Altered Realities: How virtual and augmented realities are supporting learning.

Damian Maher
University of Technology Sydney (UTS)

ABSTRACT

As the use of both virtual reality (VR) and augmented reality (AR) become more common place in society, the importance of including these technologies in schools increases. The focus of this chapter is to explore how these two technologies are being used at in primary, secondary and tertiary contexts to support student learning. In exploring these technologies, a focus starts looking at STEM related subjects with a focus on science. In investigating Science, a focus on informal learning is also undertaken. In exploring game-based learning maths is examined where the concept of location-based learning is examined. The chapter concludes by exploring how VR and AR can be used to support students with disabilities.

INTRODUCTION

Both virtual and augmented reality technologies have been available for some time and the demand for these two technologies is growing. According to a recent publication, the global augmented and virtual reality market is forecast to reach $94.4 billion by 2023. The demand for this is in the retail and e-commerce sectors (Cision PR Newswire, 2018). These technologies are also starting to have a greater impact in school classrooms in many countries as they increase in sophistication and costs are reduced. These technologies allow for experiences that would otherwise not be possible for students.

In considering virtual reality, there are two types of VR; low immersion (also referred to as desktop VR) and high immersion VR (generally involving a head-mounted display (Lee &Wong, 2014). "In desktop VR, the virtual reality environment (VRE) is displayed on a conventional PC monitor with sound coming through speakers and the interaction is controlled through a regular computer mouse" (Makransky, Terkildsen & Mayer, 2017, p. 2).

The technologies that currently support high immersion virtual reality include high end virtual goggles which are Oculus Rift and HTC Vive. These technologies require a powerful computer to run them which not all schools possess. Both of these systems have the headset tethered to the computer. Oculus Go has recently being introduced which does not require it to be tethered to a computer.

At the next level down are the PlayStation and Samsung. The PlayStation is tethered whilst the Samsung is not, but it requires a Smartphone. At the bottom end is Google cardboard, which also requires a Smartphone. Plastic headsets can also be purchased in which smart phones running AR apps can be inserted. At the top end of sophistication are virtual reality rooms. One such room is the data arena, which is located at the University of Technology Sydney (UTS). This is a room offering a 360 degree experience mediated by goggles which holds 15 users at one time.

Azuma defines AR as a system or visualization technique that has three characteristic: “1) Combines real and virtual 2) Interactive in real time 3) Registered in 3D” (1997, p. 2). Augmented reality has been used in different media and systems for decades, e.g. head-up displays in fighter planes, scoreboards in sportscasts (Seppälä et al., 2016). It is now being used to support educational practices. In fact, it has been asserted that education is one of the most promising application areas for AR (Wu, Lee, Chang, & Liang, 2013). Augmented reality, using a device's camera to overlay information on the real world, can be experienced via a mobile device such as a smart phone or tablet, usually through an app. There are also headsets or glasses that can be worn that will overlay this information. AR allows virtual information to be superimposed onto physical objects and environments (Chung et al., 2015). AR can either bring real-world objects into a virtual environment or bring virtual objects into reality (Milgram & Kishino, 1994). Additionally, research evidence suggests that AR can increase student motivation in the learning process (Bujak et al., 2013).

The popularity of Pokémon Go successfully introduced AR to a mass audience (Wingfield & Isaac, 2016) demonstrating how it can be used for entertainment purposes. There are many important ways it, and other AR apps can also support educational outcomes, some of which are explored in this chapter.

The area of Science, Technology, Engineering and Maths (STEM) is now a major focus of politicians and economists where it is recognised that professionals will be needed for worldwide innovation and global economics (Eisenhart, Weis, Allen, Cipollone & Stich, 2015). In response to this recognition, many school systems are now turning to both virtual and augmented reality to support learning in this area. A focus of the chapter will be to explore how VR and AR are being used to support STEM-based learning subjects which includes examining how AR is being used to support informal learning.

The use of games in AR and VR to support learning is an area that is increasing in schools. Using games provides real-world relevance where abstract scientific concepts can be connected with the real world (Laine, Nygren, Dirin & Suk, 2016). This can be done by situating learning processes in real-world contexts, and by bridging the virtual content and the real world with augmented and virtual reality. The different types of games used in an AR environment with a focus on location-based learning are investigated in this chapter.

