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Augmented Reality Trends in Education: A Systematic Review of Research and Applications

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ABSTRACT

In recent years, there has been an increasing interest in applying Augmented Reality (AR) to create unique educational settings. So far, however, there is a lack of review studies with focus on investigating factors such as: the uses, advantages, limitations, effectiveness, challenges and features of augmented reality in educational settings. Personalization for promoting an inclusive learning using AR is also a growing area of interest. This paper reports a systematic review of literature on augmented reality in educational settings considering the factors mentioned before. In total, 32 studies published between 2003 and 2013 in 6 indexed journals were analyzed. The main findings from this review provide the current state of the art on research in AR in education. Furthermore, the paper discusses trends and the vision towards the future and opportunities for further research in augmented reality for educational settings.

Keywords

Augmented reality, Systematic review, Trends of AR, Personalization, Inclusive learning in augmented reality

Introduction and definitions

In recent years, technology-enhanced learning (TEL) research has increasingly focused on emergent technologies such as augmented reality, ubiquitous learning (u-learning), mobile learning (m-learning), serious games and learning analytics for improving the satisfaction and experiences of the users in enriched multimodal learning environments (Johnson, Adams Becker, Estrada, & Freeman, 2014). These researches take advantage of technological innovations in hardware and software for mobile devices and their increasing popularity among people as well as the significant development of user modeling and personalization processes which place the student at the center of the learning process. In particular, augmented reality (AR) research has matured to a level that its applications can now be found in both mobile and non-mobile devices. Research on AR has also demonstrated its extreme usefulness for increasing the student motivation in the learning process (Liu & Chu, 2010; Di Serio et al., 2013; Jara et al., 2011; Bujak et al., 2013; Chang et al., 2014).

An AR system allows for combining or “supplementing” real world objects with virtual objects or superimposed information. As a result virtual objects seem to coexist in the same space with the real world (Azuma et al., 2001). However, AR is not restricted only to the sense of sight; it can be applied to all senses such as hearing, touch and smell (Azuma et al., 2001). AR allows for combining virtual content with the real world seamlessly (Azuma, Billinghurst, & Klinker, 2011). This differs from the notion of a Virtual Environment (VE) where the user is completely immersed inside a synthetic environment. In this sense, “AR supplements reality, rather than completely replacing it” (Azuma, 1997). The Reality-Virtuality continuum (Milgram, Takemura, Utsumi, & Kishino, 1995) clearly shows the relation between a real environment, AR and a virtual environment.

As an example of the current AR applications in education, Ibáñez, Di Serio, Villarán, & Delgado Kloos (2014) created an AR application for teaching the basic concepts of electromagnetism. In this application students can explore the effects of a magnetic field. For that purpose, the components used in the experiment (cable, magnets, battery, etc.) can be recognized using the camera of a mobile device like a tablet. As a result students can see superimposed information such as the electromagnetic forces or the circuit behavior using the tablet. The results of this research show that AR improved academic achievement and provided instant feedback.

Some researchers have proposed different definitions of AR. For example, El Sayed, Zayed, & Sharawy (2011) assert that AR enables the addition of missing information in real life by adding virtual objects to real scenes. Supporting this definition, Chen & Tsai (2012) point out that AR allows for interaction with 2D or 3D virtual objects integrated in a real-world environment. Cuendet, Bonnard, Do-Lenh, & Dillenbourg, (2013) argue that "AR refers to technologies that project digital materials onto real world objects." These definitions are based on one of the features of AR that is the possibility of superimposing virtual information to real objects. On the other hand, a broader perspective has been adopted in the study of Wojciechowski & Cellary (2013). They define AR as an extension of virtual reality with some advantages over virtual reality.

Current state of AR applications in education

A considerable amount of literature has been published in AR's application in educational contexts for a wide variety of learning domains. However, the state of current research in AR for education is still in its infancy (Wu, Lee, Chang, & Liang, 2013; Cheng & Tsai, 2012). According to Wu et al., (2013a) and Cheng & Tsai (2012) the research in this field should continue and should be addressed to discover the affordances and characteristics of AR in education that differentiate this technology from others. Deepening this analysis will allow for discovering the unique value of the learning environments based on AR. According to Chen & Tsai (2012) the potential of AR in educational applications is just now being explored. Dunleavy, Dede, & Mitchell (2009) point out that "we are only beginning to understand effective instructional designs for this emerging technology."

Table 1 summarizes some review studies available in the literature on the topics related to AR in education.

Table 1. Recent review studies on topics related to AR in education

Study	Analysis dimension	Studies reviewed	Summary of findings
(Martin et al., 2011)	The review considered the evolution of technology trends in education from 2004 to 2014 through a bibliometric analysis of the Horizon Reports on the topic of AR as well as on other topics of technology enhanced learning.	10	The number of articles about AR is increasing but according to the analysis this technology is in their initial stage in education. In the study the evolution of AR to mobile augmented reality is considered a successful metatrend.
(Radu, 2012; Radu, 2014)	Review of studies that compare student learning in AR versus non-AR applications.	32, 26	The findings on the positive impact are: Increased content understanding, Learning spatial structures, language associations, long-term memory retention, Improved collaboration and motivation. The findings on the negative impact are: attention tunneling, Usability difficulties, ineffective classroom integration, learner differences.
(Santos et al., 2014)	The review considered papers published in IEEE Xplore. Authors applied a meta-analysis and a qualitative analysis in the dimensions of display methaphors, content creation and evaluation techniques.	87	Authors conclude that there are three main affordances of AR: real world annotation, contextual visualization and vision-haptic visualization. Also authors state that the three affordances are supported by existing theories like: multimedia learning theory, experiential learning and animate vision theory.

