A Meta-Literature Review on Augmented Reality: The Positives and Pitfalls of an Emerging Pedagogical Application

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Abstract: *Even though being developed for decades now, Augmented Reality systems are coming into their own as public facing HMD's, tablets, and immersive display systems are emerging into the public vernacular. As the hardware and software development tools have come down significantly in price and time of production, more organizations than ever are looking at this technology as a holy grail for pedagogical insertion into educational development and training. These factors put the technology on the precipice of ubiquity. By assembling the successful data points from both researchers and applied designers, this meta-literature review not only looks at the current landscape of successful outcomes but reveals shortfalls in the research, giving a breath of opportunity to those pursuing the educational insight and points of intervention into its future application.*

Keywords: *Augmented Reality; Education; Learning;*

I. INTRODUCTION

Introduced in the early 1990's, the term augmented reality was defined by Tom Caudell (Lee 2012). Since this time, the technology has grown exponentially into the fields of medicine, entertainment, tourism, gaming and especially education (Akçayir and Akçayir 2017). AR is only a singular demonstration of multiple virtual and artificial digital environments later outlined by Milgram and Kishino (1994) wherein the authors defined four different types of "reality media"; the real environment (RE), augmented reality (AR), augmented virtuality (AV), and virtual environments (VE) (Altinpulluk 2019). Milgram and Kishino (1994) would codify their four definitions as a singular mixed reality (MR) ecosystem. However, these different modes have recently fallen under the banner of "XR" whereas X is the stand-in for V (virtual), and A (augmented), and any other new reality technologies that are developed in the near and distant future. This meta-literature review will focus on the educational aspects of AR as it is a technology that enhances real-world interactive environments with digital artifacts unlike VR that produces completely virtual and artificial environments (Höllerer and Feiner 2004).

In 2015, Martín-Gutiérrez et al. found that our learning process is interwoven with the many different societal modes of interaction surrounding digital communication and information technologies. It was observed that those who learn, gravitate toward stimuli that is authentic, original and interactive in nature. Learners who live in a digital world need their educational environments to be innovative and engaging. AR games and simulations are a way to provide these learners with the engagement needed for future technological education (Klopfer and Yoon 2004). In the over 50 years since its availability in laboratory settings and eventually to the consumer, AR's proliferation into the mainstream through mobile technology over the past 10 years has meant that it has reached a maturation stage in its development and is now accessible to everyone (Sommerauer and Müller 2014).

In education however, Bacca et al. (2014) found that AR's application to the educational environment is an emerging topic of research in academia. This analysis is backed up by the work of Wu, Lee, Chang, & Liang (2013), Cheng & Tsai (2012), and Bujak et al. (2013) who found that, "Augmented reality (AR) is just starting to scratch the surface in educational applications." This research defines an ongoing theme wherein the educational uses and application of AR need more study to determine their effective application pedagogical modalities if they are to be applied to teaching and learning. The work of Bacca et al. (2014) and Altinpulluk (2019) have found that research in the field of AR in education and training has increased year-over-year since 2014. The studies being completed in the past 10 years are important to understanding the trends in AR applications in education as they will ultimately be the foundation for all future work in the field.

II. Survey and Research Question

This literature review was conducted at the Georgia Institute of Technology in the Fall of 2019. As a database driven literature review, the author included previous meta-analyses, peer-reviewed journal articles and conference papers, included in, but limited to publications such as; Education and Information Technologies, *10th International Conference on Information Technology and Electrical Engineering (ICITEE),* Educational Technology & Society, Educational Research Review, Twenty-Sixth European Conference on Information Systems (ECIS2018), Virtual Reality (2019), Journal of Educational Technology, Keele University and University of Durham, Technical report (2007), Association for Information Systems AIS Electronic Library (AISeL), and International Journal of Environmental and Science Education. This meta-analysis follows the guidelines proposed by Kitchenham and Charters (2007), who promotes that these types of systematic analyses include three main stages: planning, conducting, and reporting the analysis. Additionally, to further restrict the scope of this literature review, the author proposes defining the following research question: (RQ1) What are the findings of modern research into the positive and negative outcomes of using AR in a teaching and learning environment?

III. DISCUSSION OF THE RESULTS

Positive outcomes:

In a recent meta-review entitled *Augmented Reality Trends in Education: A Systematic Review of Research and Applications*, Bacca et al. (2014) found that "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." This increase in learning performance was accompanied by increased academic achievement by those in the systematic review. Furthermore, More than half of the articles reviewed in this study reported back that by using AR as a pedagogical method, better learning performance was achieved. These findings were also confirmed by Garzon et al. (2019) as one hundred percent of the studies reviewed reported that, "Learning gain is the most common reported advantage" in education, followed closely by increased motivation of the students.

