Augmented Reality in Education

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Augmented reality (AR) enables an interactive experience with the real world where objects in the real world are enhanced by computer-generated perceptual information. This technology has positively influenced different fields, such as industry, entertainment, medicine, tourism, among others. This Entry will explain an overview of twenty-five years of augmented reality in education.

Keywords: artificial intelligence ; augmented reality ; education ; smartglasses ; systematic review ; WebAR

1. Introduction

Augmented reality (AR) enables an interactive experience with the real world where objects in the real world are enhanced by computer-generated perceptual information. This technology has positively influenced different fields, such as industry, entertainment, medicine, tourism, among others. Nevertheless, experts assure that this is only the beginning and that the future of AR will bring better, cheaper, and more accessible applications [1].

Twenty-five years have passed since the development of the first AR application designed exclusively to be used in educational settings. Since then, AR applications have been successfully implemented at different levels of education, different fields of education, and different educational environments providing multiple benefits for learners [2]. However, there are still some pending issues that must be addressed to obtain the best of this technology to enrich education. Furthermore, it is important to note that as AR hardware evolves, AR applications will evolve, presenting new affordances and challenges for the AR research area.

This study provides an overview of AR technology in education from its origins to the present day. It identifies its history, status, and trends in the educational context and shows how educational AR applications have undergone different phases since the first application in 1995. Consequently, based on the analysis of its evolution, the study proposes three generations of AR technology in education. Subsequently, the study identifies some pending issues from previous applications and finally, it highlights some insights to solve such issues to enhance the benefits of AR for education.

2. Overview of AR in Education

According to records in the scientific and academic literature databases, the first AR system designed exclusively to be implemented in educational settings was a tool for teaching three-dimensional anatomy. This AR tool superimposed and registered bone structures on real anatomical counterparts of a human subject to teach anatomy using a head-mounted display. The system was developed at the University of North Carolina and introduced by its creators in the first International Conference on Computer Vision, Virtual Reality, and Robotics in Medicine held in Nice, France, in 1995 [3].

The Web of Science (WoS) reports 80 AR studies in education published in that period, which focused on AR applications to complement the learning processes in the fields of Health, Engineering, and Natural Sciences. It is also important to note that most of these applications were intended for undergraduate students and that only a few educational institutions could afford these applications given their high costs [4]. Thus, we could describe the first 15 years of AR in education as a transition period because of some notable limitations that yielded a small number of AR applications. Additionally, the scope of these applications was narrow, considering that apparently only three fields of education and one level of education were benefiting from them.

Second, it is not necessary to have expensive and complex systems to develop or use the application, as everyday devices such as smartphones provide all the necessary hardware to bring AR experiences to life. This panorama was completed in 2011 with the release of Vuforia, the current most popular SDKs for developing educational AR applications [5]. Only nineteen days later, it reached 50 million users, becoming the most popular smartphone application ever, and consequently, one of the drivers of AR's popularity [6]. Consequently, the last decade of AR in education has flourished with many applications that have complemented learning processes in all fields of education and at all levels of education [7].

The internationally recognized series of Horizon Reports claims that new technologies such as AR will lead to a redesign of learning and teaching [8]. Horizon Reports argues that the increased use of AR has enabled mobile learning to become more active and collaborative, creating limitless learning experiences. In this regard, as stated by the study by Garzón, Kinshuk, Baldiris, Gutiérrez, and Pavón [9], future AR applications should consider not only technical characteristics but also an appropriate pedagogical approach that potentiates the affordances of AR for education. This panorama, united to the development of emerging scenarios for AR such as smartglasses, AR-based Web (WebAR), and the integration of Artificial Intelligence (AI) seems to pose unthinkable opportunities to enrich educational contexts.

One document type parameter was modified to be adjusted to the purpose of the search. Document type included only articles, proceeding papers, reviews, and book chapters, and excluded meeting abstracts, editorial material, corrections, and book reviews. This search resulted in 2698 studies, including 1317 proceeding papers, 1857 articles, 100 reviews, and 56 book chapters. **Figure 1**sorts the studies by year of publication, where the first study of AR in education in the WoS was published in 1996.