A large and growing body of literature has reported factors such as: uses, purposes, advantages, limitations, effectiveness and affordances of AR when they are applied in different learning domains. However, there is gap in the literature with respect to systematic literature reviews looking at these factors of AR in educational settings. Taking into account this, the aim of this systematic literature review is to present the current status of research in AR in education. The study considers categories for analyzing the current state and tendencies of AR such as the uses of AR in educational settings as well as its advantages, limitations, effectiveness; the availability of adaptation and personalization processes in AR educational applications as well as the use of AR for addressing the special needs of students in diverse contexts. The analysis of the different categories allows suggesting trends, challenges, affordances, the opportunities for further research and a general vision towards the future.

The rest of the paper is organized in five sections. First section describes the research questions addressed in this systematic review. Second section describes the methodological design of the study. Third section presents the results jointly with the discussion of the findings. Fourth section follows with a discussion on the trends and the vision toward the future. Finally, fifth section remarks some conclusions.

Research questions

There is a large volume of published studies that report advantages, limitations, effectiveness challenges, etc. of AR in education. However, since AR is an emergent technology, it is important to get an overview of the advances and real impact of its use in educational settings, describing how AR has been used for generate more student-center learning scenarios. Within this context the research questions addressed by this study are:

- What are the uses, purposes, advantages, limitations, effectiveness and affordances of augmented reality in educational settings?
- Have the inclusion of user modeling and adaptive processes been considered in augmented reality applications?
- How has augmented reality addressed the special needs of access and people preferences in educational settings?
- What are the evaluation methods considered for augmented reality applications in educational scenarios?

Method

For this review, we considered the guidelines proposed by (Kitchenham, 2004) and adapted to this literature review:

Planning:

- Selection of Journals
- Definition of inclusion and exclusion criteria of studies
- Definition categories for the analysis

Conduct the review:

- Study selection
- Data extraction (Content analysis method was applied)
- Data synthesis
- Data coding

Reporting the review: This step includes the analysis of results, discussion of findings, trends and conclusions of the review.

Regarding step 3 (Reporting the review), we followed the recommendations of the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement (Moher, Liberati, Tetzlaff, & Altman, 2009). The PRISMA statement is the international and accepted updated version of the QUORUM (Quality of Reporting of Meta-analysis) statement. In the following sub-sections we depict the most important steps followed according to the methodology.

Step 1a: Selection of journals

The aim of this step has been to choose the most relevant journals for the systematic review in a consistent way. To keep the process methodologically strong and scientifically consistent, a method has been defined in this research for selecting journals.

The Google Scholar h5-index for the category "Educational technology" was used as the starting point. This starting point was selected since this category is more specific than "Education and educational research" category from the Journal Citation Report Social Science Citation Index (JCR SSCI). In the later, most of the journals about educational technology are indexed jointly with journals about educational research in general.

We chose the top 5 journals from "Educational Technology" category from Google Scholar h5-index and we named this list "*GS list.*" In order to validate our initial *"GS list,"* we performed an iterative double check process using the JCR SSCI tool in order to consider the impact factor of each journal and its "relatedness" with others. The "relatedness" or most related journals is defined in the JCR taking into account the cited and citing relationship of the journals and is based on the number of citations from one journal to the other and the total number of articles. The iterative double check process was performed as follows: For each journal in the *GS list*, we searched the most related journals to that one using the option "Related Journals" in the JCR SSCI web application (Journal Citation Reports - ISI Web of Knowledge, 2012). As a result, we obtained one list of related journals for each journal in the *GS list*. In this way, we obtained five lists of related journals which were named as *RJ-GS1, RJ-GS2, RJ-GS3, RJ-GS4* and *RJ-GS5, w*here *RJ* stands for "related journal" and *GS#* stands for the corresponding journal from the *GS list*.

We then independently sorted each of the lists *RJ-GS1* to *RJ-GS5* taking into account the impact factor. This process is somewhat similar (by analogy) to a precipitation process (Gooch, 2007) were the journals with major impact factor will "float" in each list. As a result, we obtained 5 independent lists of journals ordered by impact factor. Despite the fact that lists were organized by impact factor, we had some similar journals in each list but at different positions. For example, the British Journal of Educational Technology was at position 7 in the list *RJ-GS1* but at position 4 in *RJ-GS2.* In the remaining lists *(RJ-GS3, RJ-GS4* and *RJ-GS5)* the journal was also in different positions. In order to overcome this situation we combined all the elements of the lists (from *RJ-GS1* to *RJ-GS5*) by pondering the position occupied by each journal through the five lists. As a result, the definite list of journals ordered according to its position was obtained. This list was named *FL-JCR-SSCI list*.

