Augmented Reality for E-Learning

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ABSTRACT

Over the last decade, rapid evolution of technology has yielded new ways to develop applications for learning. Augmented Reality (AR) as an educational medium is becoming increasingly accessible to young students at elementary school and professional learners alike. It is a new medium, combining aspects from ubiquitous computing, tangible computing, and social computing. This medium offers unique affordances, combining physical and virtual worlds, with continuous and implicit user control of the point of view and interactivity. This paper provides short introductions to the technology of Augmented Reality and E-Learning. Example applications, key technologies of AR are discussed within the context of education. This paper reports a systematic review of literature on augmented reality in education, the main finding being the classification of ongoing research in AR in education and the identification of benefits and detriments of AR for E-Learning. Furthermore, current trends, a vision for the future and opportunities for further research in Augmented Reality for educational settings have been discussed.

Author Keywords

Augmented Reality; E-Learning; Mobile Learning; Mobile Augmented Learning;

INTRODUCTION

This paper analyses how augmented reality can support the learning process and therefore, current technology statuses of Augmented Reality and E-Learning are introduced. In particular the various display and marking techniques of AR are described which are being used or could be used for applications in E-Learning. Many popular and significant AR projects that have aimed to investigate the potential of AR for E-learning have been discussed. The final sections argue about the benefits and detriments that AR has to offer when used as an education medium.

AUGMENTED REALITY

Recent technological advances, has resulted in Augmented Reality becoming a popular research topic in Computer Science due to the capability of low-cost hardware in enabling Augmented Reality applications to run with interactive performance. The following subsections discuss definition, taxonomy, affordances and hardware used in AR.

Definition and taxonomy

Augmented Reality (AR) is a technology that exactly overlays computer generated virtual imagery on physical objects in real time. It is different from virtual reality (VR), where the user is completely immersed in a virtual environment. AR lets the user to interact with the virtual images using real objects in a seamlessly. AR can be viewed as a computerized extension of our reality. Today there are two common approaches to define AR. Ronald Azuma defines AR as systems containing these three characteristics [2]:

1. Combines real and virtual
2. Interactive in real time
3. Registered in 3-D

Thus, to avoid limiting AR to specific technologies, Azuma defines AR as systems to the seamless embedding of virtual content into the real world. The possibility of real-time interactions in a 3-D environment is another fundamental characteristic. On the other hand there is Paul Milgram, who explains AR in the context of a Virtuality Continuum [33]. At extreme ends of this continuum are the Real Environment and the Virtual Environment. As indicated in the figure, the most straightforward way to view a Mixed Reality environment, therefore, is one in which real world and virtual world objects are presented together within a single display, that is, anywhere between the extrema of the virtuality continuum. (see Figure 1). Embedding only some individual objects, ARs are seen closer to the extremum reality than Augmented Virtuality, where only some objects are derived from reality.

Klopfer, 2008 [25] indicated that the term AR should not be defined restrictedly. This term could be applied to any technology that blends real and virtual information in a meaningful way. According to Klopfer and Squire (2008), AR could be broadly defined as “a situation in which a real world context is dynamically overlaid with coherent location or context sensitive virtual information.”

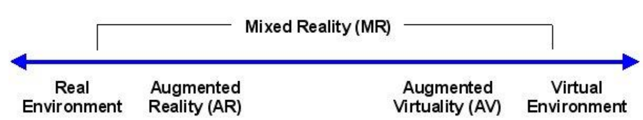

Figure 1: Simplified representation of a "Virtuality continuum"[33]

There are many possible domains that could benefit from the use of AR technology such as engineering, entertainment and education. The first AR interface was developed by Sutherland in the 1960's [45].

Although AR technologies involve high-end electronics and sophisticated tools, [7] argues that these technologies themselves are not of critical important for educational researchers. What is more important is how the technologies support and afford meaningful learning. Educators, researchers and designers of learning experiences can be more productive if they consider AR as a concept rather than a type of technology. Thus, in the following section, we discuss features and affordances of AR for educational purposes.

