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Advantages and challenges associated with augmented reality for education: A systematic review of the literature

Murat Akçayır [a], Gökçe Akçayır [b, *]

[a] Kırıkkale University, Faculty of Education, Department of Computer Education and Instructional Technologies, Kırıkkale, Turkey
[b] Gazi University, Faculty of Gazi Education, Department of Computer Education and Instructional Technologies, Ankara, Turkey

A R T I C L E I N F O

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A B S T R A C T

This study presents a systematic review of the literature on augmented reality (AR) used in educational settings. We consider factors such as publication year, learner type (e.g., K-12, higher education, and adult), technologies in AR, and the advantages and challenges of using AR in educational settings. The full range of SSCI journals was surveyed and a total of 68 research articles were selected for analysis. The findings reveal an increase in the number of AR studies during the last four years. The most reported advantage of AR is that it promotes enhanced learning achievement. Some noted challenges imposed by AR are usability issues and frequent technical problems. We found several other challenges and numerous advantages of AR usage, which are discussed in detail. In addition, current gaps in AR research and needs in the field are identified, and suggestions are offered for future research.

1. Introduction

Augmented reality (AR) can be defined as a technology which overlays virtual objects (augmented components) into the real world. These virtual objects then appear to coexist in the same space as objects in the real world (Azuma et al., 2001). AR was first introduced as a training tool for airline and Air Force pilots during the 1990s (Caudell & Mizell, 1992). Currently, AR is a popular technology that is widely used in educational settings. In this role, AR also has become an important focus of research in recent years. One of the most important reasons that AR technology is so widely used is that it no longer requires expensive hardware and sophisticated equipment, such as head-mounted displays (HMD). The technology now can be used with computers or mobile devices. Thus, using AR technology is not as difficult as it was in the past. It is used today in every level of schooling, from K-12 (Chiang, Yang, & Hwang, 2014b; Kerawalla, Luckin, Seljeflot, & Woolard, 2006) to the university level (Ferrer-Torregrosa, Torralba, Jimenez, García, & Barcia, 2015).

1.1. Relevant literature

Studies have shown that AR technology offers many advantages when used in educational settings (Cheng & Tsai, 2013). For instance, AR helps students to engage in authentic explorations in the real world (Dede, 2009). By displaying virtual elements alongside real objects, AR facilitates the observation of events which cannot easily be observed with the naked eye (Wu, Lee, Chang, & Liang, 2013). Thus, it increases students' motivation and helps them to acquire better investigation skills (Sotiriou &

* Corresponding author.
E-mail addresses: gokceakcayir@gmail.com, gokceakcayir@gazi.edu.tr (G. Akçayır).

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Bogner, 2008). According to Dunleavy, Dede, and Mitchell (2009, p. 20), AR's most significant advantage is its "unique ability to create immersive hybrid learning environments that combine digital and physical objects, thereby facilitating the development of processing skills such as critical thinking, problem solving, and communicating through interdependent collaborative exercises." A very recent study by Akçayır, Akçayır, Pektaş, and Ocak (2016) revealed that AR technology both improves university students' laboratory skills and helps them to build positive attitudes relating to physics laboratory work.

In the literature, some researchers have drawn attention to limitations associated with AR. For instance, Lin, Hsieh, Wang, Sie, and Chang (2011) stated that students find AR complicated, and that they often encounter technical problems while using it. Without a well-designed interface and guidance for the students, AR technology can be too complicated for them to use (Squire & Jan 2007). The various devices that deliver AR applications may cause additional technical problems (Wu et al., 2013). Additionally, Yu, Jin, Luo, Lai, and Huang (2009) stated that bulky AR technologies such as HMDs are not easy to handle, and that AR technologies should be developed to be smaller, lighter, more portable, and fast enough to display graphics. Aside from technical limitations, Munoz-Cristobal et al. (2015) showed that excessive additional lecture time is required to use AR effectively in education.

A considerable amount of research has been focused on AR usage in educational settings. However, though numerous AR studies have been published, the educational advantages and related utilities of AR have only recently been explored in detail (Cheng & Tsai, 2013; Martin et al., 2011). To date, no comprehensive explication of the educational effects and implications of AR exists (Radu, 2012). Therefore, a review of the advantages and challenges reported in research studies on AR technology in education can usefully suggest both best practices and areas in which to invest future research and development, so that this technology may be employed to its maximum capacity. In the present study, 68 research articles examining educational uses of AR, published up to 2015, were identified and analyzed to fill this need.

