Συνέδρια της Ελληνικής Επιστημονικής Ένωσης Τεχνολογιών Πληροφορίας & Επικοινωνιών στην Εκπαίδευση

Τόμ. 1 (2023)

13ο Πανελλήνιο και Διεθνές Συνέδριο «Οι ΤΠΕ στην Εκπαίδευση»

AR Learning and Accessibility: A Review of Inclusive Educational Practices

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Abstract

Augmented Reality (AR) bears affordances to be deployed for diverse learners' needs that may be physically or cognitively challenged to enhance their learning experience by integrating digital multimedia elements that are superimposed over real objects. This paper is a review of inclusive educational practices that leverage immersive technologies, and more specifically AR, that investigate whether these state-of-the-art technologies can ameliorate cases of inaccessibility for the diverse learner population in various educational settings. There is an investigation of the variety of contexts and disabilities to be addressed, the implementation findings, and the challenges that participants may face when using the technology from the technical, operational, cognitive, and/or pedagogical perspectives.

Keywords: augmented reality, inclusive educational interventions, accessibility, special education

Introduction

Literature on AR application affordances on special education uses suggests that AR has the potential to bring value and high-quality educational experiences to students with learning and physical disabilities in the special education setting, bridging learning and physical barriers. Quintero et al. (2019) conducted a systematic review over the last decade (2008-2018), including students with different impairments (hearing, visual, motor, or cognitive) and ethnic and vulnerable minorities. The researchers report that AR technologies enhance motivation and interaction and generate interest on the part of the student. Satisfaction and increased motivation have been observed in students, as AR may include stimulating, fun teaching aids that catch the attention of students with special needs (Serio et al., 2013; Mohd Yusof et al., 2014; Quintero et al., 2019). del Cerro Velázquez and Morales Méndez (2018) support that there are some fundamental characteristics in the educational experience based on AR, namely, (i) collaborative capacity that enables multiple users to access a shared space of virtual resources; (ii) continuous interaction by applying the appropriate technology which allows students to interact with the real world and the virtual world at the same time; and (iii) tangibility, according to which AR allows the manipulation of an object through the use of what is known as the Tangible Interface Metaphor (Billinghurst, 2002), that is far from traditional teaching methods.

Billinghurst and Dunser (2012) found that by using augmented storybooks students could tell stories and have better reading comprehension leading to more positive results in their performance. Augmented storybooks enhanced comprehension, especially for students who were less able to comprehend only text-based materials. Dunleavy et al.'s (2009) study found that teachers interviewed felt that unmotivated students or students who were identified with Attention Deficit) were 100% engaged in the learning process during an AR simulation. They further report that students who may struggle to engage under normal circumstances can

I. Kazanidis, A. Tsinakos (Eds.), Proceedings of the 13th Pan-Hellenic and International Conference "ICT in Education", International Hellenic University, Kavala. Greece, 29 September – 1 October 2023. ISSN: 2529-0916, ISBN: 978-618-83186-8-7

become more actively involved in the kinaesthetic nature employed by augmented tasks. Forsyth (2011) contends that something simple as overlaying audio can be an effective tool for students with visual impairments eliminating physical disability considerations. Wearable AR technologies such as head-mounted displays (HMDs) can address serious physical disability challenges for students that may otherwise be excluded from learning opportunities. Arvanitis et al.'s (2009) study showed that wearable AR can bring "interestingly comparable results with able-bodied users" (p. 250). Gupta et al. (2019) note that Attention Deficit Hyperactive Disorder (ADHD) is "a type of learning disability that causes the person to become less focused and easily distracted" and thus may need educational intervention to support their special learning needs, focusing on three main symptoms among ADHD students to be addressed, namely, inattentive type; hyperactive-impulsive type; and combined type. Ab Aziz et al. (2012) list the types of disabilities to be addressed with assistive technologies as follows:

1. Severe physical disability
2. Severe and mild retardation
3. Multiple disabilities
4. Disabilities that do not allow children to study in schools
5. Down Syndrome
6. Mild Autism
7. Attention Deficit Hyperactivity Disorder (ADHD)
8. Minimal Mental Retardation
9. Specific Learning Disability
10. Special Visual Disability
11. Special Auditory Disability
12. Special Remedial Students

A review of good practices in educational settings to address these needs with the support of AR technologies will further shed light on the effectiveness of their implementation and provide a valuable guide for future interventions. In order to address the aforementioned issues, the following research questions are set to be explored and answered:

RQ1: What types of physical or mental challenges have researchers tested in the special education context leveraging AR?

RQ2: What are the affordances of AR to promote an inclusive learning setting?

RQ3: What are the challenges regarding students' competency to operate novel technology?

Methodology

In this review, there will be a specific approach, focusing on AR applications designed for special education and diverse learning needs contexts that manipulate novel technologies and thus lead to a more comprehensive understanding of the experiences of AR tool users. In light of this, the methodology employed was as follows:

- *Google Scholar, Science Direct,* and *IEEE Xplore* advanced search process was conducted using a combined Boolean string with the keywords ("Augmented Reality" OR AR OR Augmented) AND (Learning OR Students) AND (Accessibility OR Disabilities OR "Special Education").

The following inclusion criteria were used:

- Articles published from 2014 to 2022; studies published in English; research from peer-reviewed journals or conferences, and books; articles focused on AR applications for people with learning disabilities; articles must be a full or short version (not an abstract) and open access.

From the list of articles that were available, there was a second phase of selection as most of the studies focused on the benefits and challenges of immersive technologies for special education needs (SEN) students but not on good practices that had been implemented in SEN settings. Only the ones that focused on addressing diverse students' needs with the design or use of an application were selected to investigate the benefits and challenges of specific educational interventions so as to draw some useful results that may support and guide future initiatives.

Findings and Discussion

Table 1 consists of a list of findings of educational interventions based on AR technologies that the present review yielded. Twelve educational interventions were selected to be presented and discussed.

Table 1. AR interventions for accessibility in education

AR intervention	Context	Added value
Gremlings in my mirror (AR videogame) by Tobar-Munoz, H., Fabregat, R., & Baldiris, S. (2014).	Students with diverse learning needs and disabilities (n=20)	An inclusive AR-enriched video game for Logical Math Skills Learning named *Gremlings in my mirror*. AR technology opened the possibility to achieve learning goals in a much shorter time. It mitigated the difficulty in cognitive processes in Maths. Technology allowed teachers to rapidly reach more pertinent, timelier goals even with less effort.
AR graphic and sound by Lin et al. (2015).	Children with disabilities (n=3)	The intervention involved physical bodily movements as children moved into an area captured by a webcam, which generated accompanying images and sounds to increase their motivation.
AR self-facial modelling by Chen, Lee & Lin (2015).	Children with autism spectrum disorder (ASD) (n=3)	The children displayed six facial expressions (happiness, sadness, fear, disgust, surprise, and anger) based on AR-3D animations of emotional expressions. The aim of the study was to impart knowledge concerning human emotions to students who have developmental disabilities.
Augmented reality in educational activities for children with disabilities by Lin, C. Y. et al (2016).	Attention deficit and memory disorders (n=21)	A game based on Aurasma functionalities intended for children with learning disabilities to arrange pieces of a puzzle aided by AR video to facilitate the learning of geometry. Performance data indicated that the use of AR technology could enhance learning motivation and frustration tolerance in children with special needs.
Interactive learning system for the hearing impaired and the vocally challenged by Hrishikesh, N., & Nair, J. J. (2016).	Hearing and vocally impaired students (n=46)	A system that employs both VR and AR to bring about a deeper immersive and more effective interactive learning experience to the students. A percentage of 40.5% of students in the experimental group showed improved performance and understanding as opposed to the control group of students.
An AR-enhanced tabletop system to promote learning of mathematics. Cascales-Martínez, A., et al. (2016).	Students with special education needs (SEN) (n=22)	A multi-touch tabletop system for applied mathematics learning in primary education with students with SEN. The students investigated a given situation and were challenged to adjust their coins or bills to collect the exact amount of money determined by the item price. The instructional content designed on the tabletop focuses on understanding and managing money, increasing knowledge, learner engagement, interaction, and satisfaction.
Athynos: Helping children with dyspraxia through an augmented reality serious game by Avila-Pesantez, D. et al. (2018).	Dyspraxia (n=40)	*Athynos* - Augmented Reality Serious Game to help Dyspraxia children improve their motor skills and hand-eye coordination The use of augmented reality in interface games is highlighted. The primary goal of the intervention is to increase student involvement and attention. A natural user interface is created utilizing Kinect sensors to recognize the students' motions in