Affordances of Augmented Reality

Although Augmented Reality is a new technology, it has characteristics and benefits that are promising to support learning. According to Chien et al., [11], AR has the ability to encourage kinesthetic learning. Furthermore, since AR use 3D registration of virtual and real objects, it lets the user view the learning content in a 3D perspective. This affordance can help students who struggle to visualize the phenomena that are not possible to be shown in the real world or if the concept is too complex. As suggested by Squire et al., [44] AR games can stimulate students' prior knowledge and increase the student level of engagement in academic activities. Moreover, AR also can enhance collaboration between students and also students and instructors [4] therefore maximising learning. It has been proved that AR environments could boost students' motivation and interest, which in turn help them to develop a better understanding of contents. Santos, M., et al, [40] 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.

Display Techniques

Way back in 1968 Sutherland stated that, the fundamental idea behind the three-dimensional display is to present the user with a perspective image which changes as he moves [45]. Based on this, today, there are three major display techniques used for AR-applications: head mounted displays (HMD), handheld displays and spatial displays.

Head-Mounted Displays

A Head-Mounted-Display (HMD) is a display device, worn on the head or as part of a helmet with a small display optic in front of one or both eyes. There can also be a wearable display that has the capability of reflecting projected images as well as allowing the user to see through it called an optical head-mounted display (OHMD). Figure 2 shows different types of head mounted displays used by a group collaborating for an AR application.

HMD can either be video-see-through or optical see-through and can have a monocular (one eye) or binocular (both eye) display optic. Video-see-through systems are different from optical-see-through systems in that they require the user to wear two cameras on his head and require the processing of both cameras to provide both the "reality" of the augmented scene and the virtual objects with unmatched resolution, while the optical-see-through employs a half-silver mirror technology to allow views of physical world to pass through the lens and graphically overlay information to be reflected in the user's eyes. The scene as well as the real world is perceived more naturally than at the resolution of the display.

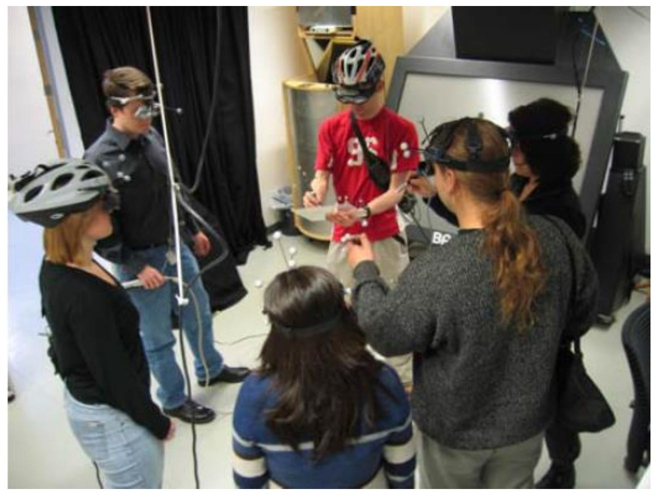

Figure 2: Head-mounted-display used by multiple collaborators for an AR application [21].

Whereas in video-see-through systems, augmented view is already composed by the computer and allows much more control over the result [8]. Thus, control over the timing of the real scene can be achieved by synchronizing the virtual image with the scene before displaying it while in an optical-see-through application, the view of the real world cannot be delayed, so the time lag introduced in the system by the graphics and image processing is perceived by the user. This results in image that may not appear "attached" with the real objects they are supposed to correspond to, they appear to be unstable, jittering, or swimming around.