Figure 1shows a steady increase in the number of studies of AR in education. Furthermore, data analysis highlights two important facts. Second, the most noticeable increases occurred from 2014 to 2015 and from 2016 to 2017. These two events brought AR to prominence technologies, attracting many developers worldwide to create AR applications for education.

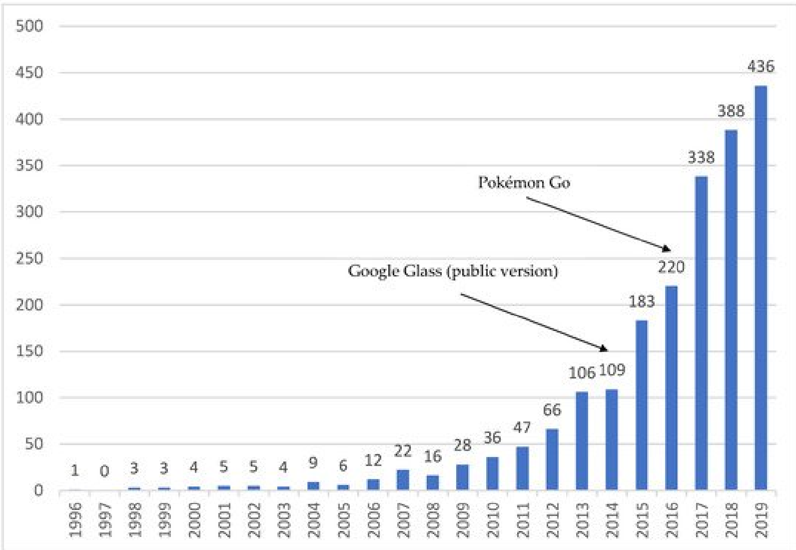

Figure 1. Number of studies of AR in education per year in the WoS.

To complete the analysis of the status of AR in education, we sorted the studies by country, university, and language. Accordingly, data indicate that the Unites States (347), Spain (273), Taiwan (114), China (113), and Germany (110) are the five most representative countries. Similarly, the State University System of Florida (31), University of La Laguna (23), Polytechnic University of Valencia (23), Harvard University (21), and University of Sevilla (21) are the most representative universities. According to the languages, data indicate that English (1898), Spanish (94), Portuguese (20), German (6), and Russian (5) are the most used languages to communicate AR in education-related studies.

To identify the trends regarding the level of education, fields of education, and delivery technology, we based our work on the studies by Garzón et al. The studies found that AR applications have been successfully implemented to teach most fields of education. On the other hand, the studies found that AR applications have been implemented at most levels of education. Based on the definition of the International Standard Classification of Education [10], the most popular levels of education are Bachelor, followed by Secondary education and Primary education.

Based on the analysis of its evolution, we pose three generations of AR applications in education (see **Figure 2**). The first generation covers the period from 1995 to 2009 and could be described as hardware-based AR, as the delivery technology was the protagonist of the AR experience. The second generation covers the period from 2010 to 2019 and could be described as application-based AR, as the AR experience focused on AR applications rather than AR hardware. Finally, the third generation runs from 2020 onward and seems to be characterized by dedicated AR devices such as smartglasses and Web-based AR.

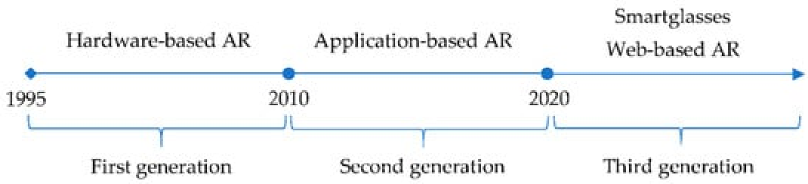

Figure 2. Three generations of AR in education.

All these systems were intended to teach subjects related to health, natural sciences, or engineering, and focused on bachelor students as target groups. The high cost of 1GARE applications was related to expensive hardware devices, the need for specialized maintenance of hardware devices, and the need for special programming skills for content development [11]. Consequently, the acquisition of AR educational applications was unfeasible for most educational institutions, which did not make the effort to afford them, considering the multiple available educational technology tools that provided similar benefits. Because of high costs and low usability, 1GARE applications were unpopular in educational environments, thus affecting their dissemination [12].