We then analyzed each journal from the *FL-JCR-SSCI list* and discarded journals that did not cover topics about educational technology. This analysis was based on the "subject categories" reported for each journal in the JCR SSCI web application. If necessary we analyzed the aim and scope of each journal to see if the journal could be considered. As a result of this process, we had a new list of journals named *ET-FL-JCR-SSCI.* Where "*ET*" stands for Educational Technology. This list contains only journals that cover the topic of Educational Technology ordered by impact factor. Table 2 shows the first 5 journals of *ET-FL-JCR-SSCI* list that corresponds to the journals selected for this review. We have to point out that this method allowed us to find the most important journals in educational technology through a double check process considering impact factor and "relatedness" in the JCR SSCI.

Table 2. List of the first 5 journals of "*ET-FL-JCR-SSCI list*"

Journal title	Impact factor (JCR SSCI 2012)
Computers and Education	2,775
Internet and Higher Education	2,013
British Journal Of Educational Technology	1,313
Australasian Journal of Educational Technology	1,363
International Journal of Computer-Supported Collaborative Learning	1,717

In order to also consider the Journal Citation Reports Science Citation Index (JCR SCI), we repeated the iterative double check process with the journals indexed in the JCR SCI and obtained another list of journals, namely *ET-FL-JCR-SCI list.* Table 3 shows the first four journals of this list that corresponds to the journals from the JCR-SCI selected for this review. At this point we decided to include in the review, studies published in the first 4 journals of each list (*ET-FL-JCR-SCI and ET-FL-JCR-SSCI*). However, the "Internet and Higher Education" journal was not considered in the review since does not have studies published about AR in education. As a result, we included one additional journal from the *ET-FL-JCR-SSCI* list so that the number of journals considered can be equal. Those journals are the most relevant journals in Educational Technology according to our analysis. Those results were validated by comparing them with the SJR and SNIP indexes obtaining similar results.

Table 3. List of the first 4 journals of "*ET-FL-JCR-SCI list*"

Journal title	Impact factor (JCR SCI 2012)
Knowledge-based systems	4,104
Expert systems with applications	1,854
IEEE Transactions on education	0,95
IEEE Intelligent Systems	1,93

Step 1b: Inclusion and exclusion criteria

Taking into account the research questions, we considered general criteria that define the time frame for the study and the type of studies that are relevant. Accordingly, we defined the following criteria:

General Criteria:
- Studies published between 2003 and 2013.
- Studies that describe applications or frameworks for augmented reality in education.

Specific Criteria:
- Studies that report advantages, disadvantages, affordances, limitations, features, uses, challenges and effectiveness of augmented reality in educational settings.
- Studies that describe applications considering a user model and/or adaptive processes combined with augmented reality.
- Studies that describe applications of augmented reality in education for people in contexts of diversity.
- Studies describing the evaluation methods for augmented reality applications in educational scenarios.

The following exclusion criteria were defined and accordingly, studies meeting these criteria were excluded:
- Studies not identified as "Articles" in the journals selected (e.g., book reviews, books, editorial publication information, book chapters, etc.).
- Studies that mention the term "augmented reality" but are actually about virtual reality or other topics (and the term appears only in the references section).

Step 1c: Categories for the analysis and data coding

In this step, we defined a group of categories of analysis with their corresponding sub-categories according to each research question. Categories help us in grouping studies according to their shared characteristics.
During the systematic review process, some sub-categories emerged and others were refined in order to cover all emerging information. The list of categories for the analysis classified by research questions (RQ) is as follows:

RQ1 - What are the uses, purposes, advantages, limitations, effectiveness and affordances of augmented reality in educational settings?
- Field of Education: Based on International Standard Classification of Education (UNESCO, 2012).
- Target Group: Based on the International Standard Classification of Education (UNESCO, 2012).
- Reported purposes of using AR.
- Reported advantages of AR.
- Reported limitations of AR.
- Reported effectiveness of AR.
- Type of AR.

RQ 2 - Have the inclusion of combined adaptive or personalized processes been considered in augmented reality applications?
- Type of adaptation process.
- Type of user modeling.

RQ 3 - How has augmented reality addressed the special needs of access and people preferences in educational settings?
- Special Need addressed.
- Intervention method.

RQ 4 - What are the evaluation methods considered for augmented reality applications in educational scenarios?

- Research sample.
- Research method
- Time dimension.
- Data collection method.

Content analysis allows to find the research trends of a topic by analyzing the articles' content and grouping them according to the shared characteristics (Hsu, Hung, & Ching, 2013). This method was applied in order to extract the information of each paper. Two of the authors of the paper manually coded the studies separately according to their characteristics and classified them according to the categories and sub-categories defined. In case of discrepancy, the coders resolved it through discussion.

Results (Steps 2 and 3)

In this section the results of conducting the review are described and discussed. In step 2a we searched manually in the selected journals and applied the inclusion and exclusion criteria in order to select the studies for the review. As a result of this process we selected 32 studies from journals. Steps 2b and 2c were carried out by reading the papers completely and the data coding process was performed taking into account the categories defined in step 1c. In order to present the results this section was organized taking into account each research question addressed.