Handheld Displays

Handheld displays consist of small computing devices with a display that the user can hold in their hands. Handheld devices use video-see-through techniques to overlay graphics onto the real environment and use sensors like digital compasses and GPS units for detecting their six degree of freedom tracking sensors, fiducial marker systems, such as ARToolKit, and/or computer vision methods, such as SLAM. There are currently three distinct classes of commercially available handheld displays that are being used for augmented reality system: smart-phones, PDAs and Tablet PCs [49]. Smart-phones are extremely portable and widespread, and with the recent advances present a combination of powerful CPU, camera, accelerometer, GPS, and solid state compass, making them a very promising platform for AR. However, their small display size is less than ideal for 3D user interfaces. PDAs present much of the same advantages and disadvantages of the smart-phones, but they are becoming a lot less widespread than smart-phones since the most recent advances, with Android-based phones and iPhones. Tablet PCs are a lot more powerful than smart-phones, but they are considerably heavier for single handed, and even prolonged two-handed, use.

Figure 3: Mobile, PDA and Tablet PC as Handheld Displays [42]

Spatial Displays

Spatial Augmented Reality (SAR) augments real world objects and scenes without the use of special displays such as monitors, head mounted displays or hand-held devices. SAR makes use of digital projectors to display graphical information onto physical objects. The key difference in SAR is that the display is separated from the users of the system. Because the displays are not associated with each user, SAR scales naturally up to groups of users, thus allowing for collocated collaboration between users. Novel approaches have taken augmented reality beyond traditional eye-worn or hand-held displays enabling additional application areas. New display paradigms exploit large spatially-aligned optical elements, such as mirror beam combiners, transparent screens, or holograms, as well as video projectors. Thus, Bimber et al., [5] call this technological variation spatial augmented reality (SAR). They suggest that in many situations, SAR displays are able to overcome technological and ergonomic limitations of conventional AR systems. Decrease in cost and availability of projection technology, personal computers, and graphics hardware, has resulted in a considerable interest in exploiting SAR systems in universities, research laboratories, museums etc.

Tracking Techniques

Tracking methods in AR depend usually on the type of environment the AR device will be introduced to as well as the type of AR system. The environment might be indoor, outdoor or a combination of both. Tracking devices consists of digital cameras and/or other optical sensors, GPS, accelerometers, solid state compasses, wireless sensors, etc. [52]. Each of these technologies has different level of accuracy and depends greatly on the type of system being developed. In ten-year development of the ISMAR/ISAR/ISMR and IWAR conferences, tracking has been the most popular topic for research. The most cited paper being a tracking paper by Kato et al., [19]. This section reviews the evolution of tracking such as sensor-based, vision-based, and hybrid tracking techniques.

Sensor-Based Tracking Techniques

Sensor-based tracking techniques are based on sensors such as magnetic, acoustic, inertial, optical and/or mechanical sensors. Each type has its respective advantages and disadvantages. For instance, magnetic sensors have a high update rate and are light, but they can be distorted by any nearby metallic substance that disturbs the magnetic field. Rolland et al., [39] provides an elaborate review of sensor-based tracking. Some of the most common tracking techniques today are:

- **Acoustic tracking** include all procedures based on sending ultrasonic sound waves within transmitter-receiver system to sense range.
- **Inertial Tracking** also allows tracking a person within an environment with the help of gyroscopes and accelerometers. The gyroscope measures the orientation of the user, whereas the accelerometer measures the user's acceleration to determine the position.
- **Optical tracking** is a tracking technology using optical sensors like cameras. Outside-in uses static cameras placed within an environment and being targeted at the dynamic object to be tracked. In inside-out tracking by contrast the dynamic object is equipped with a camera observing the static surroundings. Optical tracking goes often hand in hand with marker-based tracking.
- **Mechanical Tracking** systems have the user or object's position and orientation measured by using a direct mechanical connection between a reference point and the target. With a given reference point (starting point) every position within the environment can be derived from the relative joint measurements. This can be achieved through mechanical tracking sensors like gears, potentiometers etc.