Another area that is outlined in this chapter is the use of VR/AR to support students with disabilities. There are a wide range of disabilities that impact on school age students including physical as well as cognitive disabilities. The use of VR and AR provides opportunities for students to engage in meaningful learning using tools from fully immersive systems to smart glasses. It has been demonstrated that the use of VR and AR can have a positive effect on the outcomes for students with disabilities (Lorenzo, Lledó, Pomares & Roig, 2016). This chapter explores the types of VR/AR experiences available to support student with disabilities and how these support social communication, cognition, and motivation.

SUBJECT-SUPPORTED REALITIES

The STEM focus covers Science, Technology, Engineering and Mathematics. In using this term, the subjects can be considered individually. The term also covers the concept where all subjects are taught together in an integrated curriculum (Thibaut et al, 2018). For this chapter, the focus is on some of the individual subjects. There is also a focus on informal learning, which is underpinned by scientific understanding. Additionally, much of the literature on mathematics includes the use of games so the math content appears later in the games section. Included later in this section is discussion on non-STEM related subjects including geography and physical education.

One of the ways that VR can be used to support science learning is through the use of simulations which are designed to replace or amplify real-world learning environments by allowing users to manipulate parameters and objects in a virtual environment (Makransky, Terkildsen & Mayer, 2017).

The use of simulations has a number of advantages over real-life experiments which includes allowing students to observe otherwise unobservable phenomena, provides adaptive guidance in a virtual world that provides a high sense of physical, environmental, and social presence as well as reducing the time demand of experiments (Makransky, Lilleholt & Aaby, 2017). Another advantage of simulations is that students can conduct them at home which can allow them to prepare for real-life experiments in the classroom and to continue investigation after being introduced to the concept in class.

Whilst there are a number of advantages in the use of VR to support scientific understanding there are also limitations. One such limitation is that learning science in VR simulations may overload and distract the learner resulting in less opportunity to build learning outcomes (Makransky, Terkildsen & Mayer, 2017).

The use of the Google Expeditions app to support scientific understanding is one area of science simulations that has been investigated (Minocha, Tudor & Tilling, 2017). There were a number of simulations in the app the researchers focused on which included the human auditory system, the eruption of a volcano, and the processes of pollination. One the important implications for learning using the simulations they report on is that …"it is critical to 'time' the showing of the simulation – the simulation is only pedagogically effective when the students already have some basic understanding of the concept or process in the simulation" (p.6-7). Like all tools that support learning, it is the pedagogical practices that underpin the learning are most important.

A number of studies have been undertaken looking at how the use of VR can support learning in relation to virtual field trips. Later in the chapter the focus is on the use of AR to support learning in the field, both in informal learning settings and in location-based settings (also known as field trips). In this section the focus is on how VR can support virtual field trips in classrooms.

As reported in the literature, the opportunities for field trips in countries such as Australia, the UK and the United States are diminishing due to issues such as fear for students' well-being, health and safety issues as well as large class sizes (Minocha et al., 2017). As a result, virtual field trips can and are being used to support learning. However, whilst virtual field trips can support student understanding, research shows that electronic experiences generate some, but not all of the benefits of the real experience (Kahn Jr, Severson & Ruckert, 2009). Virtual field trip participants perform no better than students who receive classroom-based lectures and the experiences were generally less effective than field trips

Other subject-based uses

One subject area that has been investigated as to how VR can support virtual field trips is geography. In this study the authors compared a field trip to a virtual field trip for students at the Singapore university (Friess, Oliver, Quak, & Lau, 2016). Results of the research showed, not unsurprisingly, that students preferred the actual tip into the field over the virtual experience. The study found that the virtual field trips provided an important way of preparing students for the visit into the field. Virtual field trips can be used as a way of supplementing rather than replacing the field trip into the environment.

Like other VR experiences, virtual field trips also provide opportunities for students to experience locations that they would not be able to experience otherwise due to distance or because the location is too dangerous or expensive to visit.

The role of the teacher in supporting virtual field trips is important. One study investigated a virtual field trip using two approaches (Borst, Lipari & Woodworth, 2018). In the first approach the teacher was live and in the second approach the narration by the same teacher was pre-recorded. Results of this study showed that the live teacher provided more educational benefits; due to the fact the teacher was able to correct misunderstandings and respond to live questions. The authors state more research is needed to investigate what specific aspects of teacher guidance supported student understanding. This study raises the need to understand teacher input but also the input that other students can provide to each other.