In total 30 studies were analyzed from the 5 journals selected from the JCR-SSCI and 2 studies were analyzed from the 4 journals selected from the JCR-SCI. Table 4 shows the number of studies analyzed by journal. It is important to note that in the table, the year 2013* includes the papers published until February 2014.

By analyzing the year of publication of the studies considered we found that the number of published studies about AR in education has progressively increased year by year specially during the last 4 years. This means that many researchers are interested in exploring the features, advantages, limitations of AR in educational settings. According to these results, AR in education is an emerging topic and this finding corroborates the ideas of Wu, Lee, Chang, & Liang (2013) and Cheng & Tsai (2012), who point out that the research on AR in education is in the initial phase. As Bujak et al. (2013) suggest: "Augmented reality (AR) is just starting to scratch the surface in educational applications." One of the issues that emerge from these findings is that more research needs to be undertaken in the topic of AR in education.

Table 4. Number of studies analyzed in this review by journal

Journal	Studies analyzed (2003-2013*)
JCR-SSCI Journals	Total: 30
Computers & Education	23
Internet and Higher Education	0
British Journal of Educational Technology	4
Australasian Journal of Educational Technology	1
International Journal of Computer-Supported Collaborative Learning	2
JCR-SCI Journals	Total: 2
Knowledge-based systems	0
Expert systems with applications	1
IEEE Transactions on education	1
IEEE Intelligent Systems	0

In the following subsections, our findings with respect to each research question are presented.

What are the uses, purposes, advantages, limitations, effectiveness and affordances of augmented reality in educational settings?

With respect to the uses of AR in education, Table 5 presents the results obtained from the data coding process in the category of "Field of education." This table clearly shows the use of augmented reality by each field of education.

The most striking result to emerge from the data is that most of the studies (40.6%) were applied in the field of "Science." This result indicates that most of the research done in AR applied to education has been concentrated on identifying the benefits of AR in science education. A possible explanation of this is that AR has demonstrated to be effective when applied to lab experiments (Ibáñez, Di Serio, Villarán, & Delgado Kloos, 2014; Lin, Duh, Li, Wang, & Tsai, 2013; Enyedy, Danish, Delacruz, & Kumar, 2012), ecology (Wrzesien & Alcañiz Raya, 2010), field trips (Kamarainen et al., 2013), mathematics and geometry (Blake & Butcher-Green, 2009), scientific issues (Chang, Wu, & Hsu, 2013) and in general, activities where students can see things that could not be seen in the real world or without a specialized device. Besides that, students "do not have to use their imagination to envision what is happening. They can see it" (Furió, González-Gancedo, Juan, Seguí, & Rando, 2013) which also means that AR is effective for teaching abstract or complex concepts. A prior study has noted the importance of AR in science education. (Cheng & Tsai, 2012).

Following "Science" learning, "Humanities & Arts" was the second field of education in which AR was applied the most (21.9%). Studies in this field of education focused on language learning (Liu & Tsai, 2013; Chang, Lee, Wang, & Chen, 2010; Ho, Nelson, & Müeller-Wittig, 2011; Liu & Chu, 2010), visual art and painting appreciation (Di Serio, Ibáñez, & Kloos, 2013; Chang et al., 2014), and culture and multiculturalism (Furió et al., 2013). Interestingly, AR has been widely used in language learning due to the possibility of augment information and combining it with contextual information to provide new experiences in language learning. On the other hand, thanks to the possibility of adding virtual information to the real world AR has been applied in painting appreciation in order to provide an enhanced experience.

In "Social Sciences, Business and Law" and "Engineering, manufacturing and construction," AR is being explored. Only 12.5% of the studies reviewed applied AR in "Social Sciences" and 15.6% applied AR in Engineering, manufacturing and construction.

Finally the results of our review show that the less explored fields of education are "Health and welfare" (3.1%) and Services and Others (travelling, transport, security services and hotel) with 6.3% of the studies reviewed. According to our review, no investigations have delved in the field "Educational" (teacher training in all levels of education) as well as the field of agriculture. The present results are significant in order to encourage researchers to explore the use of AR in teacher training and agriculture, forestry, fishery, veterinary, etc.

Table 5. Augmented reality uses by "Field of education"

Sub-category	Number of studies	Percentage (%)
Educational	0	0.0
Humanities & Arts	7	21.9
Social Sciences Business and Law	4	12.5
Science	13	40.6
Engineering, manufacturing and construction	5	15.6
Agriculture	0	0.0
Health and welfare	1	3.1
Services and Others	2	6.3

Regarding the "Target group," this category refers to the level of education of participants in the experiments in which the study of AR in education was carried out. Table 6 summarizes the results. This table is quite revealing in several ways. First, it is worth noticing that AR has been mostly applied in higher education settings (Bachelor's or equivalent level) and compulsory education (primary, lower and upper secondary education). Most of the studies reviewed in these target groups applied AR for motivating the students, explaining topics, adding information and other purposes that are discussed later. It seems possible that AR has been applied in settings with this target group in order to improve the educational experience of the students and motivate and engage them by taking advantage of the features of this technology. In the studies reviewed there were no evidence of AR applications in the field "Early childhood education" (0%). A possible explanation of this result is that the technology could not be ready for being used by children since many aspects of interaction, such as the tracking and use of markers, need to be solved. We encourage researchers to explore the use of AR in this field.