Vision-Based Tracking Techniques

Sensor-based tracking systems are perceived to be analogous to open loop systems and hence have error. Vision-based tracking techniques use image processing methods to calculate the camera pose relative to real world objects and so are analogous to closed loop systems which correct errors dynamically [3]. In computer vision, most of the available tracking techniques can be divided into two classes: feature-based and model-based. The rationale underlying feature-based methods is to find a correspondence between 2D image features and their 3D world frame coordinates. The camera pose can then be found from projecting the 3D coordinates of the feature into the observed 2D image coordinates and minimizing the distance to their corresponding 2D features [52].

Hybrid Tracking Techniques

According to Zhou et al., [52] For some AR applications computer vision alone cannot provide a robust tracking solution and so hybrid methods have been developed which combine several sensing technologies. For example, Azuma et al., [2] proposed that developing AR systems that work outdoors required a tracking system based on GPS, inertial and computer vision sensing. However today there is a growing consensus to combine inertial and computer vision technologies to provide closed-loop-type tracking. Vision-based tracking has low jitter and no drift, but it is slow, and outliers can occur. Furthermore, drastic motions often lead to tracking failure and recovery is time-consuming with a temporary loss of real-time tracking abilities. Compared to vision-based tracking methods, inertial tracking offers attractive complementary features. It is fast and robust and can be used for motion prediction when rapid changes occur, which is of interest to us for building learning applications with AR.

E-LEARNING

E-learning, sometimes called distance-learning, is a formalized teaching and learning system designed to be carried out remotely by using electronic communication. Earlier E-Learning was believed to be learning that is accessible through technological tools that are web-based, web-distributed or web-capable. In the recent years, new technologies are developing with the potential to have a deep impact on education [16], including games, augmented reality, new human–computer interfaces, and ubiquitous and mobile technologies [29].

According to Khan [24], after careful reflection with consideration of factors that must be weighed in creating effective open, distributed and flexible learning environments for learners worldwide, the following definition of E-learning is formulated: E-Learning can be viewed as an innovative approach for delivering well-designed, learner-centered, interactive, and facilitated learning environment to anyone, anyplace, anytime, by utilizing the attributes and resources of various digital technologies along with other forms of learning materials suited for open and distributed learning environment. E-learning recognizes the shift from teaching to learning and puts the learner before the instructor. With the advent of the new technologies, Institutions have had to change their mental set and move away from traditional learning modes to more innovative and participative ones [14].

MOBILE LEARNING

Mobile Learning or m-learning can be characterized as 'learning across multiple contexts, through social and content interactions, using personal portable electronic devices.' A form of e-learning distance education, m-learners can use mobile device educational technology in many locations at their time convenience. Earlier m-Learning was limited, consisting mostly of existing courses that were converted to be accessible via a mobile device. As educators and designers became comfortable with designing for mobile, there were more and more learning experiences designed with mobile in mind. Mobile experiences take advantage of the unique affordances of mobile technologies to become more interactive instead of usual 'read and click next' courses onto a mobile device. Mobile learning continues to evolve year after year and it has the obvious advantage of mobility and ubiquity over traditional e-learning. As a result learning on a mobile device is more contextual and heuristic, which is an additional benefit to the learner who is on the move.

AUGMENTED REALITY AS A MEDIUM FOR EDUCATION

Virtual information overlaid on the real content can help users of Augmented Reality enhance their perception of the real world and support them in better understanding of the real objects. This is a great advantage in the use of augmented reality for learning. One of the important aspects of E-learning systems is user interaction. A user is forced to learn without any form of interaction when learning with previous e-learning systems. As a result, they are likely to lose interest quickly, and the produced content may be forgotten after being learnt. E-learning system can extend to include intuitive interaction by using the Augmented Reality. Educational content can be experienced through a wide variety of media, ranging from non-interactive books to highly interactive digital experiences that fully engage the user's senses. This paper is primarily concerned with analyzing the educational potential of augmented reality technology, as compared to other educational mediums. Augmented reality brings virtual information into a user's physical environment and allows the user to interact with the virtual content therefore making the experience fun and engaging. There are many potential benefits which augmented reality technology can bring to a learning experience, such as enhanced entertainment through whole body interaction, advancing education through in situ interactive visualizations, and improving rehabilitation and skill development through physical manipulation [23].