This analysis described AR as an especially valuable technology for education as it can support seamless interaction between real and virtual environments. However, the limited number of available user studies did not allow it to identify the real impact of AR on education. This is considered the first analysis of user studies and concludes that the novelty effect becomes a motivating factor for students to learn to use AR applications. However, the study predicts the possibility that the novelty engagement will fade as students become accustomed to this method of learning, and consequently they warned of an uncertain future for AR in education.

First, the fact that AR applications could be deployed in mobile devices meant that more people could access AR, eliminating the need to purchase expensive devices. Additionally, the emergence of game engines, SDKs, and libraries to develop AR applications enabled easier methods to develop AR applications, saving time and money. Moreover, as mobile devices became everyday use technology These two novel applications raised the interest of a great number of developers and users of AR technology, positioning it among the most relevant alternatives in educational technology.

This study stated that AR has substantial potential implications and numerous benefits for teaching and learning. The study posed, accurately, that such directions would guide the future of AR in education. Two years later, Wu, Lee, Chang, and Liang [13] published the most cited study of AR in education. The study highlights learning gains and motivation as the main advantages of AR in education, while the most important challenge is the inclusion of pedagogical strategies to accompany AR interventions.

Although AR has become one of the most interesting technologies in the digital industry, trends seem to indicate that it has not reached its full potential. In this sense, the future of AR appears to evolve beyond head-mounted displays and smartphones, with three main scenarios that have emerged recently, namely, smartglasses, WebAR, and AI.

The first scenario characterizes by stand-alone headsets such as HoloLens, Oculus Rift, or the upcoming iGlass, which are part of a new generation of smartglasses. According to ABI Research, shipments of smartglasses worldwide will rise from 225 thousand units in 2017 to around 32.7 million in 2022 [14]. This poses a new frame for the future of AR applications, that will potentially influence industry, medicine, tourism, education, among others, providing important advantages over other forms of technology.

The second scenario appears as a solution for the reluctance of some people to experience AR via smartphone applications. To experience AR on smartphones, users must install a dedicated application. However, users often remove it after a few uses and other potential users do not take the trouble to download it at all. Hence, in 2017, WebAR appears to enable smartphone users to discover AR technology via the Web, eliminating the installation process [15].

Finally, the third scenario brings together AR and AI to create solutions to different problems of everyday life [16]. This union bridges the physical and digital worlds, moving the boundaries of the digital world beyond screens and into the multisensory 3D world. AI fuels AR, enabling the shift to more realistic and engaging experiences and a more powerful customization of applications. Consequently, the integration of AR with AI opens a new direction for developers and researchers to explore and experiment, which will potentially create a renewed paradigm for AR.

3. Pending Issues of AR in Education

Despite the multiple proven benefits of using AR in educational settings, there are some pending issues that need to be addressed to enhance the impact of AR on education. Based on the previous literature, this study identifies four major issues that should guide future research directions, namely, accessibility, usability, dissemination, and pedagogical approaches.

The first issue is related to accessibility, which mainly affects people with some type of disability. In education, the term special needs refers to students who have some type of disability, including blindness or vision impairment, deaf or hard of hearing, intellectual disabilities, and physical disabilities. Despite some efforts and the proven benefits of AR for special needs education, most AR applications for education still lack accessibility characteristics [7]. In this sense, the incorporation of accessibility features in AR applications has the potential to bring the numerous advantages of this technology to enhance special needs education.

The second issue refers to usability, which is related to the ease of use of AR applications. In fact, different studies have indicated that the most reported challenge of AR in education refers to the complexity of using AR systems [7][17][18][19]. As pointed by Akçayir and Akçayir [17], AR involves multiple senses and requires simultaneous tasks from students, which may overload their attention, affecting the usability of AR systems. Therefore, it is important to consider design strategies that favor the usability of AR applications to ensure that they can be easily implemented in any educational context.