On the other hand, "Post-secondary non-tertiary education" (0%) and "Short-cycle tertiary education" (3.1%) are target groups that need further research on the impact of AR in educational settings. This target groups are part of the

Vocational Educational Training (VET) in which AR could provide benefits in the learning process for facilitating the access to the labor market. So far, not many studies have been reported in this area. Finally, there were no evidence of using AR in "Masters or equivalent level" (0%) and "Doctoral" (0%) educational settings. This result may be explained by the fact that Master's and PhD students typically are involved in creating new AR applications for the other levels.

Table 6. Target group in which AR studies were carried out

Sub-category	Number of studies	Percentage (%)
Early childhood education	0	0.00
Primary education	6	18.75
Lower secondary education	6	18.75
Upper secondary education	4	12.50
Post-secondary non-tertiary education	0	0.00
Short-cycle tertiary education	1	3.13
Bachelor's or equivalent level	11	34.38
Master's or equivalent level	0	0.00
Doctoral	0	0.00
Informal Learning	2	6.25
Not mentioned in the study	2	6.25

With respect to category "Purposes of using AR" in education, table 7 summarizes the results. Since one study can report more than one purpose, each study can meet more than one sub-category. It can be seen from this data that most of the studies used AR with the purpose of explaining a topic (43.7%) and augment information (40.6%). Explaining the topic refers to the use of an AR application in order to support the learning of a specific topic (Wrzesien & Alcañiz Raya, 2010; Chang et al., 2013). On the other hand, "augment information" refers to the use of AR for providing supplemental material by means of markers placed on printed material that students used to access digital resources (Huang, Wu, & Chen, 2012; Chen, Teng, & Lee, 2011)..

Table 7 also shows that the purposes of using AR combined with "Educational Game" (18.7%) and for "Lab experiments" (12.5%) are being explored. In this sense, we encourage researchers to explore in detail the uses of AR in educational games in order to identify its features, advantages and drawbacks. Furió et al., (2013) claim that "there are few mobile learning games that use this technology." Further research regarding to the role of AR for supporting lab experiments needs to be done, for example, the analysis of the impact of AR for reducing the cost of lab experiments or its strengths for offering a most inclusive experience for people with disabilities. Furthermore, according to the results, very little was found in the literature on using AR for activities for "Exploration" and discovering the world through AR (3.1%) and no studies were found with focus on using AR for evaluating a topic (0%) and the use of AR for other educational purposes (0%) different from the ones mentioned before.

Table 7. Purposes of using AR in educational settings

Sub-category	Number of studies	Percentage (%)
Explaining the topic	14	43.75
Evaluation of a topic	0	0.00
Lab experiments	4	12.50
Educational Game	6	18.75
Augment information	13	40.63
Exploration	1	3.13
Other purposes	0	0.00

Another category analyzed in this systematic literature review deals with the "Reported Advantages" of AR in educational settings. Table 8 shows the results of the reported advantages identified in the studies analyzed. Since one study can report more than one advantage, each study can meet more than one sub-category. From the results, it can be seen that the major advantages reported in the studies are: "Learning gains" (43.7%) and "Motivation" (31.2%). These results corroborate the benefits of AR for improving the learning performance and motivating students (Liu & Chu, 2010; Di Serio et al., 2013; Jara et al., 2011; Chang et al., 2014). Some studies have reported other advantages of AR that are listed in table 8. However, these advantages need to be further explored in order to understand the real benefits of AR-based learning experiences. On the other hand, very little was found in the literature on advantages of AR in educational settings such as: "Increase capacity of innovation" (6.2%), "creating positive attitudes" (6.2%), "Awareness" (3.1%), "Anticipation" (3.1%), "Authenticity" (3.1%), and "Novelty of the technology" (0%). In this sense, there is a need of more research in order to validate if those factors are advantages of AR in education.

Although interaction and collaboration have emerged as main advantages of AR, surprisingly data collection methods (discussed later in research question 4) such as focus groups or conversational analysis did not appear during the review. There are many evaluation mechanisms that have not been explored because the technology is not enough mature, so there is a gap between the affordances of AR, its advantages, uses, research methodologies and the evaluation mechanisms applied.

Table 8. Reported advantages of AR in educational settings

Sub-category	Number of studies	Percentage (%)
Learning gains	14	43.75
Motivation	10	31.25
Facilitate Interaction	5	15.63
Collaboration	6	18.75
Low cost	4	12.50
Increase the experience	4	12.50
Just-In-time Information	4	12.50
Situated Learning	3	9.38
Student-centred	3	9.38
Students' attention	3	9.38
Enjoyment	3	9.38
Exploration	4	12.50
Increase capacity of innovation	2	6.25
Create positive attitudes	2	6.25
Awareness	1	3.13
Anticipation	1	3.13
Authenticity	1	3.13
Novelty of the technology	0	0.00

Turning now to the category "Limitations of AR", this category aims to identify the limitations of AR in educational settings. Results are shown in Table 9. From this data it can be seen that the most reported limitation in the studies reviewed are "Difficulties maintaining superimposed information" (9.3%). Students may feel frustrated if the application does not work properly or if it is difficult for them to use the markers or the device in order to see the augmented information. In order to overcome this limitation there is a need of improving the algorithms for tracking and image processing. In addition to this, it is recommended that further research be undertaken in usability studies for AR applications in education as well as guidelines for designing AR-based educational settings.