EXAMPLE APPLICATIONS OF AUGMENTED REALITY FOR E-LEARNING

Woods et al., 2004 presents five projects developed at the Human Interface Technology Laboratory in New Zealand (HIT Lab NZ) that have explored different techniques for applying AR to educational exhibits. These exhibits have received very positive feedback and appear to have educational benefits involving spatial, temporal and contextual conceptualization and provide kinesthetic, explorative and knowledge-challenging stimulus.

Kaufmann et al., 2007 [22] presented a hardware setup that allowed attaching 12 or more HMDs to a single PC. This paper was among the earliest to demonstrate how a collaborative, educational, augmented reality application could be used by six students wearing HMDs on a single PC simultaneously with interactive framerates.

In 2007, Schmalstieg and Wagner [42] introduced Studierstube as a framework for the development of handheld Augmented Reality. Two mobile AR games were developed namely, “medien.welten” and “Expedition Schatzsuche.” Medien.welten was a case study designed for a target group of high school students aged 12-15. This game had a group of players (two or three students) receiving one handheld display that showed a map of the exhibition and specified the current position of the players and list of solved and remaining tasks. In Expedition Schatzsuche game, each of the subjects had been given their own handheld to play the game. The evaluation results indicate that the students were very motivated and highly satisfactory [42].

In 2007, Squire and Klopfer, [44] collaborated with environmental science faculty at Massachusetts Institute of Technology and developed an augmented reality application called Environmental Detectives. This game had students to play the role of an environmental engineer and provided students with experience in conducting the environmental investigation in the real world. Each pair of students could see their location on a map since they were given a mobile device equipped with GPS. Environmental Detectives was found to assist students in understanding the social nature of scientific practice.

CONNECT was a project developed by Arvanitis et al. in 2009 [1], that used an Mobile AR system to support students learning science both in the formal and informal learning environments. The CONNECT concept required students to wear a head mounted display (HMD). It related computer-mediated learning platform in order to visualize and interact physically and intellectually with the learning. A study had been conducted with learners with physical disabilities. Interestingly the comparison of disabled students and able-bodied students showed that they had almost the same results. This finding provides some support for the conceptual premise that the CONNECT project has the potential to improve the landscape of education especially for children with disabilities.

Juan, Alem and Cano (2011) [17] presented mobile AR game, ARGreenet that aim to increase people awareness of how important of recycling is and how to do it. In their study, they compared the ARGreenet with the basic mobile phone game for recycling topic. The participants involved in this study were a total of 38 children, where all of them experienced both games but in different orders. The evaluation aspects consist of: the knowledge of recycling gained by the children, their level of engagement, fun and easy to use, perceived willingness to change behavior and comparison toward AR and non-AR games. Results showed that there is no significant difference between the two games; however 69.4% of the children preferred the ARGreenet game, which they perceived as easy to use and more engaging and fun than basic mobile phone game. In addition, the findings also show that the games had a positive influence on their behavior.

Chen at al., 2011[9] developed an AR application to teach Graphics course to engineering students. Two teaching aids were developed; a tangible model and an augmented reality (AR) model, to help students better understand the relationship between 3D objects and their projections. The AR interface showed great potential in enhancing students’ interest in learning although both the tangible and segmented reality models able to serve as effective teaching aids for engineering graphics courses.

Tang and Ou (2012), [46] developed an AR project with which students could breed their own virtual caterpillars on host plants using the programs on their smart phones, and become familiar with a butterfly’s life cycle by observing their growth. The campus AR butterfly ecological learning system was designed based on the learning unit of “Butterfly’s Life Cycle” in nature science for the fourth-grade students in elementary schools. The statistical tests indicate that the learning effectiveness of the AR butterfly ecological learning system was higher.