1.2. The purpose of the study

Investigating prior research in a field is important, as this reveals the current state of the field and offers guidance to researchers who are seeking suitable topics to explore (Höffler & Leutner, 2007; Karatas, 2008; Seo & Bryant, 2009). Moreover, such systematic reviews provide a concise reference for policymakers, who must make critical decisions regarding funding and applications (Hwang & Tsai, 2011; Shih, Feng, & Tsai, 2008). The examination of prior research in a field also helps researchers to determine which subjects are of continuing importance (Davies, Howell, & Petrie, 2010; Nolen, 2009).

There are many literature review studies in the fields of global education and technology (Hwang & Tsai, 2011; Wu et al., 2012). In these studies, researchers focus on topics such as e-learning (Lu, Wu, & Chiu, 2009; Shih et al., 2008), mobile and ubiquitous learning (Hwang & Tsai, 2011; Wu et al., 2012), blended learning (Drysdale, Graham, Spring, & Halverson, 2013), and educational technologies (Hew, Kale, & Kim, 2007; Kucuk, Aydemir, Yildirim, Arpacik, & Goktas, 2013). But reviews of research on AR technology are less common (Bacca, Baldiris, Fabregat, & Graf, 2014) because AR has only recently become very popular in educational settings. To fill that gap in the literature, in this study we located and then analyzed all of the published studies in the Social Science Citation Index (SSCI) journal database (to the end of 2015) which address educational uses of AR technology. The purpose is to present a systematic review of the literature on AR used in educational settings (e.g., formal learning, informal learning, and training in a workplace). More specifically, the following research questions (RQ) are addressed:

RQ1. What is the distribution over time of the studies published in the SSCI-indexed journals that examine educational uses of AR?

RQ2. What learner types (types of participants) are commonly selected for the research studies published in the SSCI-indexed journals?

RQ3. Which AR technologies are most used for educational purposes within the studies published in the SSCI-indexed journals?

RQ4. What are the advantages of AR in educational settings, indicated in the studies published in the SSCI-indexed journals?

RQ5. What are the challenges imposed by AR in educational settings, indicated in the studies published in the SSCI-indexed journals?

2. Method

2.1. The manuscript selection process

In review studies, various methods are used by researchers to select manuscripts. Examples include selecting a defined set of articles from important journals within the field (Hwang & Tsai, 2011; Nolen, 2009), selecting all articles published within the leading journals of the field (Karatas, 2008; Shih et al., 2008), and using databases in which the studies are indexed — such as ProQuest (Drysdale et al., 2013), Education Resources Information Center (ERIC), and SSCI (Kucuk et al., 2013).

For this review, we selected scientific articles on the educational uses of AR, published in journals that are indexed in the SSCI database. We employed this method because it is easy to access the field tags of SSCI indexed articles, such as topic and research area (Luor, Johanson, Lu, & Wu, 2008). The Web of Science site (WOS) was the point of access. WOS provides a search engine for all of the SSCI indexed journals. In WOS, we used the advanced search function, and input the search terms "augmented reality," "augmenting reality," and "mixed reality." Because some authors use the terms augmenting reality and mixed reality interchangeably with the term augmented reality, we used all of these terms, and the Boolean operator "OR" to combine multiple search terms. While conducting the search, no time period was specified (the database holds articles dating from 1980 to 2015). However, the categories "education & educational research," "education special," "education scientific discipline," and "psychology educational," the document type "article," and the language "English" were selected as the search parameters. The last search was conducted on 15 January 2016.

In the first search, 102 articles were discovered. These were downloaded to a computer in an electronic format. The selected articles then were examined by the two researchers (each of whom have years of experience in the Instructional Technology field) to determine whether they were suitable for the purpose of the study. During this examination, a set of inclusion and exclusion criteria were adopted (see Table 1). Following our application of the criteria, 68 articles were found to be relevant to the purpose of the study.

2.2. The data coding and analysis processes

All of the articles were coded and analyzed by the two researchers. The first three research questions (RQ1, RQ2, and RQ3) address the publication year, learner type, and AR technologies. The year is the date of publication in the journal, which is indicated in the article. Learner type was divided into six sub-categories of participants: K-12 students (primary and secondary students), higher education students (in college, university, or postgraduate students), teachers (of K-12 or a higher education institution), adult students (working full-time or studying via AR from outside of scholarly environments), kindergarten students, and not applicable/specified (the learner type was not clearly specified, or the study discussed the use of AR in education but did not collect data from any learner type). In some studies, more than one learner type was used (e.g., Squire & Klopfer, 2007), such as university students together with K-12 students. In such studies, more than one code was applied for the learner type. The category of AR technologies was divided into three sub-categories: desktop computers, mobile devices (e.g., smartphone, tablet PC), and other (e.g., vision glasses, Kinect, special equipment developed by the researcher/s).