Another limitation reported was "Paying too much attention to virtual information" (6.2%). This limitation is related to the novelty of this technology when it is used for the first time in the classroom. So, students may be distracted by the virtual information showed or the technology itself. "Intrusive Technology" (6.2%) was also a limitation reported which is connected with the use of HDM (Head-mounted displays) (Zarraonandia, Aedo, Díaz, & Montero, 2013) because the device can interrupt the natural interaction with others.

Other limitations reported in the studies are: "Designed for a specific knowledge field" (3.3%) and "Teachers cannot create new learning content" (3.1%). In this sense, it is recommended that further research be undertaken in authoring tools for creating AR activities so that teachers can create their own content with AR support.

Table 9. Limitations of AR in educational settings

Sub-category	Number of studies	Percentage (%)
Designed for a specific knowledge field	1	3.13
Teachers cannot create new learning content	1	3.13
Difficulties maintaining superimposed information	3	9.38
Paying too much attention to virtual information	2	6.25

Short periods of validation	1	3.13
Intrusive Technology	2	6.25
Not specified in the study	22	68.75

With respect to the category "Effectiveness of AR," table 10 shows the results. Since one study can report more than one sub-category of effectiveness, each study can meet more than one sub-category. Most of the studies reported that AR applications lead to "Better learning performance" (53.3%) in educational settings. "Learning motivation" (28.1%) and "Student engagement" (15.6%) were also reported. The results show that AR is a promising technology for improving the student's learning performance and motivate the students to learn thanks to the interaction and graphical content used. "Improved perceived enjoyment" (12.5%) and "Positive attitudes" (12.5%) were less reported but are also important in educational settings.

Table 10. Effectiveness of using AR in educational settings

Sub-category	Number of studies	Percentage (%)
Better learning performance	17	53.13
Learning motivation	9	28.13
Improve perceived enjoyment	4	12.50
Decrease the education cost	0	0.00
Positive attitudes	4	12.50
Student engagement	5	15.63

Regarding the "Type of AR" considered in the studies reviewed, table 11 summarizes the results. We considered three types of AR according to the classification of Wojciechowski & Cellary (2013): marker-based AR, marker-less AR and location-based AR. Marker-based AR is based on the use of markers. Markers are labels that contain a colored or black and white pattern that is recognized or registered by the AR application through the camera of the device in order to fire an event that can be, for instance, to show a 3D image in the screen of the device located in the same position where the marker is. Marker-less AR is based on the recognition of the object's shapes. And location-based AR superimposes information according to the geographical location of the user.

The results in table 11 reveal that most of the studies used "Marker-based AR" (59.3%) which means that most of the applications developed for educational settings use markers. A possible explanation for this result is that currently the tracking process of markers is better and more stable compared to the marker-less tracking techniques. The use of static markers decrease the tracking work needed and reduce the number of objects to be detected (El Sayed et al., 2011). Therefore for educational settings the use of markers could be recommended so that students can have a better experience with the technology until better techniques for tracking can be developed for marker-less AR. "Marker-less AR" has not been widely used in educational settings (12.5%). However, there is a trend of using Microsoft Kinect sensors and similar technologies in order to create AR applications for educational settings (Fallavollita et al., 2013; Pillat, Nagendran, & Lindgren, 2012). Microsoft Kinect provides some advantages in tracking and registering objects in marker-less AR.

Table 11. Types of AR applied in education

Code	Sub-category	Number of studies	Percentage (%)
SC1	Marker-based AR	19	59.38%
SC2	Marker-less AR	4	12.50%
SC3	Location-based AR	7	21.88%
SC4	Not specified in the study	2	6.25%

Interestingly, the development of "Location-based AR" (21.8%) applications is major compared to marker-less AR applications. This can be due to the availability of sensors in mobile devices like the accelerometer, gyroscope, digital compass and the possibility of using GPS. These technological advancements open possibilities for developing applications of AR that can be aware of the user's location in order to show information according to the geographical position and/or orientation.

Have the inclusion of combined adaptive or personalized processes been considered in augmented reality applications?

In the studies reviewed only 2 out of 32 studies report some kind of personalized process and 1 out of 32 considered a user modeling process. Barak & Ziv (2013) created "Wandering" which is an application for creating location-based interactive learning objects (LILOs) and considers personalization as an "important requirement of the 21st century skills" (Barak & Ziv, 2013). Personalization is considered for meeting the needs and interests of the individual learners. However, in the study where the authors describe the Wandering application is not clear if they have a user model. On the other hand, Blake & Butcher-Green (2009) propose an application for customized training based on a scaffolding instructional approach and an agent architecture in order to training individuals from diverse backgrounds. The type of adaptation process considered by the application is personalization based on historical training profiles. However in the paper is not clear if the information for the user model comes from the learner's profile. In addition to this, the authors states that the system was being integrated with the AR environment when the paper was written. The results of the paper are based on a simulated AR environment (Blake & Butcher-Green, 2009).