Physical education (PE) is another subject that has been supported through the use of virtual technologies. There are a number of benefits in using VR to support PE teaching. Some of these benefits include the ability to provide varying environments as well as the ability to reduce injuries (Zhang & Liu, 2016). Another advantage is that students can get increased feedback through controlling the environment.

An example of where VR has been used to support physical education is with soccer. In the study a platform called Copefoot was used to train adolescent soccer players (age 15 years) how to make tactical decisions (Pasco, 2013). In using this system avatars were used where the player interacts with them providing opportunities for real-time interactions to take place. A limitation suggested of this system is that is requires the player to mimic an action rather than carry out a skill.

In another study, VR was used to support the development of jumping skills for five year old students. Results of the study showed that motivation induced by the sports practice, including the use of virtual reality video games with repetition exercises with bodily extension and elongation movements, positively influenced the locomotor jump pattern in children (Liao, 2015).

Informal learning

The learning that occurs in museum settings (which include zoos, educational visitor centers, art galleries, and museums) is referred to as informal learning where the learning typically is free choice, exploratory, open-ended, and social (Griffin & Symington, 1997) and often fits within a scientific way of thinking. The place of free-choice is highly valued by informal educators because students are intrinsically motivated to make choices that are most meaningful to them (Falk & Dierking, 2000). Museums are now embracing the use of mobile technologies to support the learning experience (Maher, 2015).

Given the ownership and use of mobile devices by many young people, the use of augmented reality can successfully support learning. As museums move away from the traditional static displays that were once a feature of learning, the use of AR technologies to enable a more interactive experience is becoming commonplace.

The use of different modalities (multimedia) to support a better museum experience is an area that is being investigated. The multimedia principle states that people learn better from words and pictures than words alone (Sommerauer & Müller, 2014). A traditional museum exhibition included a static display (such as a dinosaur with some written information and some sound and generally draws on few modalities. With the use of AR typically through the use of a mobile device, both sound and animation can be included to increase the learner experience along with gesture and touch. One such way that AR supports learning through increased multimedia is that it provides a better flow of information to the user about the museum/gallery exhibitions (Miyashita et al., 2008).

In understanding how AR can be used to support learning there are many aspects that can affect outcomes, one of these being gender. In one study a reality iPad-based mobile game, called The Great STEM Caper, was investigated at a science centre (Atwood-Blaine & Huffman, 2017). An open-source, location-based game platform called ARIS (i.e. Augmented Reality and Interactive Storytelling) was used to create an iPad-based mobile game.

Results of this study showed that females outscored the males on every measure of the game. The females tended to be more collaborative while the males tended to be more competitive. As the authors suggest, the results of this study have implications for the design of mobile-based technology to encourage interaction in an informal science centre setting. It is important therefore, that the students' needs are considered when using AR to support learning.

GAMES AND GAMIFICATION

The use of games and gamification are important mechanisms that support learning. Games provide participants with opportunities to learn from their involvement within a structured experience. "Learning from doing provides an important paradigm shift away from the tutor as knowledge disseminator, expert and authority figure towards the role of the participant as an active processor of information" (Allery, 2004, p.504). Game-based learning (GBL) can also help support motivational gain and engagement in the child's learning (Papastergiou, 2009). Science is particularly well-served by a game-based instructional approach. Several science goals are embedded in game play, such as critical thinking, decision making, practices of inquiry and problem solving (Klopfer, 2008). In focusing on both VR and AR, the term 'digital game-based learning' (DGBL), which describes the process of learning, while playing a computer game (Prensky, 2007) is used.

The term gamification refers to the use of game mechanics in non-gaming contexts (Deterding, Dixon, Khaled, & Nacke, 2011). Examples of gamification elements include points, badges, leader boards, and storyline as well as progress bars and feedback (Nah, Eschenbrenner, Zeng, Telaprolu & Sepehr, 2014).