History can be very tedious to learn and remember for students. Martín, Díaz, Cáceres, Gago and Gibert (2012) [29] presented an educational application called EnredaMadrid to cope with this complexity. The objective of EnredaMadrid is to teach the history of the city in the 17th century to students through previous online training and a physical technological gymkhana. This application was built using mobile device based on geo-localization and AR technology. The evaluation was carried out through questionnaires and the results indicate that AR is the most positive element in EnredaMadrid. Students also stated that AR definitely contributes to make learning more fun and motivating when learning the history of a city.

Rather recently in 2014, Blanco-Fernández et al. [6] have developed REENACT which is aimed at engaging groups of people into immersive experiences to improve their learning about historical battles and wars from the points of view of reenactors and historians. REENACT relies on handheld devices and an advanced technological facility that comprises social networking features, augmented reality capabilities and repositories of multimedia contents.

Also in 2014, He at al., designed and developed mobile-based English learning software for pre-school children in order to solve the problem of bored students and teachers’ non-standard pronunciation. It was found that the students learning with mobile-based AR software had greater learning achievement than control group ones.

Table 1 summarizes the selected research works.

Researcher	Application	Content	Participants
Woods et al., 2004	Multiple AR Exhibits such as SOLAR System, Black Magic Kiosk, Volcano Kiosk, EyeMagic Storybook.	Science and History Museum exhibits.	Museum Visitors
Kaufmann et al., 2002, 2006, 2007	Construct3D	Mathematics and Geometry	Several groups consisting of 6 students each
Schmalstieg and Wagner 2007	medien.welten	History	19 students (aged 12-15)
Squire, Klopfer et al., 2007	Environmental Detectives	Environmental Engineering Education	58 University students 18 High school students
Juan et al., 2008	AR Human Body System	Learning letters and words	32 Primary School Students (aged 5-6)
Arvanitis et al., 2009	CONNECT	Science	5 students with disabilities
Pérez-López et al., 2010	3 Desktop AR Applications and HUMANAR library	Human digestive and circulatory systems	Students (aged 10-11)
Juan et al., 2011	Games: ARGreenet and BasicGreenet	How to recycle	38 children (aged from 8 to 13 years)
Chen et al., 2011	Desktop PC AR Application	Engineering Graphics Courses	35 engineering-major students
Martín et al., 2012	EnredaMadrid	History	65 people (aged over 36 years)
Tarng and Ou 2012	Butterfly Ecological Learning System	Science	60 elementary school students
Kose et al., 2013	Mobile AR Application	Computer Science courses	200 Computer Science University Students
Santos et al., 2013	AR X-ray	K-12 Education	Pilot user study: 23 Students (aged 5-15) Second user study: 47 students (aged 11-16)
Blanco-Fernández et al., 2014	REENACT	Human History	61 University Students
He at al., 2014	Mobile AR English learning software	English Vocabulary	40 Pre-School children
Munoz et al., 2014	Gremlings in My Mirror	Logical Mathematics Skills	20 students from a school for children with special needs

Table 1: A summary of selected studies on AR for E-Learning.

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. According to Wu et al., [51] and Cheng & Tsai [10] 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 the discovery of the unique value of the learning environments based on AR. According to Chen & Tsai [9] the potential of AR in educational applications is just now being explored. 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 [10]. 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 135 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.

LEARNING BENEFITS FROM AUGMENTED REALITY MEDIUM

This section describes the positive impact that augmented reality experiences have been shown to have on learners, as compared to non-AR initiatives.

Better understanding of content

A large proportion of the surveyed papers indicate that for certain topics, AR is more effective at teaching students compared to other media such as books, videos, or PC desktop experiences. AR has been found to be very effective in making it easier to learn complex spatial structures and functions such as in such as geometrical shapes, chemical structures, mechanical machinery, astronomy configurations, or spatial configuration of human organs. Lindgren and Moshell [26] compare children's learning of astronomy between two systems: a PC-based application where children interact with a mouse and a projector-based mixed reality (MR) application where children interact by walking on a floor surface. Although quantitative significant differences were not found, the qualitative analysis shows differences in the way children conceptualized the content. The MR group was found to be focused on the dynamics of planet movements, while the PC group seemed more focused on surface details such as the visual look of the planets. The results of this research point to potential cognitive differences in student's experience of AR versus PC environments.