Table 1 Summary of some systematic reviews related to the usage of AR in educational environments

Study	Review purpose	Studies reviewed	Main findings
Bacca et al. (2014a, b)	This review analyzed studies published between 2003 and 2013 from six indexed journals. It is focused on uses, advantages, limitations, effectiveness, challenges and features of AR in educational environments	32	There is an increase in the number of published studies in the last four years. Most applications of AR are related to Natural Sciences and Humanities and Arts. The most reported advantages of using AR in education are learning gains, motivation, interaction and collaboration
Diegmann et al. (2015)	This reviewed focused on empirical studies to analyze the benefits of using AR in comparison with other conventional learning tools	25	The most reported advantage of using AR in education is the improved learning curve. That is, students learn faster and easier with AR applications compared to non-AR applications. The reduction in the cost of AR technologies has helped to spread its use in educational environments
Tekedere and Göker (2016)	This study conducted a meta-analysis focused on AR applications for education in order to establish a new point of view for future research. The analysis covers the period between 2005 and 2015.	15	The use of AR applications for education has increased in the last five years. The meta-analysis indicated an average effect size of $d = .67$ that corresponds to "medium" effect. This may indicate that application of AR technologies in education has positive effects on students.
Akçayir and Akçayir (2017)	This review analyzed studies published between 2011 and 2016. It is focused on year, learner type, advantages and challenges of AR in educational environments	68	There is an increase in the number of published studies in the last four years. The most reported advantage in the studies is that it promotes enhanced learning achievements

Garzon, Pavon, and Baldiris. "Systematic Review and Meta-analysis of Augmented Reality in Educational Settings." Virtual Reality 23.4 (2019): 447-459. Web

Additionally, this trend of learning motivation was confirmed and further explored by Altinpulluk (2019) and Garzon et al. (2019) stating, "that the most positive effect of AR on education is for academic success and learning motivation." Academic success being the most positive findings in the research surveyed shows promise of AR as not only a learning tool, but a launchpad of success for students under the right conditions. As a student uses AR pedagogical tools in the classroom, the interaction with virtual worlds using digital technologies such as AR enhances their natural abilities (Ferrer-Torregrosa et al. 2015; Ibáñez et al. 2014). These finding have further been reinforced by Yilmaz's (2018) and Bacca et al. (2014) as analyses bore similar results stating that, "the motivation for learning after academic achievement is understood to be the most effective educational advantage of the AR"

Beyond heightened motivation and increased academic achievement, other phenomena were reported in many academic studies on the uses of AR in education. "Working memory" helps with decreasing cogitative load on learners further enhancing spatial ability. As AR places digital (voxel, 3d, video, text, etc.) objects next to physical objects, cognitive load decreases in the limited working memory of the subject (Santos et al. 2014). Cheng and Tsai (2013) describe this as a state where, "activating multiple senses in the learners' brain improves knowledge retention." Working memory retention provides an advantage to students while in the process of learning (Garzon et al. 2019).

Working memory, in the studies surveyed, contributed to the engagement and efficiency of educational environments by the way of building interaction models that improve the learners physical, kinesthetic, ocular, and spatial abilities (Billinghurst and Dunser 2012). This engagement enhances collaboration and motivates problem-solving skills in learning environments (Sayed et al. 2011). These motivating factors of engagement are telegraphed by additional studies that suggest that AR facilitates the cognition of abstract concepts (Garzon et al. 2019).

With enhanced student engagement and cognition, byproducts appear from the use of AR assistance in the classroom. Students reported that the classroom application of AR was more satisfying (because of play) in classroom environments (Chen & Tsai, 2012; Munoz-Cristobal et al., 2015). Surveys of students in classrooms that used AR as addendums to traditional pedagogical models reports that AR assisted in "enhancing enjoyment" and "raising the level of engagement." Traditionally, finding fun and innovative ways to teach have been roadblocks to effective education. AR, in fact, seems to make the classroom environment entertaining and exciting (Ibanezet al. 2014; Lu & Liu, 2015).