To find answers for RQ4 and RQ5, the data from all 68 articles were analyzed by the two researchers. First, to establish coding reliability, 17 (25%) of the articles were picked randomly and blind coded by the two researchers. As is typical in the literature, Cohen's kappa was selected to check the inter-rater reliability (Akçayır & Akçayır, 2016; Strijbos, Martens, Prins, & Jochems, 2006). The 17 articles, each coded by the two researchers separately, were analyzed using the SPSS program package. The Cohen's kappa was found to be 0.76. Viera and Garrett (2005) maintain that any value between 0.61 and 0.80 represents a substantial agreement. After validating the coding scheme, the two researchers independently coded the rest of the articles.

To determine the advantages and challenges (RQ4 and RQ5), all of the findings/results, discussions, and conclusion sections from the 68 articles were read. We searched for code words to identify the advantages and challenges. The resulting data were collected in a MS Office Excel document. The data obtained from the articles were then analyzed using the content analysis technique. This has been defined as a systematic, replicable technique for compressing many words of text into fewer content categories, based on explicit rules of coding (Berelson, 1952).

No ready-made template was used to determine the advantages and challenges because pre-developed forms can unduly direct researchers while coding and can be misleading for the intended purpose (Akçayır & Akçayır, 2016). Therefore, Tesch (1990) eight steps (as described in a study by Williamson, 2015) were employed to open code the data. The eight steps are: (1) get a sense of the whole; (2) pick one document and think about its underlying meaning, then write thoughts in the margin; (3) make a list of all topics, cluster similar topics, and make columns to distinguish between major, unique, and leftover topics; (4) code the text; (5) find the most descriptive wording for your topics and turn them into categories; (6) make a final decision on the abbreviation for each category and alphabetize these codes; (7) assemble by final code and perform preliminary analysis; and (8) recode, if necessary.

3. Results and discussion

3.1. RQ1: what is the distribution over time of the studies published in the SSCI-indexed journals that examine educational uses of AR?

When the distribution of the articles examining the educational uses of AR were analyzed across the years of publication, we found that starting in 2007 the number of studies steadily increased over time. Horizon Reports forecasted in 2006

Table 1
Inclusion and exclusion criteria.

Inclusion criteria	Exclusion criteria
a. Must involve AR as a primary component.	a. Editorials are excluded.
b. The article must be about the use of AR for educational purposes, even outside of a scholarly environment. For example, articles on specific training in an industry, which are educational, are included.	b. Articles that mention the term "augmented reality" but are actually about virtual reality or other topics.

(Johnson, Laurence, & Smith, 2006) that AR would be a promising technology in the long term, and that AR would have a significant impact and garner attention in the coming years (2009–2010). As forecasted, AR indeed has become more popular. The number of educational AR studies has steadily increased over time, indicating that more research interest has been focused on it (see Fig. 1).

Fig. 1 reveals that research in this area has dramatically increased since 2011. One of the possible reasons for this increase is that AR usage via mobile devices has become widespread. After 2010, advances in mobile technologies (especially smartphones and tablets) and an increase in the number of mobile device owners (Statista, 2015) made AR available more broadly to the public. The recent literature reflects that AR technology is increasingly accessed with mobile devices, and that this is now easier to do (Martin et al., 2011; Wu et al., 2013) because mobile devices have become simpler and more portable (Johnson, Laurence, Smith, & Stone, 2010).

Fig. 1 also shows that AR research has intensified during the last four years. This suggests that a similar level of interest will continue in 2016 and after. Particularly in developing countries, the availability of technology (e.g., mobile devices, the Internet) and of software programs to develop AR applications is increasing rapidly. Thus, it seems likely that the use of AR in educational settings will increase and that more research will be devoted to it.

3.2. RQ2: what learner types (types of participants) are commonly selected for the research studies published in the SSCI-indexed journals?