		order to improve their hand-eye coordination.
Aira by Lannan, A. (2019). A Virtual Assistant on Campus for Blind and Low Vision Students.	Blind and Low Vision (BLV) students (n=7)	Aira, an augmented reality application, is used as a visual interpreter, in post-secondary settings. The results indicate that Aira improves the quality of life for BLV individuals, by sub-scores in activities of daily living and emotional well-being, as well as a significant improvement in the total overall scores.
Augmental-ly by Gupta, T. et al. (2019). Improving accessibility for dyslexic impairments using augmented reality.	Dyslexia (n=14)	*Augmental ly* focuses on improving reading comprehension performance for individuals suffering from dyslexia. The main features of the application include real-time text detection, customizable font styles, reader mode and read-aloud text. Students improved their readability and comprehension skills. Motivation, engagement, and satisfaction were also enhanced.
BadanKu by Rahman, N. A. et al. (2020)	Students With learning disabilities	A mobile AR learning application to help children (7-9 yrs old) with learning disabilities learn the topic of the human body for the subject of self-management. Such a user-friendly interface can help students use this application with ease and a high degree of efficiency.
Augmented Reality Based Learning Environment for Children with Special Needs by Shaltout, E. H. et al. (2020).	Students with SEN (n=7/ 5 with ASD and 2 with Down Syndrome)	A low-cost AR-based educational environment. Educational cards are divided into numerous implicit categories, such as animals and birds. In the AR environment, these cards serve as markers. The words on the cards are then scanned using a smartphone camera, and a 3D object connected with the word is mounted. Sharp intricacies, spikes, and chisels are among the qualities of the scanned word that are used to create these 3D objects.
An innovative transmedia-based game development method for inclusive education by Kaimara, P. (2021).	Students with SEN (n=11)	WUIM (Waking up in the Morning) story was designed to teach the morning routine to an audience that consists of pre-schoolers and first-grade students with and without SEN, focusing on self-directed, collaborative learning through peer-mentoring and gaming experience by employing a human avatar and a supporting actor which provide image fidelity to ensure natural representation. A human pedagogical agent as a tutorial is presented. The intervention is based on a transmedia digital game-based system including in-vivo instruction, play-based interventions, picture-based systems, social stories, video-based instruction, and computer-based intervention.

Types of Challenges Addressed

Addressing the first research question, as Table 1 clearly depicts, findings suggest that of the twelve interventions investigated, there is an interest in supporting physical or mental challenges with either a focus on each of the challenges or special educational needs and disabilities in general which include cases of dyslexia, autism spectrum disorder (ASD), blind and low vision cases (BLV), hearing and vocally impaired students, dyspraxia, ADHD, and memory disorders, among others. It was also observed that there is an interest in addressing even non-physically or mentally challenged students recruiting interest, attention, and motivation.