These findings can be partially explained through multimedia learning theory suggested by Mayer (2009) as spatial and continuity principles are applied to AR "play" in the classroom (Chiang et al. 2014a). Students viewing AR as "games" rather than learning could explain the engagement in young learners as many children spend time playing digital games (Lee, 2012). Seeing that playing digital AR games expand the imagination for young learners, research from Cai et al. (2014) suggest that AR assists imagination of concepts small and large. Simulation of molecules and solar systems provide and augmented scale that visualizes structures unknown (Núñez et al. 2008), assisting learners that have difficulties with concepts surrounding spatial recognition. Students no longer have to imagine concepts when it can be presented through a digital augmented overlay. Students, "do not have to use their imagination to envision what is happening. They can see it (Furió, González-Gancedo, Juan, Seguí, & Rando, 2013)." Prior research in this field corroborate these findings, particularly as it applies to AR's use in teaching the sciences (Cheng & Tsai, 2012). Dunleavy, Dede, and Mitchell (2009) articulately summarize the advantages of AR's enhancement of imagination as its "unique ability to create immersive hybrid learning environments that combine digital and physical objects, thereby facilitating the development of processing skills such as critical thinking, problem solving, and communicating through interdependent collaborative exercises. (Dunleavy et al. 2009)"

Additional advantages of the use of AR enrichment in the classroom outline the observed potential enhancement of collaboration, critical thinking and problem solving (Wasko 2013). These augmented virtual environments create virtual playgrounds for collaborative work around digital content (Bujak et al. 2013). By interacting with classmates and course content, learning is further facilitated with increased engagement.

However, analytical surveys show, "that the level of education does not moderate the impact of AR on education" (Garzon et al. 2019). Even though Saracchini et al. (2015) found that only seven percent of studies focused on adults, AR was observed to be an effective and easy to learn toolset for an post-secondary adults. Adults were found to be receptive to safety training as skilled workers applying industrial maintenance tasks were observed to reduce errors by using engagement from AR platforms to focus on key tasks (Gavish et al. 2015). These studies point to the ongoing maturity of AR in a wide range of fields as its application has taken hold in education beyond the classroom." (Garzon et al. 2019)

Negative Outcomes:

As with any emerging technology applications into the educational sphere, problem areas were identified and explored by the researchers covered in this meta-review. "Fifteen percent of the selected studies reported some disadvantages or problems when using AR in educational settings." (Garzon et al. 2019). Despite some benefits using AR in education, this developing technology faces many difficulties to overcome. Compared to other studies in the field of educational applications, research and findings remain immature compared to mature applied technologies in education (Wu et al. 2013). This immaturity would explain the mixed messages coming out of recent research. As described in the benefits of this meta-analysis, studies have reported a decrease in cogitative load in students that use AR in the classroom, while concurrently, other studies reported cognitive *overload* and AR limiting students multitasking abilities (Akçayır et al. 2017; Radu 2012). It's been noted that the tools are complex, technical problems persistent, and application in the classroom (as with most new pedagogical tools) faces resistance from educators. However, of the studies surveyed, many determined that as the tools to create AR content and distribution evolve, most problems will be overcome (Bower et al. 2014).

The top two limitations found in educational AR applications was cognitive load and difficult implementation by content creators and teachers in situ. Managing hardware and software at this stage of AR development is plagued with technical problems and therefore has caused resistance in the acceptance of this technology from educators (Dunleavy and Dede 2014; Garzon et al. 2019). It's also worth noting that initial acceptance of AR in the classroom has been spurred by a novelty effect that may minimize over time (Di Serio et al. 2013). Hsiao, Chen, and Huang (2012) confirmed this effect and concluded that the positive outcomes of AR in the classroom may ultimately provide negative data over time as the technology becomes commonplace. As students and educators familiarize themselves with the tools and applications of AR, interest in its use may be reduced over time.

The struggles implementing this technology are spread over a wide swath of issues, mainly surrounding limited educational resources provided to educators. Teachers who desire to create AR applications for their specific field must create new learning content. While the tools for creating this content exist, they are currently complex and time consuming. New authoring tools must be created to mitigate this problem if teachers are expected to create and implement their own course content (Bacca et al. 2014). These limitations are compounded when you consider the additional cost of development/implementation of applications for large groups (Furio et al. 2013), and lecture time needed to apply AR in a classroom setting (Munoz-Cristobal et al. 2015).

By far the most common applied pitfall reported in the results of the surveys analyzed were software development complications and technical difficulties of AR. Lin et al. (2011) found that students had the most difficulty with the technology. Classroom AR was reported to be complicated and riddled with technical problems during use from teachers as well (Garzon et al. (2019). However, students recounted that AR interfaces and guidance was too complicated to use in the long-term (Squire & Jan 2007; Garzon et al. 2019). A well-designed UI that incorporates effective HCI (human computer interface) methods is essential in tackling the usability issues students face with a technology that requires detailed user interaction (Cheng and Tsai 2013).