Focusing on mathematics and games, both VR and AR can support student learning. In the area of VR, a game called Archer supports students' understanding of degrees. In this archery game the goal is to shoot arrows as far as possible. To help the players achieve this, the students are shown the degree of the angle between the ground and the direction they are aiming for (Herman & Pontus, 2017). The game allows for multiple attempts to be undertaken and provides students with information on the degrees of the shots so that they can make changes using mathematical concepts. Much of this mathematical understanding would be difficult to understand without the use of this and other VR programs. One difficulty in mathematical learning is the level of abstract thinking required (İncikabi, L., & Kiliç, Ç. (2013). The use of VR and AR can support such thinking through the use of games.

Opportunities to integrate subjects (some non-STEM related) exist in using VR and games. One example is reported on where maths and music are combined (Lim, Lee & Ke, 2017). In the study a virtual reality game was designed and developed to integrate a musical activity (beat-making) into the math learning of fractions for year 6 students. For the study, OPENSIMULATOR, which is a multi-user 3D application server that hosts virtual environments, was used. A western American town including a music shop was constructed in the virtual environment. The focus of the game was for students to produce beats using information provided as fractions which supporting understanding, eg 4/4, 8/8 and 16/16 all equal one. One of the features of games is that instant feedback is provided which can support understanding. This game was able to provide such feedback in a VR environment.

In considering the use of AR and gaming, one of the possibilities is that they can be location-based, allowing players to interact with their environments at real locations in real time (Hinske, Lampe, Magerkurth, & Röcker, 2007). Students are able to use mobile devices to run AR apps whilst on field trips. Such trips provide an important interface between teaching and learning (Day, 2012) and provide for opportunities not easily experienced in the classroom, with direct pedagogical benefits (Scott, Fuller, & Gaskin, 2006).

One famous AR game, discussed in the introduction is Pokémon Go. Research conducted into this app with adults showed that in using the app from a location-based perspective, “it is not important *where* you play; rather, the place of playing *becomes* important to you” (Oleksy & Wnuk, 2017, p. 7). The authors found that the role of gamification mediates the effects of social interactions and game satisfaction on place attachment.

Another research project conducted looking at the use of the app focused on the cognitive performance and emotional intelligence of adolescents (Ruiz-Ariza, Casuso, Suarez-Manzano & Martínez-López, 2018). Results of the study found that in playing the game, there was an increased attention concentration span for plays and that the players had better social relationships than non-players. The social benefits of using the app for adults was also reported on in a study conducted by Rauschnabel, Rossmann and tom Dieck, (2017).

Other location-based AR research has been undertaken focusing on the use of games. In one of these studies students visited a butterfly garden where they received points for answering questions correctly (Hwang, Wu, Chen, & Tu, 2016). The activity included a gaming strategy to encourage students to seek answers and make observations on their own. In another study students visited an archaeological site in Cyprus using an AR learning environment on mobile tablet devices (Efstathiou, Kyza, & Georgiou, 2018). The authors found that the AR app was effective in promoting students' historical empathy and conceptual understanding. These studies show that the use of AR in location-based settings is able to support students' understanding. Like formal learning, the use of these technologies also allows students to learn in a variety of settings outside of the classroom.

SUPPORTING STUDENTS WITH DISABILITIES

The use of virtual and augmented realities has shown to support students with a number of different disabilities. One area that these technologies have proven to support young people is with those who have been diagnosed on the Autism Spectrum Disorder (ASD). Having this disorder is characterised by impairments in communication, reciprocal social interaction and restricted repetitive behaviors or interests (Faras, Ateeqi & Tidmarsh, 2010). Much of the research that has been carried examining the use of VR to support young people with ASD has focused on social and emotional skills (Lorenzo, Lledó, Arráez-Vera, & Lorenzo-Lledó, 2018).

The use of VR to support young people with ASD first began in the mid 1990s. In 1996, a seminal study investigated the potential of using VR as a learning tool for two children with ASD (Strickland et al., 1996). The equipment at that time was basic and quite bulky but the research project demonstrated that children with ASD responded to the virtual scenarios in a meaningful way.

More recent research into the use of VR to support young people has looked at various aspects of children with ASD beyond the use of goggles. In a study conducted by Ip et al. (2018), a virtual reality room was set up which they called the half CAVE. In this environment 94 primary -aged students were placed in a series of virtual settings includes washrooms, buses and classrooms where there were opportunities to engage in social interactions. Results of the study showed significant improvements in the children's emotional expression and regulation as well as social-emotional reciprocity.