Affordances of AR Technologies for Inclusion in Education

The list of findings proves that there is an ongoing effort and progress to successfully employ AR technologies to enhance accessibility and inclusion in the educational setting. The applications designed and developed are intended to support specific learning groups, though not exclusively. According to the Universal Design for Learning (UDL) framework (CAST, 2018), all students can benefit from the multiple means of representation, engagement, and action and expression. Kaimara et al. (2021) discuss that the WUIM story was designed for students with and without special education needs, as this transmedia-based game development method provides a dynamic learning ecosystem. The researchers contend that "[s]tudents construct their knowledge from a variety of different sources, across different media platforms, through meaningful, challenging, technology-enhanced experiences, no matter their starting point" (p. 136). This is a very promising approach, as the study does not only focus on supporting the specific students' challenges in isolation but within a social, supportive, and all-inclusive context.

The multimodality of AR, if purposefully leveraged in the educational context based on a well-designed pedagogical framework, can provide ample opportunities for accessibility and inclusion as defined by the UDL principles. *Gremlings* and ATHYNOS comply with Gee's (2009) properties for good games that provide deep, problem-based learning opportunities and pathways to mastery through entertainment and pleasure. This pedagogical approach is in alignment with the UDL principles as it offers children visual and auditory ways to acquire information and different pathways and opportunities for interaction. As a learner-centered approach, according to learners' background and context, it enhances opportunities to optimize their full potential, be aware of their actions, and reflect on their learning. Game-based learning promotes learning in a pleasant, appealing manner, relieves frustration, and enhances engagement and satisfaction through the reward tokens that provide reinforcers. *Augmental ly* study results showed that the improvement of 21.03% in reading time, allows this prototype application to serve as a tool that not only eases these hindrances presented to individuals with dyslexia but also makes way for a healthier and richer experience in an inclusive learning context. From a pedagogical perspective, the intervention succeeded in increasing learner motivation, engagement, and confidence, while decreasing readability and comprehensibility challenges.

Aira design for blind and low vision learners, according to the researchers, is based on seven vectors, namely, developing competence; managing emotions; moving through autonomy toward interdependence; developing mature interpersonal relationships; establishing identity; developing purpose; and developing integrity. The intervention offers opportunities, experiences, and challenges encountered by students with disabilities that are as unique as the individuals themselves. The psychological aspect is also emphasized by the interactive system proposed by Hrishikesh and Nair (2016) in delivering the lesson and the concepts to the students that are hearing impaired and vocally challenged. Students interact with the objects displayed in an immersive and playful manner and see for themselves how the objects in view change and animate according to different interactive gestures.

Life skills and social interaction is also promoted by the multi-touch tabletop system as the students investigate a given situation and are challenged to adjust their coins or bills to collect the exact amount of money determined by the item price, which provides an interactive, collaborative learning environment for multiple users based on constructivism. The researchers observed the enthusiasm and motivation of the novelty of technology as well as ease of use in challenging activities such as adding and subtracting euros and turning them into cents to make precise calculations. This challenge in a collaborative problem-based activity contributed to scaffold learning, which applies to the theory of Vygotsky's (1978) zone of proximal development (ZPD). Accordingly, the WUIM project encourages participatory learning, incorporating the basic principles of learning theories of constructivism and connectivism (Alper & Herr-Stephenson, 2013). Students construct their knowledge from a variety of different sources, across different media platforms, through meaningful, challenging, technology-enhanced experiences, no matter their starting point. Lannan (2019) stresses the importance of Chickering's (1969) theory of identity development, grounded in the psychosocial theory, examining the personal and interpersonal lives of college students.

The AR affordances that this study yielded for inclusive teaching and learning practices could be summarized as providing a) a dynamic, learner-centered ecosystem; b) transmedia-based pathways to mastery through entertainment and pleasure; c) participatory learning; and d) identity development, while decreasing frustration, comprehensibility and interpersonal interaction challenges. These affordances do not only benefit special education needs students but all learners in an educational setting.