The third issue is related to dissemination, which derives from aspects such as cross-platform deployment and the need for download and installation. Most AR applications are designed to be implemented on a specific platform and lack cross-platform support, which affects their dissemination. Consequently, to reach more users, developers of AR applications must go through repeated development cycles to accommodate multiple platforms, increasing production time and costs [1]. This causes users to often delete the application after a few uses to save space on their devices and other potential users

Finally, the fourth issue is related to the lack of pedagogical approaches when integrating AR applications into learning activities. This issue has been identified by different studies, signaling that in most cases teachers use AR applications without considering pedagogical aspects, reducing the effectiveness of the interventions [20][21]. To complement this point, different studies indicate that the lack of formal pedagogical approaches when applying AR to learning activities tends to confuse and frustrate students [22][23]. Therefore, it is necessary to identify which pedagogical approaches are the most appropriate for each educational setting, to encourage stakeholders to consider technology together with pedagogical strategies to guarantee the best of AR for education.

4. Insights to Enhance the Benefits of AR for Education

The affordances of the 3GARE suggest a promising future for educational AR applications. In this section, we indicate how emerging AR technologies such as smartglasses and WebAR, along with AI, can provide solutions to overcome some of the pending issues of AR in education.

While progress on assistive technologies has been made, there are still barriers that prevent users with special needs from having efficient AR experiences. Moreover, it is important to recognize that special needs education includes a broad set of needs, each of which requires a different solution [24]. In this regard, new AR technologies have the potential to turn AR into a digital sixth sense that enables people to master skills in ways that are not possible with other available technologies.

From our point of view, smartglasses are a key component to improve the accessibility of AR systems. We highlight that 7 out of the 11 studies were focused on special needs education, which is an encouraging figure in terms of social inclusion. Smartglasses are embedded with several components, such as camera, compass, calculator, thermometer, accelerometer, speaker, microphones, and navigation system. In addition, smartglasses are powered with AI, which allows them to provide multiple solutions to different types of needs.

One of the groups that potentially benefited the most from smartglasses is blind or visually impaired people. Additionally, smartglasses allow document scanning to turn the document into speech and image reader to understand a picture by describing scenes, colors, and objects in the image. These features provide blind and visually impaired people enough autonomy to carry out daily activities, without much dependency on other people. This autonomy has created the possibility for this group of people to attend educational contexts, almost under the same conditions as non-visually impaired students [25].

Another group that benefits from smartglasses are individuals with hearing impairments, including the deaf or hard of hearing. However, students with hearing impairments must keep turning away from the interpreter to take notes, which means wasting valuable seconds of communication in the classroom. Smartglasses can take audible information and convert it to visual information or add captions to it. Furthermore, these devices allow students to receive live sign language interpretation superimposed on the classroom environment [26].

In this regard, different studies point out that smartglasses hold the key to improving social and communications skills of people with ASD [16][27]. Additionally, users remain hands-free, so they can use their hands to participate in non-verbal social communication and undertake educational activities [16]. Consequently, studies report improvements in social interactions, through improvements in non-verbal communication, social engagement, and eye contact. Additionally, the studies report reductions in ASD symptoms including irritability, lethargy, stereotypic behavior, hyperactivity, and inappropriate speech.

Finally, people with physical disabilities that cause motor impairment such as quadriplegia, cerebral palsy, lost or damaged hands, muscular dystrophy, arthritis, among others, can also benefit from smartglasses. People who suffer from any of these disabilities may need to use devices such as head wands, mouth sticks, among others. However, the smartglasses' features provide multiple benefits that allow them to participate in educational scenarios, without much dependency on other people or invasive assistive technologies. All smartglasses' features can be activated by voice, which means that this group of people can take notes, take pictures, record scenes, and audios, etc., without having to move their hands or any other part of the body except their mouth.

The study proposed five groups of usability principles for AR applications that have guided the development of some 2GARE applications, namely, user-information, user-cognitive, user-support, user-interaction, and user-usage. User-cognitive is related to cognitive aspects required to minimize memory and cognitive overloads. User-interaction is related to the responsiveness of the application, the ability to provide feedback to users, and the need to minimize users' effort when using the application. However, despite the proven benefits, different studies have indicated that including these principles to AR applications demands too much work, time, and money.

As an alternative, we pose that WebAr-based applications have the potential to improve the usability of AR systems. The main advantage of WebAR over other AR applications, as for usability, is that people are familiar with Web-based applications and, consequently, using WebAR-based applications happens to be naturally easy [28]. Moreover, as WebAr does not require users to download any specific application, all they need is to do is visit a website in their devices' browser to enjoy the AR experience. This simplicity translates into great usability, promoting better engagement, which will potentially enhance the popularity of WebAR in educational settings.