Long term memory retention

Several works of research indicate that content learned through AR experiences is memorized more strongly than through non-AR experiences. As mentioned earlier, studies by Vincenzi et al. [48] and Valimont et al. [47] show that when students learn about aircraft turbines, content learned through an AR experience, they are significantly more likely to be able to recall it a week later, than compared to learning through paper or video media. Further, Macchiarella et al. [28] show that for students who learned about turbines using the AR experience, the long-term memory did not significantly degrade after one week. Students who learned from other media, such as books or videos, showed significant decreases in memory recall, although interestingly, at the time of training, no significant differences were found in the short-term memory between the groups.

Better Collaboration

AR experiences have been shown to be highly effective in group collaboration, as indicated by several papers surveyed. Morrison et al. [34] observed students navigating a neighborhood using either an AR map (i.e., a mobile device displaying AR content on a paper map) or a digital map (i.e., a mobile device showing a digital map based on GPS location). In the AR group, the student collaboration was proved to be more effective. Using the AR application, they created a shared space where team members could collaborate and create shared meanings, as opposed to the more individual experience of a student using a GPS mapping application. As discussed earlier, Kaufmann et al., 2007 [21] presented a hardware setup that allowed attaching 12 or more HMDs to a single PC. For teacher-students training or demonstrations, where it is not feasible to equip each user with the same full set of interface devices, this is an ideal collaboration scenario. While studying how people collaborate in solving spatial problems under head-mounted AR versus projector-based AR versus non-AR conditions, Billinghurst et al. [4] found that the use of gestures is similar between AR and face-to-face condition, yet different than the projector-based condition (where significantly less deictic gestures occurred). This effect likely occurs because in the similar conditions, people are facing each other while collaborating. However the subjects reported several usability issues that may account for the detriments in collaboration.

Increased motivation

The users' high enthusiasm to engage with AR experiences is noted in multiple papers, where users report feeling higher satisfaction, having more fun, and being more willing to repeat the AR experience. Interestingly, user motivation remains significantly higher for the AR systems (vs. the non-AR alternative) even when the AR experience is deemed more difficult to use than the non-AR alternative.

CHALLENGES OF AUGMENTED REALITY AS AN EDUCATION MEDIUM

Although using AR for teaching and learning seemed promising, some research indicated negative effects on learning such as low engagement [23]. Kerawalla et al. found that while teachers recognized the benefits of using an AR system in classrooms, they would like to have more control over the content in the system so they could adapt the needs of their students. This suggests that, like many emerging innovations, AR provides new challenges along with possibilities.

AR poses certain pedagogical issues that are common to other technological additions to learning and teaching. For example, the novelty of the technology may detract from the learning experience (e.g. students focusing on shiny new devices rather than their learning objectives). The technology may also guide how and where the learning occurs and it is important to make sure the learning is not altered to fit around the device's limitations (e.g. do students need to work where there is a shaded area so they can see the screen, rather than standing in the best place to understand the context; do educators need to factor in extra time to change batteries and hence there is a reduction in the amount of time spent actually being physically in location). There may also be a need for additional technical support if the AR is not easy to use and install.

There is also the problem of the technology being more engaging than the surrounding environment and instead of making the most of being at a particular location, students' attention is inappropriately focused on the AR devices and tools. In this situation, it is important to consider if the technology actually removes the students from the immediate experience of the location rather than augmenting it.

