, 2012) or staff training (Pejoska, Bauters, Purma, & Leinonen, 2016) (7%). AR technology is also employed in fields such as language education (5,8%), special education (4,7%), preschool education (3,5%), history education (2,3%) and astronomy education (%2,3). Apart from these educational fields, the ratio of studies collected under the other studies is 11,6%. These studies focus on different topics such as teacher training (Muñoz-Cristóbal et al., 2014), art education (Di Serio et al., 2013) and robotic training (Tanner, Karas, & Schofield, 2014). There are also studies that examined the impact of AR on applied training areas such as assembly, repair and maintenance (Gavish et al., 2015; Westerfield, Mitrovic, & Billingham, 2015). This finding shows that AR is a technology that can be employed in education and training of very diverse fields.

**Table 3 Distribution of training/education fields**

<b>Education Field</b>	<b>f</b>	<b>%</b>
Biology Education	17	19,8
Engineering Education	11	12,8
Medical Training	10	11,6
Other	10	11,6
Physics Education	6	7,0
Informal Education	6	7,0
Language Education	5	5,8
Chemistry Education	5	5,8
Mathematics Education	5	5,8
Special Education	4	4,7
Preschool Education	3	3,5
History Education	2	2,3
Astronomy Education	2	2,3

### ***What is the distribution of sample levels preferred in educational AR?***

Table 4 presents the distribution of AR studies based on sample level. In general, Table 4 displays that the majority (74,7%) of the study samples was composed of undergraduate students (36,8%) and K-12 (primary school, secondary school and high school) students (37,9%). Undergraduate students were found to be the most preferred sample groups in studies conducted to identify trends in educational technologies (Kucuk et al., 2013). It can be claimed that AR is different than other educational technologies since it is extensively used in the education of secondary school (19,5%) and primary school (11,5%) students. Primary and secondary (lower grade) students are in concrete operations stage of Piaget's cognitive development

stages (Piaget, 1976). Students in this developmental level learn concrete concepts that they can perceive through their sensory organs more comfortably. Hence, learning tools that will facilitate to concretize abstract concepts are needed in this period. AR ensures teaching abstract concepts by making them concrete (Sayed, Zayed, & Sharawy, 2011). The reason why AR is preferred in educating primary and secondary school students is related to the fact that AR ensures concretization.

It was found that AR studies had a low ratio of preference for using high school students as (6,9%). The ratios of studies conducted on special education students and teachers were found to be similar (5,7%). AR enriches the real time images perceived by sensory organs by adding virtual objects (Sirakaya, 2016). It can be claimed that this characteristic provides AR with the ability to generate appropriate learning environments for individual with special needs. Future studies may take this finding into consideration and focus on studies on special education.

Parents (4,6%), other samples (4,6%) and primary school students (3,4%) were found to be included in sample selection respectively. The least studied sample was graduate students (1,1%). The advantages cited above show that AR is a suitable tool for educating primary school students.

**Table 4 Distribution of sample levels**

Sample Level	f	%
Undergraduate students	32	36,8
Secondary school students	17	19,5
Primary school students	10	11,5
High school students	6	6,9
Special education	5	5,7
Teachers	5	5,7
Parents	4	4,6
Other	4	4,6
Preschool students	3	3,4
Graduate students	1	1,1

#### ***What is the distribution of the number of samples educational AR preferred in educational AR?***

It was found that the most preferred sample size in educational AR studies was between 31-100 (39,0%) (Table 5). This finding may be related to the fact that experimental studies are generally preferred to identify the effects of AR use in educational. As a matter of fact, studies conducted on educational technologies (Kucuk et al., 2013) and educational AR (Bacca et al., 2014) to determine trends also used this sample size as well. This sample size was followed by sample size of 11-30 (13,3%) and sample size of 101-300 (12,4%). 5,7% of the studies were conducted with 1-10 participants whereas 2,9% of the studies did not provide sample size. Only 1 study (1,0%) was conducted with the participation of more than 1000 participants.

**Table 5 Distribution of sample size**

Sample size	f	%
Between 31-100	41	39,0
Between 11-30	14	13,3
Between 101-300	13	12,4
Between 1-10	6	5,7
Not identified	3	2,9
More than 1000	1	1,0
Between 301-1000	0	0

**What is the distribution of data collection tools used in educational AR studies?**

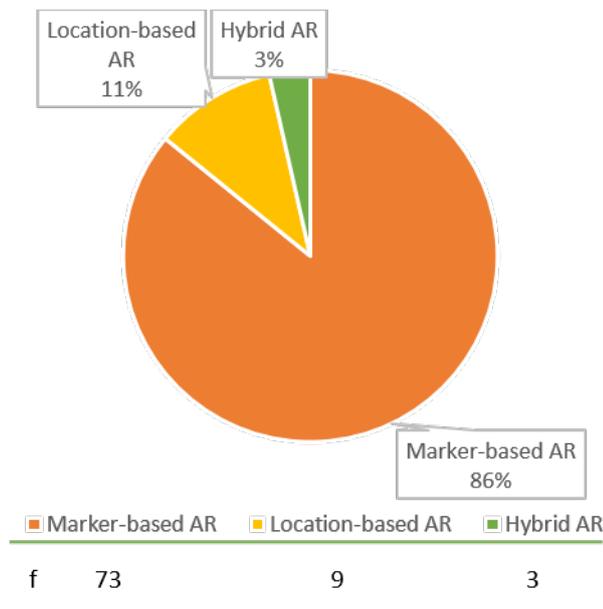
It was found that the most common data collection tool in educational AR studies is survey (29,9%) and the least common employed data collection tool is (8,4%) (Table 6). Widespread use of student surveys about use of AR in educational environments may have contributed to this finding. Other data collection tools are achievement tests (16,9%), interviews / focus groups (13,3%), other (13,3%), attitude, personality or aptitude tests (10,2%) and observations (9%) respectively.