The use of augmented reality to support special needs students is not as well researched compared to the use of virtual reality. However, the use of apps to support such students has been carried out in a number of studies. One area that has been investigated is the use of location-based AR as a means to increase functional navigation skills. This research has been conducted with young adults but could be applied to younger students. In one study the effects of a printed map, Google Maps on a mobile device, and a location based AR navigation application on an iPhone were investigated (McMahon, Smith, Cihak, Wright & Gibbons, 2015). The results of the study showed that location-based AR was functionally more effective than paper and mobile device Google Maps use.

A further study focused on the participants using an iPhone app called Heads Up Navigator; 3D Augmented Reality Navigation. (Smith, Cihak, Kim, McMahon & Wright, 2017). This app combined the use of Google Maps with AR features to enable real-time navigation prompts to users. Through the use of commercially available devices and apps, students were able to navigate to a chosen destination which they we not able to do without the AR app. The use of commercially available apps is significant as this means students in schools can be supported to assist their daily living skills without needing expensive equipment.

Research into the use of AR to support special needs students has also been undertaken looking at the use of smart glasses. In one study a software program called The Empowered Brain was trialled in conjunction with the use of smart glasses (Keshav et al, 2018). The smart glasses would monitor the attention of the students in relation to the teachers' face. Game-like points and rewards would be provided when the students paid attention. If the student looked away from the teacher for an extended period of time, and demonstrated reduced attention, the software would provide guidance to direct them back to the teacher. Results of this study indicate that there were enhanced social communication skills for the students.

Ways that VR have been used to support students with physical disabilities has also been investigated. One example is where VR has been used is to support deaf students. Research on deafness in children and adolescents shows that they have reduced orientation, kinesthetic and rhythm perception ability, the later which can impact on the physical ability of balance (Kaltsatou, Fotiadou, Tsimaras, Kokaridas & Sidiropoulou, 2013). This can lead to depression (Woodcock & Pole, 2007).

One study investigated students with severe hearing loss and how the use of Nintendo Wii Fit Plus supported students to develop balance abilities. (Tzanetakos, Papastergiou, Vernadakis & Antoniou, 2017). The results of the study showed that the balance games constitute a feasible, safe, easy to-use and motivational mode of balance training for adolescents with deafness.

One important aspect of this study was that the parents of the students were involved the project where students used the games at home as well as at school to help develop their balance. Where the technology is affordable, this link it provides between home and school is important allows for more effective support for the young people with disabilities.

CONCLUSION

Much of the literature reported on in this chapter is on exploratory studies carried out to investigate how VR and AR can support learning. In reviewing the literature and research on the both virtual reality and augmented reality, it was noted that there is far more literature on augmented reality. A reason suggested for this is that it is easier to work with augmented reality apps (which can be downloaded on tablets or laptops) than it is to purchase the equipment needed for virtual reality.

There are some cost effective ways of using VR in the classroom. While Google Cardboard (which was discussed earlier) is a cheap container, smart phones are needed and these are expensive. Using Google cardboard can work in secondary and university settings depending on university rules but would be more difficult to use in primary schools where few students have smart phones. Low immersion VR can be run on desktops but these are becoming less common in schools as a result of the introduction of mobile devices.

The use of VR allows for students to experience virtual field trips, which can support them as they prepare for trips into the field. The use of AR is then able to support learning while students are in the field or in informal learning settings. As noted in the chapter, informal learning can be supported where students can work with AR either in preparation for the visit or while on location.

In focusing on STEM, a lot of the research and literature in the AR area has been conducted in the science area. This observation is backed up by a review of Yilmaz (2018), which showed that science education is the most explored field comparing different subjects. This review also showed primary school education was the most researched area of education where secondary and tertiary education was also considered. Maths was also covered where a lot of the research in this area has been conducted looking at aspects of gamification.

One concept that was touched upon in several places in the chapter was motivation. This aspect is an important part of learning has a positive effect on student achievement (Furió, Juan, Seguí & Vivó, 2015). Findings indicate that learning in an AR environment results in greater student motivation compared to non-AR learning environments (Tobar-Munoz, Baldiris & Fabregat, 2017). Additionally, it has been found that greater learner interest, enjoyment and satisfaction results from learning with AR compared to more traditional classroom instruction (Tobar-Munoz et al., 2017).