From a teaching perspective, it is also critical to consider first what are the learning objectives and goals that a tutor or educator wants their students to achieve, before considering how best to achieve these. It may be that AR is not the best method to employ and that other, cheaper, more robust techniques are much more appropriate to the learning activity that is taking place. Additionally, providing an immediate overlay of labels on e.g. geographic/architectural features could possibly lead to a detriment in developing observation skills through excessive scaffolding and reinforcing. In this situation, it may be better to offer a more staged approach where AR is offered as an add-on, once students have acquired a certain level of proficiency in interpreting their environment without needing the use of such tools.

Learning detriments from augmented reality have been appropriately summarized by Radu 2014 [38]. Radu, 2014, identifies the following issues with AR for E-Learning:

Attention tunneling

In many of the surveyed papers, students reportedly experienced higher attention demands from AR system. This resulted in the student ignoring important parts of the experience or feeling unable to properly perform team tasks.

Usability difficulties

Often users rate AR systems as more difficult to use than the physical or desktop-based alternatives. As reported earlier, interestingly, some of these studies also found that users like the AR systems more than the alternatives.

Ineffective classroom integration

Kerawalla et al. [23] indicate that in the non-AR experience, the students (under the presence of the teacher) were more engaged in exploration and role-play activities around the learning content. On the other hand, during the AR experience, the teacher dominated the discussion and limited student engagement with the educational content presented through AR.

Learner differences

Some studies showed that although low and average achiever students showed learning gains through the AR experience, high-achieving students did not receive the same benefits. The high-achieving students showed more learning gains in a traditional classroom where AR was not used. The AR-based educational content was found to be too limited in scope and did not contain novel information for the high-achieving students.

DISCUSSION

In general an observation can be made regarding the type of applications that are being developed to test the potential of augmented reality for e-learning. Following are the different categories of applications:

- Spatial Learning Applications
- Discovery Applications
- Skills Training Applications
- Impossible Interaction Applications
- Augmented Books Applications
- Gamified Learning Applications

Through the literature review of several AR publications, this analysis has identified several positive and negative effects of AR on learning, as well as potential factors underlying these effects. As mentioned above, the factors and effects discussed in this paper are mediated by the unique design of each augmented reality experience. Future work can investigate how AR designers can maximize the potential learning benefits and generate guidelines for designing effective educational AR experiences. A related direction for future work is identifying other factors which may be beneficial in AR experiences but which have not been accounted in the above analysis, such as improving teacher support by providing facilities for customizing content and monitoring student learning. Furthermore, the interaction of student learning and human developmental factors should be taken into account, such as investigating how student's developing cognition, motor, and spatial skills influence their ability to use and understanding AR-based educational content. Also, there is a lack of research that have been able to provide a strong set of guidelines for educators to design e-learning applications that are classroom friendly. AR for e-learning experiences need to be designed with curriculum and pedagogy in mind. Future research must identify curriculum topics that are currently difficult to teach using other media and are worth the investment cost for AR. It is very important to identify what type of content can be most efficiently explained through AR technology. Designers must also understand how to create experiences that integrate into classroom pedagogy, such as structuring AR content so that it can be integrated into multiple points along the curriculum, designing for multiplayer AR experiences so that students can collaborate, designing experiences that can be tailored by teachers to custom fit into their curriculum, designing intelligent applications that monitor and adapt to student progress, and designing AR applications that integrate with existing content such as textbooks and learning games.

CONCLUSION

Augmented reality has unique affordances that can affect the learning experience. Developments in AR technology have enabled researchers to develop and to evaluate augmented reality learning experiences. These developments encompass hardware, software and the authoring of content. 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, Engineering and Humanities & Arts are the fields of education where AR has been applied the most. Health 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 has been found to be very widely used along with location-based AR. 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 have been found to be: better understanding, motivation, interaction and collaboration.
- Limitations of AR are mainly: attention tunneling, learner differences, too much attention to virtual information, ineffective classroom integration 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 for the specially-abled children. Here there is a potential field for further research.

This work contributes to existing knowledge in Augmented Reality for E-Learning 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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