In nearly half of the articles (51%), K-12 students were selected as the learner type (see Fig. 2). University students (29%) were the second most commonly preferred learner type. Though a general tendency in the field of educational technologies is to include university students as a learner type (Drysdale et al., 2013; Kucuk et al., 2013; Wu et al., 2012), this is clearly not true for all AR technology research, as these percentages indicate. Since elementary students and early adolescences are at the concrete operational stage according to Piaget's stages of cognitive development, they must see, hear, or in some other way use their senses to know (Martin & Loomis, 2013). Thus, the strong visualization features of AR play an important role in learning for students in this stage. This may explain why K-12 students are the most preferred sample groups. Another potential explanation is that many children spend a great deal of time playing digital games; therefore, researchers may find AR games highly suitable to engage young students in learning (Lee, 2012). Researchers also utilized subjects from the Kindergarten level and found positive learning outcomes (e.g., Han, Jo, Hyun, & So, 2015).

Seven percent of the research focused on adult learners. AR was found to be a potentially effective tool for elderly people and easy for them to use (Saracchini, Catalina, & Bordoni, 2015). A recent study by Gavish et al. (2015), with a participant pool of 40 expert technicians in industrial maintenance and assembly tasks training, revealed that AR training helps technicians to prevent errors by focusing trainees on key points in the task. The researchers suggested that AR platforms should be more widely used to train technicians.

Our review also revealed that a notable gap exists for AR studies focused on students with special needs. Only one of the articles investigated teachers' perceptions concerning mobile device AR usage by students with special needs, and this study concluded that further research is needed (Mohd Yusof, Daniel, Low, & Ab. Aziz, 2014). Similarly, Wu et al. (2013) stressed that very few technologies are designed for students with special needs.

3.3. RQ3: which AR technologies are most used for educational purposes within the studies published in the SSCI-indexed journals?

Technology plays an important role in AR (Wu et al., 2013), and AR can be accessed with different technologies, such as tablet PCs or HMD. Different AR technologies have different characteristics with regard to cost, accessibility, and usability in

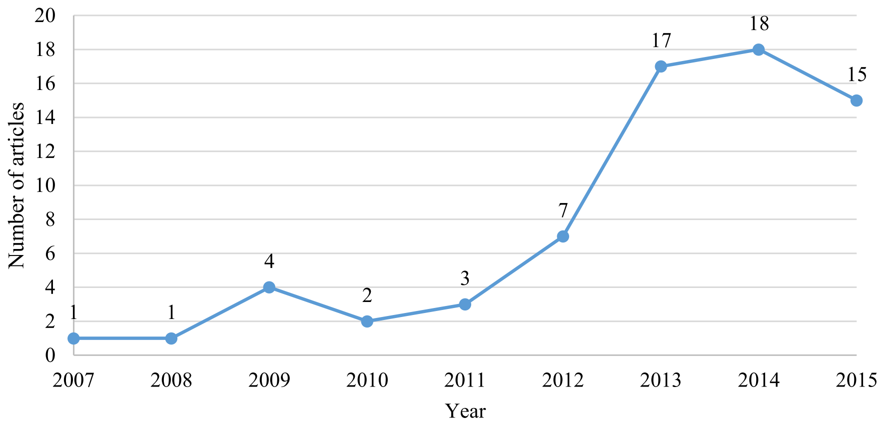

Fig. 1. Number of articles published by year.

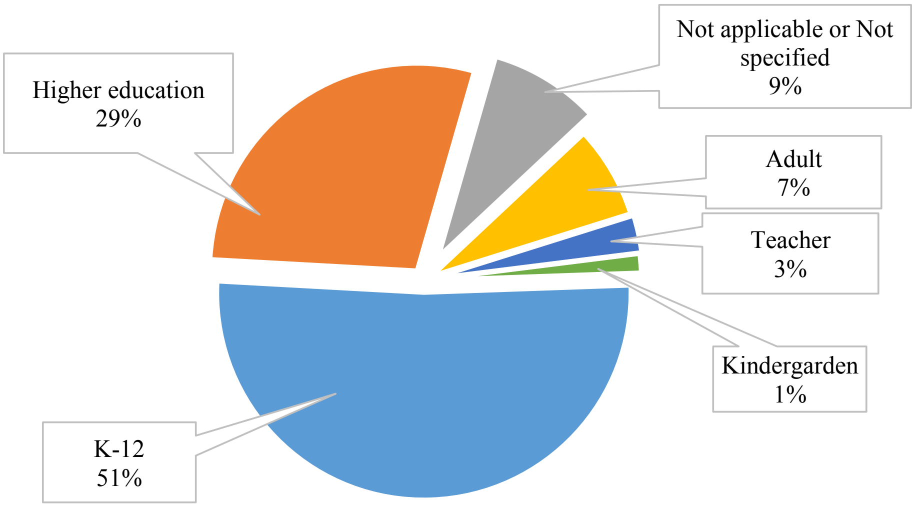

Fig. 2. Learner types.

educational settings. Therefore, we sought to identify which are the most preferred AR technologies in education. We found that the most commonly preferred delivery technology is mobile devices (60%) (see Fig. 3). These are favored for several reasons.