An aspect related to motivation is engagement. Engagement refers to the extent to which a learner applies a level of attention and curiosity to a situation in an effort to achieve a desirable result (Student Engagement, 2014). Understanding levels of learner engagement is useful as a way to determine the effectiveness of the environment in progressing high-quality learning (Krause & Coates, 2008). High student engagement can lead to greater learning outcomes and increased motivation (Krause & Coates, 2008). AR has shown to lead to high levels of engagement.

In a study of focusing on mathematics in high school, it was reported high engagement with the subject material was a positive effect of AR technology use (Estapa and Nadolny, 2015). In another study based in a high school setting, the students felt using an AR app to explore geometric shapes was "more exciting than normal class" and "interesting" (Laine, Nygren, Dirin & Suk, 2016, p.52). Similar studies conducted in primary schools also show high levels of engagement.

Another area covered this chapter has been exploring the use of both VR and AR to support students with disabilities. The aspects covered in this chapter cover a small proportion of what is being undertaken in the field. One of the main aspects of cognitive disability is ASD and both VR and VR have been shown to be effective in supporting students with this condition.

One aspect that is considered to be important for students with disabilities is inclusion, which involves keeping young people connected to mainstream schools in the communities in which they live rather than moving them to specialist schools which can be located a long way from where they live. Providing ways that allow students with disabilities to participate in mainstream education is important and the use of VR and AR can be used towards such ends. As these technologies become more sophisticated and the costs reduce there will be a broader range of students who will be able to be supported as well as the ability to support students in more effective ways.

At the time of writing this chapter, France had just banned all mobile devices (including smart phones, tablets and smart watches) in schools for students under 15 years of age. Some schools in other countries also ban the use of mobile devices such as Australia (SBS, 2018). Such a move impacts on the use of AR and VR in both classrooms and in informal learning settings. Discussion is needed at both policy and school levels to ensure that the technologies needed to support learning are available in schools. As suggested in this chapter, both AR and VR technologies are expected to increase in use and sophistication and thus it is important that they, and the devices they run on, are available to support learning for students.

REFERENCES

ABC News (2018). France passes new law banning smartphones, tablets and Smart watches in Schools. Retrieved from http://www.abc.net.au/news/2018-08-01/france-bans-smartphones-and-tablets-in-classrooms/10060590

Allery, L. A. (2004). Educational games and structured experiences. *Medical Teacher*, *26*(6), 504-505.

Atwood-Blaine, D., & Huffman, D. (2017). Mobile gaming and student interactions in a science center: the future of gaming in science education. *International Journal of Science and Mathematics Education*, *15*(1), 45-65.

Azuma, R. T. (1997). A survey of augmented reality. *Presence 6*(4), 355–385

Borst, C. W., Lipari, N. G., & Woodworth, J. W. (2018). Teacher-Guided Educational VR: Assessment of Live and Prerecorded Teachers Guiding Virtual Field Trips. Retrieved from https://vrlab.cmix.louisiana.edu/papers/Borst_Lipari_Woodworth_Teacher GuidedVR.pdf

Bujak, K. R., Radu, I., Catrambone, R., Macintyre, B., Zheng, R., & Golubski, G. (2013). A psychological perspective on augmented reality in the mathematics classroom. *Computers & Education*, *68*, 536-544.

Bursztyn, N., Walker, A., Shelton, B., & Pederson, J. (2017). Assessment of student learning using augmented reality Grand Canyon field trips for mobile smart devices. *Geosphere, 13*(2), 260-268.

Chang, K. E., Chang, C. T., Hou, H. T., Sung, Y. T., Chao, H. L., & Lee, C. M. (2014). Development and behavioral pattern analysis of a mobile guide system with augmented reality for painting appreciation instruction in an art museum. *Computers & Education*, *71*, 185-197.