How has augmented reality addressed the special needs of access and people preferences in educational settings?

In the studies reviewed from journals there was no evidence of AR applications in educational settings that address the special needs of students. This finding corroborates the idea of Wu, Wen-Yu, Chang, & Liang (2013) who state that few systems have been designed for students with special needs. According to Lindsay (2007) the opportunities for children with special needs and disabilities can be improved by a major policy initiative called "inclusion". Inclusive education is more than integration because integration refers to the learner adapting to the educational setting while inclusion means that the educational setting adapts to the learner in order to meet their needs (Lindsay, 2007). Within this sense AR may offer unique advantages and benefits in order to create inclusive AR-based educational settings. Further research is needed in order to identify the effectiveness and advantages of AR applications for addressing the special needs of students.

What are the evaluation methods considered for augmented reality applications in educational scenarios?

With respect to the evaluation methods for AR applications in educational settings we considered four sub-categories for the analysis. The results show that, regarding to "Research Samples" (table 12), most of the studies used medium research samples "between 30 and 200" (78.1%) and some studies considered small research samples "30 or less than 30" (18.7%). In our review we did not find studies that used research samples greater than 200 participants ("More than 200" (0%)). A possible explanation of this result is that greater research samples would need more devices (handheld devices, PC, web cam, tablets, etc.) so that each participant can have one device.

Table 12. Research samples in the studies reviewed

Sub-category	Number of studies	Percentage (%)
30 or less than 30	6	18,75
Between 30 and 200	25	78,13
More than 200	0	0,00
Not Specified in the study	1	3,13

Regarding the "Research Methods," table 13 shows that most of the studies applied "mixed methods" (46.8%), "Qualitative-Exploratory-Case study" (21.8%), "Quantitative-Descriptive research" (15.6%) and "Qualitative-Exploratory-Pilot Study" (12.5%) as research methods to conduct the study. Few studies have applied "Quantitative-Explanatory and Causal research" (3.1%) and "Qualitative-Exploratory-Experience Survey" (0%).

Table 13. Research methods applied

Sub-category	Number of studies	Percentage (%)
Qualitative-Exploratory-Case Study	7	21,88
Qualitative-Exploratory-Pilot Study	4	12,50
Qualitative-Exploratory-Experience Survey	0	0,00

Quantitative-Descriptive Research	5	15,63
Quantitative-Explanatory and Causal Research	1	3,13
Mixed Methods	15	46,88
Other	0	0,00

Turning now to the "Time dimension" of the studies reviewed, table 14 shows that almost all of the studies were identified as "Cross-sectional" (93.7%) and only 6.2% of the studies were identified as "Longitudinal Study." An implication of this result could be that the novelty of the technology in cross-sectional studies may affect the results since students can be engaged with the AR application because it is new for them. Future studies conducted as longitudinal studies need to be undertaken in order to follow the students in the long term and identify the advantages, benefits, limitations when students are exposed to this technology for a long period and also when students are used to using AR in the classroom as well as analyze the student's behavior in different learning scenarios.

Table 14. Time dimension of the studies reviewed

Sub-category	Number of studies	Percentage (%)
Cross-sectional Study	30	93,75
Longitudinal Study	2	6,25

Finally, for "Data Collection methods" as table 15 shows, most of the studies applied "Questionnaires" (75%), "interviews" (28.3%), "surveys" (18.7%) and "cases observation" (9.3%) as data collection methods. "Focus group" (0%) and "Writing Essay" (3.1%) have either not been used or used very little. Since one study can apply more than one data collection method this study counts for more than one category.

Table 15. Data collection methods

Sub-category	Number of studies	Percentage (%)
Questionnaires	24	75,00
Interviews	9	28,13
Focus-groups	0	0,00
Survey	6	18,75
Cases observation	3	9,38
Writing Essay	1	3,13
Other	1	3,13

Trends and future vision

This study presents a detailed systematic review of the state of the art in Augment reality as a promising technology for supporting technology-enhanced learning. In this section we discuss our main findings highlighting what we consider as the strongest future directions of research in this field.

AR technology

Marker-based AR as mentioned in the results section is the most used approach for supporting the development of AR learning experience, followed by the location-based AR. A possible explanation for this result is that currently the tracking process of markers is better and more stable compared to the marker-less tracking techniques. Besides that one of the advantages of marker-based AR is the facility of implementation due to the available libraries which support the development process. There is a challenge around the improvement of recognition algorithms for human forms as a promising feature in the process of achieving more immersive and not intrusive AR learning experiences (Zarraonandia et al., 2013). Accessibility and usability of the AR learning experiences are two important issues to be addressed in future research since few studies have reported research on this field. In fact, only 4 out of 32 studies consider those factors (Di Serio et al., 2013; Ibáñez et al., 2014; Ho et al., 2011; Cuendet et al., 2013). Further research need to be undertaken in usability studies for AR applications in education as well as guidelines for designing AR-based educational settings.