According to Henrysson, Billinghurst, and Ollila (2005), mobile devices offer an ideal platform for AR applications. They are very cost-effective and easy to use, especially for younger students (Furió, González-Gancedo, Juan, Seguí, & Costa, 2013). Desktop computers can support AR applications, but they are not portable due to hardware limitations (Chiang et al., 2014b). In contrast, mobile devices provide many advantages, such as portability, encouragement of high social interactivity, and independent operability (Hwang, Tsai, Chu, Kinshuk, & Chen, 2012). They are also beneficial to students who engage in outdoor observations and learning activities (Chiang, Yang, & Hwang, 2014a). In addition, location-based AR on mobile devices enables students to immerse themselves in the learning process (Chiang et al., 2014b), and it increases their collaboration skills (Bressler & Bodzin, 2013; Yu et al., 2009). The 2010 Horizon Report indicated that users will no longer need to be tethered to their desktop computers because of wireless mobile technology (Johnson et al., 2010).

In the reviewed studies, desktop computers (24%) followed mobile devices in popularity. The category "other" (16%) in Fig. 3 includes Kinect, HMD, 3D vision glasses, and other technologies developed by researchers who conducted the studies. Desktop computers and other technologies offer positive advantages, apart from the attractive cost of technologies such as Kinect (Lindgren & Johnson-Glenberg, 2013). However, Bronack (2011) argued that the use of technology in educational activities in itself is not as important as the use of technology which clearly supports meaningful learning. As mobile devices are portable and enable students to make on-the-spot inquiries with their location-based AR applications, they facilitate meaningful learning. It is expected that mobile devices will be more popular in the future.

3.4. RQ4: what are the advantages of AR in educational settings, indicated in the studies published in the SSCI-indexed journals?

After open coding, identified advantages were arranged into four categories (learner outcomes, pedagogical contributions, interaction, and other) (see Table 2). We then divided these into three subsections (learner outcomes, pedagogical contributions and interaction, and other).

Before discussing the advantages of AR, it is important to note that in most of the reviewed studies the AR that was used was new technology (first time in use) (El Sayed, Zayed, & Sharawy, 2011). The researchers therefore sometimes mentioned an uncontrolled novelty effect, which might diminish over time (Di Serio, Ibáñez, & Kloos, 2013). Hsiao, Chen, and Huang (2012) noted this issue and also stated that when AR becomes commonly used in curricula, the students' learning attitudes and motivations might not remain so positive. In other words, if some advantages of AR are due to a novelty effect, they too may diminish as students become more familiar with the AR technology.

3.4.1. Learner outcomes

The advantages of AR which are related to students' learning outcomes — such as learning achievement, motivation, and attitude — are gathered under the learner outcomes category. Most of the studies reported that AR technology in education leads to "enhancement of learning achievement" in educational settings. Numerous studies have indicated that AR promotes enhanced learning performance (Chang, Hou, Pan, Sung, & Chang, 2015; Ferrer-Torregrosa et al., 2015). Lu and Liu (2015) stated that the students in their study adopted a positive attitude toward AR-enhanced learning activities. They appeared

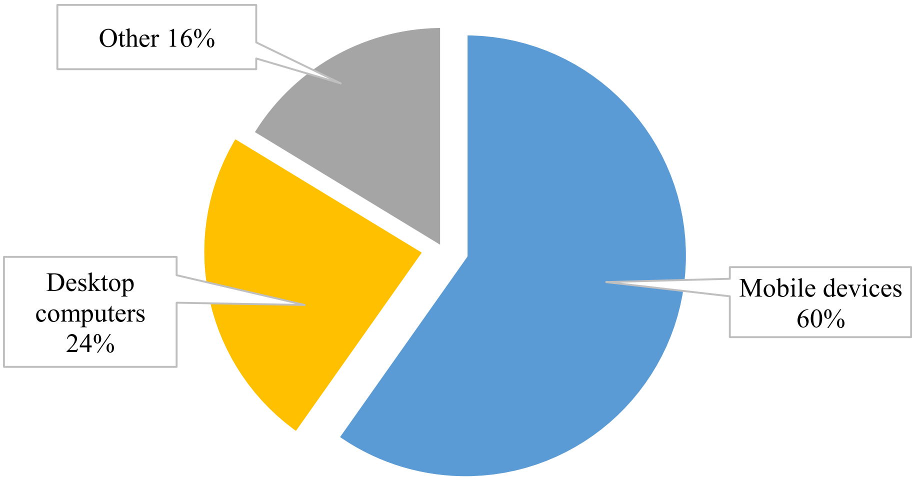

Fig. 3. Distribution of AR technologies used.