Cision PR Newswire. (2018). *Global Augmented Reality (AR) and Virtual Reality (VR) Market is Forecast to Reach $94.4 Billion by 2023 - Soaring Demand for AR & VR in the Retail & E-Commerce Sectors. Report by Research and Markets*. Retrieved from https://www.prnewswire.com/news-releases/global-augmented-reality-ar-and-virtual-reality-vr-market-is-forecast-to-reach-94-4-billion-by-2023---soaring-demand-for-ar--vr-in-the-retail--e-commerce-sectors-300689154.html

Day, T. (2012). Undergraduate teaching and learning in physical geography. *Progress in*

Physical Geography, 36, 305–332

Deterding, S., Dixon, D., Khaled, R., & Nacke, L. (2011). From game design elements to gamefulness: Defining gamification. *Proceedings of the 15th international Academic MindTrek Conference: Envisioning Future Media Environments* (pp. 9- 15). ACM.

Efstathiou, I., Kyza, E. A., & Georgiou, Y. (2018). An inquiry-based augmented reality mobile learning approach to fostering primary school students' historical reasoning in non-formal settings. *Interactive Learning Environments*, *26*(1), 22-41.

Eisenhart, M., Weis, L., Allen, C. D., Cipollone, K., & Stich, A. (2015). High school opportunities for STEM: comparing inclusive STEM-focused and comprehensive high schools in two U.S. cities. *Journal of Research in Science Teaching, 52*(6), 763–789.

Estapa, A., & Nadolny, L. (2015). The effect of an augmented reality enhanced mathematics lesson on student achievement and motivation. *Journal of STEM Education: Innovations and Research*, *16*(3), 40

Falk, J. & Dierking, L. (2000). *Learning from museums: Visitor experiences and the making of meaning*. Walnut Creek, CA: Altamira Press.

Faras, H., Al Ateeqi, N., & Tidmarsh, L. (2010). Autism spectrum disorders. *Annals of Saudi medicine*, *30*(4), 295.

Friess, D. A., Oliver, G. J., Quak, M. S., & Lau, A. Y. (2016). Incorporating "virtual" and "real world" field trips into introductory geography modules. *Journal of Geography in Higher Education*, *40*(4), 546-564.

Furió, D., Juan, M., Seguí, I., & Vivó, R. (2015). Mobile learning vs. traditional classroom lessons: A comparative study: Mobile vs. traditional learning. *Journal of Computer Assisted Learning, 31*(3), 189-201

Griffin, J., & Symington, D. (1997). Moving from task-oriented to learning-oriented strategies on school excursions to museums. *Science education*, *81*(6), 763-779.

Herman, R., & Pontus, F. (2017). Virtual reality's effect on engagement in educational games. Unpublished thesis. Accessed from https://www.diva-portal.org/smash/get/diva2: 1119245/FULLTEXT01.pdf

Hinske, S., Lampe, M., Magerkurth, C., & Röcker, C. (2007). Classifying pervasive games: on pervasive computing and mixed reality. *Concepts and technologies for Pervasive Games-A Reader for Pervasive Gaming Research*, *1*(20), 1-20

Hwang, G. J., Wu, P. H., Chen, C. C., & Tu, N. T. (2016). Effects of an augmented reality-based educational game on students' learning achievements and attitudes in real-world observations. *Interactive Learning Environments*, *24*(8), 1895-1906.

İncikabi, L., & Kiliç, Ç. (2013). An analysis of primary school students' conceptual knowledge of geometric solids. *Journal of Theoretical Educational Science*, *6*(3), 343-358.

Ip, H. H., Wong, S. W., Chan, D. F., Byrne, J., Li, C., Yuan, V. S., ... & Wong, J. Y. (2018). Enhance emotional and social adaptation skills for children with autism spectrum disorder: A virtual reality enabled approach. *Computers & Education*, *117*, 1-15.

Kahn Jr, P. H., Severson, R. L., & Ruckert, J. H. (2009). The human relation with nature and technological nature. *Current Directions in Psychological Science*, *18*(1), 37-42.

Kaltsatou, A., Fotiadou, E., Tsimaras, V., Kokaridas, D., & Sidiropoulou, M. (2013). The effect of a traditional dance training program on dancing skills, rhythm and orientation abilities and on intrinsic motivation of individuals with hearing loss. *Journal of Physical Education and Sport, 13*(3), 438-446

Keshav, N., Vahabzadeh, A., Abdus-Sabur, R., Huey, K., Salisbury, J., Liu, R., & Sahin, N. (2018). Longitudinal socio-emotional learning intervention for autism via smartglasses: Qualitative school teacher descriptions of practicality, usability, and efficacy in general and special education classroom settings. *Education Sciences*, *8*(3), 107-121

Klopfer, E. (2008). *Augmented learning: Research and design of mobile educational games*. Cambridge, MA: MIT Press.