Some recent studies have reported new research directions:

- There is a need for "new methods for creating interactive 3D content for AR learning environments" (Wojciechowski & Cellary, 2013; K.-E. Chang et al., 2014) and creating authoring tools for teachers to create content.
- Understand how to design AR learning experiences according to the topic taking into account the skills of learners (Bujak et al., 2013).
- Creating multisensory experiences with AR (Ho et al., 2011) and explore their impact in the learning outcomes.
- Carry out more studies for understanding the user experience and knowledge construction processes in AR applications (Lin et al., 2013).

Attention to diversity and special needs in the learning process

Although there are not many reported papers considering samples which include people with special need of access to educational context, the multimodal possibilities of AR applications seems to be a good option for addressing the special necessities of diverse population.

Some challenges are the definition of frameworks for user model representations as well as frameworks to support personalization processes. In fact, a starting point could be the analysis of existing frameworks for AR (Bujak et al., 2013; Chen et al., 2011; Price & Rogers, 2004) in order to analyse the feasibility of integration of these frameworks to offer an augmented but also an adaptive learning experience to users. These frameworks should at least include the definition of semantics to represent the user's profiles and their context, semantics to represent the metadata of the AR resources as well as semantic to represent different possibilities of adaptations.

On the other hand, the multimodal possibilities of AR applications seem to be a good option for supporting therapy processes for people with sensorial and physics impairments. It demonstrates that AR increases the motivation of the user developing specific tasks which is one of the challenges in therapy processes (Correa, Ficheman, Nascimento, & Lopes, 2009). Finally, it can thus be suggested that frameworks for personalized AR should consider pedagogical and didactical components in order to guide the development of AR-based educational settings.

The need for longitudinal studies

Based on the conducted analysis, we conclude that more studies need to be undertaken considering a large scale evaluation and longitudinal evaluations in future researches. Many cross-sectional studies have been conducted as shown in the results of this review, being an efficient research method in order to establish comparisons between AR learning experiences with respect to other cases of learning experience. However, in the case of educational settings is also important to study the evolution of knowledge and skills over time, as proposed by longitudinal studies. Long term analysis of the AR learning experience could give important inputs about the suitability of this technology for supporting significant learning (Mendoza Gómez, 2005).

Vocational educational training (VET) as target groups for future research

According to our research, only 3.1% of the studies were carried out considering a sample of students from vocational educational training institutions. From our point of view, VET institutions are promising research partners not only for validation but also for demonstrating the possibilities of AR learning scenarios for improving and acquiring professional competences. Possibilities offered for AR could reduce the cost of carrying out some learning experience where expensive learning material is necessary. For example, physical materials to learn how to create a gem could be difficult to buy by institutions with limited economic resources. In this sense, combining virtual objects as different kind of physical materials with real objects such as the students' hands could be a good option to explore.

Conclusions

In this paper a systematic literature review was reported. In total 32 studies from journals were analyzed by using the content analysis method. We analyzed the following factors of the studies selected: Field of education, target group, type of AR, reported purposes, advantages, limitations, affordances and effectiveness of AR in educational settings. Besides that, adaptation processes and user modeling in AR as well as the addressing of individual special needs with AR applications was also considered for the analysis. Regarding the evaluation methods we analyzed the research sample, research method, and time dimension of the study. Furthermore, we defined a validated method for selecting journals through a methodologically strong and consistent process that can be applied for systematic reviews in other topics.

A short summary of the main findings of this review are:

- The number of published studies about AR in education has progressively increased year by year specially during the last 4 years.
- Science and Humanities & Arts are the fields of education where AR has been applied the most. Health & welfare, Educational (teacher training) and Agriculture are the research fields that were the least explored fields.
- AR has been mostly applied in higher education settings and compulsory levels of education for motivating students. Target groups like early childhood education and Vocational educational Training (VET) are potential groups for exploring the uses of AR in future.
- Marker-based AR is the most used type of AR. In addition location-based AR is being widely applied. This can be due to the availability of sensors in mobile devices like the accelerometer, gyroscope, digital compass and the possibility of using GPS. Marker-less AR needs some improvement in algorithms for tracking objects but the use of Microsoft Kinect is becoming more and more popular.
- The main purpose of using AR has been for explaining a topic of interest as well as providing additional information. AR educational games and AR for lab experiments are also growing fields.
- The main advantages for AR are: learning gains, motivation, interaction and collaboration.
- Limitations of AR are mainly: difficulties maintaining superimposed information, paying too much attention to virtual information and the consideration of AR as an intrusive technology.
- AR has been effective for: a better learning performance, learning motivation, student engagement and positive attitudes.
- Very few systems have considered the special needs of students in AR. Here there is a potential field for further research.
- Most of the studies have considered medium research samples (between 30 and 200 participants), and most of the studies have used mixed evaluation methods. The most popular data collection methods were questionnaires, interviews and surveys and most of the studies were cross-sectional.

This work contributes to existing knowledge in AR in educational settings by providing the current state of research in this topic. This research also has identified relevant aspects that need further research in order to identify the benefits of this technology to improve the learning processes.

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