Table 2
The advantages of AR in educational settings.

Inductive categories	Sub-categories	*f*	Sample research
Learner outcomes	Enhancing learning achievement	32	Lu & Liu, 2015
	Enhancing learning motivation	10	Chiang et al., 2014a
	Helps students to understand	7	Kamarainen et al., 2013
	Provide positive attitude	6	Wojciechowski & Cellary, 2013
	Enhancing satisfaction	4	Han et al., 2015
	Decreases cognitive load	2	Santos et al., 2014
	Enhancing confidence	2	Lu & Liu, 2015
	Enhances spatial ability	2	Lin, Chen, & Chang, 2015
Pedagogical contributions	Enhances enjoyment	8	Ibáñez et al., 2014
	Raising the level of engagement	6	Liu & Tsai, 2013
	Increases interest	4	Zhang et al., 2014
	Provides collaboration opportunities for students	3	Lin, Duh, Li, Wang, & Tsai, 2013
	Facilitates communication between students and lecturer	2	Zarraonandia et al., 2013
	Promotes self-learning	2	Ferrer-Torregrosa et al., 2015
	Combines the physical and virtual worlds	1	Dunleavy et al., 2009
	Allows learners to learn by doing	1	Hsiao et al., 2012
	Student-centered technology	1	Kamarainen et al., 2013
	Enables multi-sensory learning	1	Lu & Liu, 2015
	Enables learners to quickly receive information	1	Chiang et al., 2014b
Interaction	Providing interaction opportunities (student-student)	4	Kamarainen et al., 2013
	Student-material	2	Lin et al., 2011
	Student-teacher	1	Zarraonandia et al., 2013
Other	Enables visualization of invisible concepts, events, and abstract concepts	5	El Sayed et al., 2011
	AR is easy for students to use	4	Di Serio et al., 2013
	Reduces laboratory material cost	1	Ferrer-Torregrosa et al., 2015

happy and playful as they "learned through play." Their conclusion was that AR enhanced the learning achievements of the students. In another study by Chiang et al. (2014a), the researchers concluded that the mobile device AR approach can improve students' learning performance. They suggested that Mayer (2009) spatial and continuity principles from the multimedia learning theory explain their results. According to the authors, providing well-integrated and organized, relevant materials (e.g., images, texts, videos) can help to prevent incidental cognitive loads. This improves the students' learning performance.

The review findings also indicate that AR can "enhance learning motivation," "help students to understand," "enhance positive attitude," and "enhance satisfaction." According to Chiang et al. (2014a), as an alternative to forcing students to search for relevant information regarding their learning content on their own, AR technology provides immediate and relevant information, as well as guidance to the students, which may increase their learning motivation. AR components such as videos and 3D images can help students to more fully understand their learning content (Yoon, Elinich, Wang, Steinmeier, & Tucker, 2012). This method is also perceived by students as more satisfying than classroom lessons (Chen & Tsai, 2012; Munoz-Cristobal et al., 2015).

Some researchers reported specific AR-related learner outcomes such as “decreases cognitive load” and “enhances spatial ability.” These results require further exploration. For example, Santos et al. (2014) showed that AR juxtaposes real objects, virtual text, and other symbols (e.g., images, videos), which reduces cognitive load in the limited working memory. However, this advantage is reported in only two research studies. In another study, Bressler and Bodzin (2013) likewise stated that well-designed AR systems can reduce students' cognitive overload. But these authors indicated that the claim should be further explored. According to these results, we conclude that AR technology may improve students' learning performance, and that researchers have focused heavily on academic achievement in AR research. Other learning outcomes, such as satisfaction and confidence, were less investigated but are also important in educational settings.