**Table 6 Distribution of data collection tools**

Data collection tool	f	%
Survey	48	29,9
Achievement test	28	16,9
Interview / focus group interview	22	13,3
Other	22	13,3
Attitude, personality or aptitude tests	17	10,2
Observation	15	9,0
Document	14	8,4

**What is the distribution of AR types used in educational AR studies?**

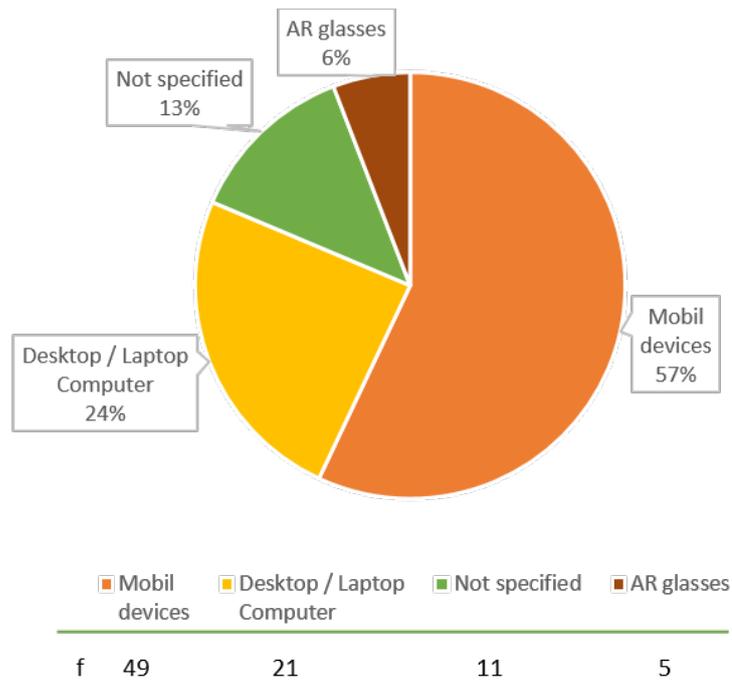
Marker-based AR was preferred in the majority of educational AR studies (86%) (Figure 4) followed by location-based AR (11%) and hybrid AR (3%) in a limited number of studies. Marker-based AR is a relatively easy technology to use (Thornton et al., 2012). Also, compared to others, it is easier to develop marker-based AR applications (Lu & Liu, 2015). The fact that location-based and hybrid AR applications were used less in studies may have been related to lack of technical skills on the part of researchers in developing these applications. However, location-based AR presents an important advantage to students by allowing them to learn outside the classroom (Chiang et al., 2014). It is necessary to increase the number of location-based AR studies in order to discover different dimensions of educational AR and to evaluate educational AR in terms of diverse variables.



**Figure 4. AR type**

**What is the distribution of delivery technology used in educational AR studies?**

The most preferred delivery technology in educational AR studies is mobile devices (57%) (Figure 5). Similar results (Akçayır & Akçayır, 2017) that point to mobile devices as the most preferred delivery technology in educational AR studies were found. Use of mobile devices for educational purposes provides various affordances such as portability, interactivity, context sensitivity, connectivity and individuality (Churchill & Wang, 2014). Use of AR applications in mobile devices allow students to make observations outside of classroom and learn by doing (Chiang et al., 2014). The reason why mobile devices are mostly used in educational AR studies may be related to the advantages of mobile devices.



**Figure 5. Delivery technology**

**CONCLUSION AND SUGGESTIONS**

This study examined 105 educational AR articles indexed in ERIC, EBSCOhost and ScienceDirect databases with content analysis method. Selected articles were coded according to the following headings: year of publication, method, research topic, sample level, sample size, data collection tool, AR type and delivery technology. Data analyses set out to establish trends in educational AR studies.

The number of educational AR studies has increased over the years. It is foreseen that educational AR will be more widespread in the future along with recent advances in mobile technologies. The significance of AR use for educational purposes and the increase in the number of AR studies will continue in the upcoming years. It can be argued that the results of this systematic review are significant to guide future studies.

Research results present that AR is a technology used in education in diverse fields. Science, engineering and medical training are the fields in which AR is employed the most. Similarly, AR is utilized in training different sample levels which can be explained with a unique characteristic of AR: combining real and virtual. With this characteristic, AR stands out as an effective educational tool that can be used for different sample levels and training in various fields.

Suggestions regarding future studies are provided below:

- Quantitative methods are used the most in educational AR studies whereas qualitative methods are preferred the least. Future studies can utilize qualitative methods instead of quantitative ones to bridge the gap in AR studies.
- Future studies may include teachers the implementers of the system, as samples. Hence, teachers may be encouraged to practice AR in the classroom since they will discover the educational potential of AR.
- Future studies can be conducted on less studied sample groups such as special needs students, preschool students, parents and graduate students. Therefore, educational potential of AR can be examined in depth.
- AR is generally utilized in science, engineering and medical training. Studies that will be conducted in social and artistic fields may help discover different dimensions of AR.
- Marker-based AR is preferred in almost all existing AR studies. Future studies may employ location-based AR.
- Studies that utilize AR goggles are needed. These studies may help discover different educational potentials of AR technology.

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