8 M. Akçayır, G. Akçayır / Educational Research Review 20 (2017) 1–11

Table 3
The challenges in AR use within educational settings.

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

Akçayır, Murat, and Akçayır, Gökçe. "Advantages and Challenges Associated with Augmented Reality for Education: A Systematic Review of the Literature." Educational Research Review 20 (2017): 1-11. Web.

Additional problems that persist surround the physical component of the AR devices themselves. Yu et al. (2009) found that head mounted displays used in AR are not easy to handle due to their bulk. Researchers suggest that for the technology to be widely accepted, problems with portability, weight, tracking, calibration, excessive software loading times, and CPU speed must be addressed before widespread use where to occur. Many of these problems have been addressed since the reporting in 2009, yet a large hurdle still exists in the realm of public social acceptance (Van Krevelen and Poelman 2010).

Overall, concrete conclusions in the field of AR in educational settings is its own biggest drawback. Comprehensive research must still be performed to determine the implications of educational value in AR (Radu, 2012). Many areas of application study still need to be conducted for this comprehensive analysis to take shape. Little data in the fields of agriculture, engineering, business, forestry, construction and manufacturing exist for a complete picture of the effects this technology could have on education (Garzon et al. 2019)."The distribution is rather consistent for children (Early childhood education and Primary education), teenagers (Lower secondary education and Upper secondary education) and Bachelor's or equivalent level. Post-secondary non-tertiary education was not considered as a target group in any of the selected studies. This level of education corresponds to vocational education and training (VET) and is composed of students that have completed secondary education (or most of it) and want to be prepared for a specific labor without enrolling to a university." (Garzon et al. 2019). Additionally, Bacca et al. (2015) found that it is indeed these populations that could benefit the most from the advantages of AR learning due to the increased motivation, concentration, and attention that the technology offers.

IV. CONCLUSIONS

Since 2010 the number of studies into the applications of AR in education have increased steadily (Bacca et al. 2014). Systematic reviews seem to indicate that AR is on the precipice of maturity (Garzon et al. 2019). Studies have shown that AR provides increased collaboration, interaction, motivation, and learning gains (Bacca et al. 2014). Due to the fertility of AR in education, more studies need to be concluded to provide a complete picture of the positives and pitfalls of this educational application. Cutting-edge AR technology such as smart glasses and holographic displays have not been sufficiently explored to provide foundations for future study (Altinpulluk 2019). Empirically proven design principles and holistic models have yet to be developed for AR environments, weakening the foundation of further examination (Akçayır et al. 2017). Bacca et al. (2014) discovered in the research minutia of AR that, "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."

Additionally, research into the actual design of AR experiences that compensate for the skills and abilities of the learners are absent from many studies (Bujak et al., 2013).

These designed experiences need further study in the classroom to better construct educational outcomes for efficient learner knowledge production (Lin et al., 2013). AR experiences need novel authoring tools for teachers to efficiently create learning environments that incorporate 3D content and multisensory experiences (Wojciechowski & Cellary, 2013; K.-E. Chang et al., 2014; Ho et al., 2011). This rapid development is crucial to increase use of AR in the classroom, therefore yielding a larger dataset for future research (Broll et al. 2008). Increased acceptance and practice of AR would drive the cost of hardware and software solutions, further expanding application in educational scenarios.

Education and Information Technologies (2019) 24:1089–1114 1103

Table 6 Physical environments in which AR researches are carried out

Physical Environment	*f*	Percent (%)
Classroom	19	32,75
Laboratory	6	10,34
Outdoor	4	6,89
Activity Room	4	6,89
Hospital	3	5,17
Home	2	3,44
Campus	2	3,44
Botanical Garden	2	3,44
Museum	2	3,44
Art Gallery	2	3,44
Library	2	3,44
Heritage Site	2	3,44
Lake & Pond	2	3,44
Workplace	1	1,72
Science Festival	1	1,72
Ecological Area	1	1,72
Unspecified	3	5,17
Total	58	100

Altinpulluk, Hakan. "Determining the Trends of Using Augmented Reality in Education between 2006-2016." Education and Information Technologies 24.2 (2019): 1089-114. Web.

However, development of AR in ancillary environments and diverse populations is an urgent need as "The most common target group in the selected studies is Primary education.” Garzon et al. (2019). Research concerning education and training outside of the post-secondary classroom is severely lacking from all systematic reviews and research. Bacca et al. (2014) find that “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." AR's potential should be extended to students with special needs, early childhood facilities, underserved communities, continuing education, vocational trades and other non-university settings. Only then can AR's true potential as an effective educational tool be evaluated.

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