3.4.2. Pedagogical contributions

Table 2 shows the results for the reported pedagogical contributions of AR in the studies that were analyzed. According to these results, the most prominent contributions of AR are “enhancing enjoyment” and “raising the level of engagement.” AR can make boring instruction more entertaining (Ibáñez, Di Serio, Villarán, & Kloos, 2014; Lu & Liu, 2015). The use of AR technology via AR-based games makes learning more fun (Bressler & Bodzin, 2013; Mohd Yusof et al., 2014). Utilizing mobile AR guidance, students can be more engaged and perform better (Chang et al., 2014; Liu & Tsai, 2013). AR allows the teacher to assign responsibility to the students, and it allows students to make their own decisions. These contributions enhance student engagement (Munoz-Cristobal et al., 2015).

Though enhanced learning interest was less reported as a finding, Zhang, Sung, Hou, and Chang (2014) showed that AR increases learning interest; the students in their study concentrated more fully on the topic when using AR. In another study by Dunleavy et al. (2009), mobile AR technology facilitated collaborative learning in hybrid learning environments (which combine digital and physical objects). Lu and Liu (2015) designed a different and interesting multisensory AR system that utilizes students' vision, hearing, speech, and whole body movement. This system increased the students' physical activity and improved their large motor skills. However, this contribution was reported in only one study within the 68 reviewed research articles. That finding requires further investigation to determine whether it is a real contribution of AR.

3.4.3. Interaction & other

AR advantages related to learners' interactions (student-student, student-material, and student-teacher) were grouped under the interaction category. Nearly 10% of our reviewed studies reported that AR technology promotes more interaction among students (Kamarainen et al., 2013), and more between students and the learning material – thus facilitating “learning by doing” (Hsiao et al., 2012). Zarraonandia, Aedo, Díaz, and Montero (2013) defined advantages differently than in other studies; they stated that AR increases communication and interactions among teacher-students.

In the “other” category, AR technology was said to be useful for visually supporting students, and for enabling their visualization of intangible concepts. It is also easy for students to use. According to Dunleavy et al. (2009), AR can be used to superimpose augmented components (e.g., virtual objects, information) onto physical environments. Therefore, AR supports learners by helping them to visualize abstract concepts or unobservable phenomena, such as electron movements or magnetic fields (Wu et al., 2013). Some researchers reported that students found AR both easy to use and enjoyable (Di Serio et al., 2013).

3.5. RQ5: what are the challenges imposed by AR in educational settings, indicated in the studies published in the SSCI-indexed journals?

Though AR provides many advantages in educational settings, researchers have reported some challenges imposed by AR technology (see Table 3). The most reported challenge is that AR is “difficult for students to use.” Usability is an important technical factor (Chang et al., 2014), which affects educational effectiveness. For example, without well-designed interfaces, students may experience difficulties when using this technology (Munoz-Cristobal et al., 2015). Cheng and Tsai (2013) argued that usability issues must be addressed because AR technology involves extensive user interaction. According to Chiang et al. (2014a), instant hints or learning guidance could be provided to students to prevent AR usability issues. Usability difficulties may cause time loss for students, and may require excessive additional lecture time. A recent study by Gavish et al. (2015) reported that an AR-using group in their study required significantly longer mean training times compared to their non-AR-using group. They suggested that this result in part may have been due to the novelty of the AR technology.

Another issue that must be considered in an AR learning environment is students' cognitive overload (Dunleavy et al., 2009). Cheng and Tsai (2013) suggested that students might experience cognitive overload in an AR learning environment due to the amount of material and complexity of tasks.

Most of the other reported challenges involve application-related and technical problems. Most of the technical problems were experienced in location-based AR applications. Global Positioning System (GPS) error is a problem caused by the AR application miss-perceiving a location and/or direction (Chiang et al., 2014a). Similarly, “low sensitivity in trigger recognition” is more frequently experienced in location-based AR applications (Cheng & Tsai, 2013). A conclusion that may be drawn from these studies is that greater care should be taken by researchers who are planning to use location-based AR applications. Future technological developments are expected to fix most of the current problems experienced in location-based AR applications. Furió et al. (2013) also reported that when AR technology is used with large groups, it may be cost prohibitive, and normal class sessions might not provide enough time to implement some AR applications.

Table 3
The challenges in AR use within educational settings.