These models include phases of analysis, design, development, implementation, and evaluation that guide the development process of educational applications. Additionally, it is important to consider specific pedagogical approaches when designing the application. [9], the integration of a specific pedagogical approach to a given educational context will improve the impact of AR in educational interventions. These elements are related to (1) match between the real and virtual worlds, (2) efficiency of use, (3) consistency between virtual elements and educational purposes, (4) aesthetic and minimalist design, (5) help and documentation, and (6) user satisfaction.

Hardware-based AR and application-based AR have issues that have hindered AR from having broader dissemination in educational settings. On the one hand, hardware-based AR implementation is known to be expensive and lacks flexibility. On the other hand, application-based AR involves an additional upfront download and installation process, which impacts cross-platform deployment and increase production costs and development time. Alternatively, as it has been noted, to access WebAR, all users require is a mobile device and a browser, which has the potential to encourage more users to experience AR.

Another affordance that WebAR brings to education is the possibility of creating educational content through authoring tools [29]. Authoring tools allow developers to create educational applications by using preprogrammed elements, eliminating the need for specific programming experience [30]. By using authoring tools, inexperienced developers can create educational content in the format of learning objects, that can be reused in other educational contexts. Therefore, the integration of authoring tools into the field of WebAR will empower inexperienced teachers and developers to create educational content, also promoting the dissemination of AR.

In another context, recent years have brought together AR and AI as complementary technologies, making AR experiences more realistic and engaging. These technologies work seamlessly together to create personalized experiences that adapt to each students' needs and preferences [31]. AI helps designers use data about students' preferences to tailor educational content to each student's situation. Additionally, AI helps designers learn from every student interaction, thereby enhancing the delivery of the pedagogical content [32].

Deep learning is another important benefit that AI brings to AR. Deep learning involves machine learning algorithms to model high-level abstractions in data using computational architectures that support multiple and iterative nonlinear transformations of data [33]. Deep learning achieves unprecedented levels of accuracy that can be applied to computer vision, speech recognition, natural language processing, and audio recognition. In summary, it provides smaller, faster, and more accurate models that are replacing traditional approaches underpinning AR experiences [25].

The affordances of the 3GARE are not only related to new deployment technologies, but also to pedagogical strategies to enhance the impact of AR on education. The study concludes that many games are introduced into education without a methodological approach, just because students like to play and that, on the other hand, there are many educational games that are not interesting to play. The study focuses on vocational education and training since, as mentioned by the authors, the emphasis on the use of AR in vocational contexts is mainly focused on technical implementation issues. The authors propose some pedagogical observations on the use of AR in vocational practices to achieve long-term benefits for vocational students.

[9] conducted the first meta-analysis of the 3GARE to identify, in the light of the learning theories, how the pedagogical approaches affect the impact of AR on education. The study analyzed 46 empirical studies published between 2010 and 2019 to conclude that AR interventions that included pedagogical approaches showed better results than AR interventions that did not do it. The study poses that the unique characteristics of AR have the potential to support and enhance a variety of pedagogical approaches, including situated learning, collaborative learning, inquiry-based learning, and project-based learning. Furthermore, the study notes that results in individual studies may vary depending on a wide range of factors, such as the pedagogical approach, the learning environment, the learner type, and the domain subject.

In general, interventions conducted in informal settings performed better compared to interventions conducted in formal settings. Similarly, the most effective pedagogical approach in informal settings is project-based learning, while collaborative learning obtained the best results in formal settings. Regarding the level of education, the most benefited target group seems to be Bachelor-or-equivalent-level students, and there is no pedagogical approach that benefits a particular target group the most. The results of this study provide a broad overview of the inclusion of pedagogical approaches to educational AR experiences, and therefore can be used as the bases for the design of AR interventions in the 3GARE.

Finally, as a framework to integrate the pedagogical approaches in AR interventions, we highlight the use of instructional models such as Biggs' 3P model [34]. This model proposes that the learning experience consists of three stages, namely, presage, process, and product. Additionally, it includes curriculum, teaching method, classroom climate, and assessment from the teaching context. Lastly, the product stage involves the nature of the learning outcomes as a product of the interaction of the elements in the process stage.

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