Challenges in Operating Novel Technology

The design and successful implementation of an intervention depends on the usability aspect. Within the school context, challenges regarding students' digital competencies to manipulate novel technology can be ameliorated with the support of the instructors. This review revealed that in most cases there were supportive videos and instructions to explain the operation of the application. One user of the Aira app stated that "access" is not enough if not accompanied by training. More specifically, Lannan (2019) comments on the need for training to use an app, as access is not limited to availability. The author notes that "[a]ccessibility isn't just about having 'access'. If an accommodation is provided, but not the training or support to use it in a productive manner, then accessibility hasn't truly been provided." (p. 8).

During the use of the multi-touch tabletop, the students worked effectively in a collaborative manner and did not report facing challenges in operating the novel technology. The fact that the whole system was provided on familiar desktops was an advantage. In the case of *Augmental-ly*, there was a provision for the UI of the app to be kept as minimal and non-intrusive as possible, with clickable text boxes and settings buttons that allow the users to tweak the styling of the text according to their needs. Testers' feedback further helped with provisions and improvements with regard to their experience (UX). Accordingly, during the evaluation of the WUIM project, challenges included children's and experts' remarks about technical and operability issues including user interface, e.g., font size, and tablet stability issues for children with fine motion difficulties. To accommodate these challenges, the project team enlarged the fonts and procured special tablet cases with handles. Following good practice of regular applications, we can therefore recommend making accessibility settings for font sizes available in a centralised fashion, interfacing with system settings for accessibility where possible.

Considerations and Limitations

The implementation and study of the interventions bring to light some considerations to be examined for future study and reference. As such, it is observed that the specific interventions were implemented in a limited number of beneficiaries and for a short time (Lian & Sunar, 2021). They should also be tested on a larger scale to ensure generalization. In light of this, while the usability of the aforementioned interventions is suggested to apply to an all-inclusive learning environment, not all studies have employed a mainstream education setting with experimental and focus groups to test results and significant difference. Another major consideration is that some systems require a complex system of desktop computer platform and hardware, as well as connection to devices with sensors, that are environmental and technical requirements which are also listed in the European Committee Standardization

(CEN) eXtended Reality (XR) accessibility considerations and recommendations workshop agreement (June 2023). Cai et al. (2021) observe that large and cumbersome equipment reduces portability, limiting the approaches to certain areas of implementation while stressing the cost and need for affordable solutions to ensure the popularization of the recommended interventions. Accordingly, training of instructors to successfully employ novel technologies and adapt them to their own unique context based on a pedagogical framework as part of a continuous professional development requirement is to be examined. This prerequisite includes instructors' digital and pedagogical competencies to train students to operate the technology in an autonomous manner, beyond dependence on their instructor, diminishing stress and frustration. Network quality of service, age appropriateness, and privacy and security issues should also be considered when dealing with applications in a digital environment to ensure the smooth delivery of content.

Conclusion

The integration of Augmented reality in educational environments has the potential to revolutionize the way we learn and enhances opportunities for accessibility and inclusion of physically and mentally challenged individuals, nevertheless, not exclusively this population. The multimedia elements are superimposed over real-world objects to help learners better understand the world they live in and develop life skills through a purposefully well-designed pedagogical framework that can facilitate the learning process and maximize opportunities for learners to reach their unique full potential. AR good practices were investigated in this paper, focusing on special education needs and challenges to be addressed, varying from the autism spectrum, dyslexia, and dyspraxia to hearing and visual impairment. Findings reveal that there is a considerable interest to employ novel technologies specially designed to support learners in an all-inclusive learning context. Very promising digital game design systems, AR tabletop systems, and mobile apps are designed and developed to address cases of disadvantaged populations that respond to UNESCO's (2017) call for "no one to be left behind". AR in education is still in its infancy, still "shapeable", and considerations and limitations can inform future research and improvements in the field. According to Ryan (2006), "*Everyone has the right to participate in what the world has to offer and to reap the benefits of this involvement*".

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