Challenges	*f*	Sample research
AR is difficult for students to use	7	Munoz-Cristobal et al., 2015
Requires more time	4	Gavish et al., 2015
Low sensitivity in triggering recognition	4	Chang et al., 2014
GPS errors cause student frustration	3	Chiang et al., 2014a
Not suitable for large group teaching	3	Yoon et al., 2012
Causes technical problems (camera, Internet, indoor use)	3	Chang et al., 2015
Causes cognitive overload	2	Dunleavy et al., 2009
Distracts students' attention	2	Chiang et al., 2014b
Expensive technology	2	Furió et al., 2013
Large file size limits the sharing of content	1	Ke & Hsu, 2015
Ergonomic problems	1	Chang et al., 2015
Difficult to design	1	Chang et al., 2014
Inadequate teacher ability to use the technology	1	Dunleavy et al., 2009

4. Conclusion

Though AR dates back to the 1990s, it does not have a long history in educational studies. However, we found an increase in the number of recent research studies on this topic. With expected technological developments, the utility of AR technology should improve in the near future. Thus, its usage likely will be more widespread, and more research will be focused on it. That future research should in turn provide more insights for its effective application in the field of education. Educators may also become more confident in their skills to use it.

It is clear that AR can potentially support learning and teaching. However, when the reviewed research studies are compared to each other, some conflicting conclusions can be seen. For instance, while some studies reported that AR decreases cognitive load, others reported that it causes cognitive overload. Similarly, while the top challenge imposed by AR applications is their usability, their ease of use also appears in the list of reported advantages. Whether there is a real usability issue – and if there is, whether that stems from inadequate technology experience, interface design errors, technical problems, or the teacher's lack of technology experience (or negative attitude) – still needs to be clarified.

AR offers unique advantages, such as its "combination of virtual and real objects in a real setting." But, as with all technologies, there are some challenges to be considered when using AR. Notably, there are significant pedagogical issues (e.g., need for more class time, unsuitability in crowded classrooms, instructors' inadequate experience with technology) and technical issues with AR technology that need to be overcome. However, we believe that these challenges are relatively minor, and that they should not prohibit the use of AR. For instance, the current technical problems, such as low sensitivity trigger to recognition and GPS error, will likely be resolved by new developments in the future. It should also be noted that there are some prerequisites for the use of this technology, such as hardware (mobile devices, tablets, etc.) and an Internet connection. When these requirements to use AR applications are met and the challenges are considered, AR applications should be even more useful in education.

5. Future research

The following existing gaps and needs in AR research were derived from the findings of this study. These points are presented to guide future research.

- Solutions to reported technical problems encountered in AR applications should be explored (sensitivity trigger to recognition, GPS error, file size, etc.).
- While AR technology has been improving, it can still be difficult for students to use; therefore, more studies related to the development and usability of AR applications are needed. Within this line, learners' opinions about usability and preferences must be examined in AR based learning environments.
- To resolve aforementioned pedagogical issues of AR, researchers should attempt to develop holistic models and design principles (empirically proven) for AR environments.
- Future research may investigate the use of AR applications to support ubiquitous learning, collaborative learning, and informal learning, how they should be used, and which methods and techniques should be more effective. In short, the effects of AR applications can be more thoroughly examined.
- The use of AR applications with emerging technologies, such as vision glasses, and also educational outcomes both should be researched, to determine potential advantages.
- The potential of AR could be further expanded by designing it for implementation with diverse populations, such as students with special needs, and early childhood and lifelong learners.
- Regarding student interactions with the environment in location-based AR applications, their suggested solutions to problems which they encountered should be more deeply explored.

- Additional research could be directed toward student satisfaction, motivation, interactions, and student engagement to better understand the advantages of AR in educational settings.
- Some advantages and challenges results apparently conflict with each other in the literature. For example, some studies reported that AR is difficult to use, while others stated that ease of use is an advantage. Similarly, it is not clear whether AR applications might cause cognitive overload. Therefore, the conditions relating to the problem of cognitive overload in AR technology applications should be researched (topic, age group, interface characteristics, etc.).
- More studies aimed at understanding multi-sensory experiences in relation to AR-applications should be conducted, to explore their impact on learning outcomes.
- A detailed explanation of the materials development process and the factors to be considered in design would facilitate the work of those who may want to use this technology in their future research.
- Some AR research results may be due to an uncontrolled novelty effect; further studies are required to determine whether a novelty factor will continue to significantly affect results in longer term applications.

6. Limitations of the study

Research articles evaluated in review studies are selected according to various criteria (e.g., Drysdale et al., 2013; Hwang & Tsai, 2011; Nolen, 2009; Shih et al., 2008). Here, only studies published in SSCI journals were analyzed. It is possible to find research articles on the educational uses of AR in other databases, such as ERIC and ProQuest. In this systematic review, “article” was selected as the document type. Future researchers may wish to examine conference papers, reviews, editorials, theses, and dissertations. With such wider bases of data, it is possible that different advantages and challenges may be found regarding educational uses of AR technology.

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