Krause, K. & Coates, H. (2008), Students' engagement in first year university. *Assessment and Evaluation in Higher Education, 33*(5), 493-505. Retrieved from http://www98.griffith.edu.au/dspace/bitstream/handle/10072/26304/53553_1.pdf? sequence=1

Laine, T. H., Nygren, E., Dirin, A., & Suk, H. J. (2016). Science Spots AR: a platform for science learning games with augmented reality. *Educational Technology Research and Development*, *64*(3), 507-531.

Lee, E. A. L., & Wong, K. W. (2014). Learning with desktop virtual reality: Low spatial ability learners are more positively affected. *Computers & Education*, *79*, 49-58.

Lim, T., Lee, S., & Ke, F. (2017). Integrating music into math in a virtual reality game: Learning fractions. *International Journal of Game-Based Learning (IJGBL)*, *7*(1), 57-73.

Liao, T. (2015). Application of virtual reality technology to sports. In *International Conference on Circuits and Systems (CAS 2015)*.

Lorenzo, G., Lledó, A., Arráez-Vera, G., & Lorenzo-Lledó, A. (2018). The application of immersive virtual reality for students with ASD: A review between 1990–2017. *Education and Information Technologies*, 1-25.

Lorenzo, G., Lledó, A., Pomares, J., & Roig, R. (2016). Design and application of an immersive virtual reality system to enhance emotional skills for children with autism spectrum disorders. *Computers & Education*, *98*, 192-205.

McMahon, D., Smith, C. C., Cihak, D. F., Wright, R., & Gibbons, M. (2015). Effects of digital navigation aids on adults with intellectual disabilities: Comparison of printed map, Google map, and augmented reality via iPad and iPhone. *Journal of Special Education Technology*, 30, 157–165. doi:10.1177/0162643415618927

Makransky, G., Lilleholt, L., & Aaby, A. (2017). Development and validation of the multimodal presence scale for virtual reality environments: a confirmatory factor analysis and item response theory approach. *Computers in Human Behavior*,*72*, 276-285.

Makransky, G., Terkildsen, T. S., & Mayer, R. E. (2017). Adding immersive virtual reality to a science lab simulation causes more presence but less learning. *Learning and Instruction*. Retrieved from https://doi.org/10.1016/j.learninstruc.2017.12.007

Maher, D. (2015). Connecting classroom and museum learning using mobile devices. *Journal of Museum Education*, *40*(3), 257-267.

Milgram, P., & Kishino, F. (1994). A taxonomy of mixed reality visual displays. *IEICE TRANSACTIONS on Information and Systems*, *77*(12), 1321-1329.

Minocha, S., Tudor, A. D., & Tilling, S. (2017). Affordances of mobile virtual reality and their role in learning and teaching. In *Proceedings of the 31st British Computer Society Human Computer Interaction Conference* p. 44). BCS Learning & Development Ltd..

Nah, F. F. H., Eschenbrenner, B., Zeng, Q., Telaprolu, V. R., & Sepehr, S. (2014). Flow in gaming: literature synthesis and framework development. *International Journal of Information Systems and Management*, *1*(1-2), 83-124.

Oleksy, T., & Wnuk, A. (2017). Catch them all and increase your place attachment! The role of location-based augmented reality games in changing people-place relations. *Computers in*

Human Behavior, *76*, 3-8.

Pasco, D. (2013). The potential of using virtual reality technology in physical activity settings. *Quest*, *65*(4), 429-441.

Prensky, M. (2007). Digital game-based learning (Paaragon House ed.). St. Paul, Minn.: Paragon House.

Rauschnabel, P. A., Rossmann, A., & tom Dieck, M. C. (2017). An adoption framework for mobile augmented reality games: The case of Pokémon Go. *Computers in Human Behavior*, *76*, 276-286.

Ruiz-Ariza, A., Casuso, R. A., Suarez-Manzano, S., & Martínez-López, E. J. (2018). Effect of augmented reality game Pokémon GO on cognitive performance and emotional intelligence in adolescent young. *Computers & Education*, *116*, 49-63.

Scott, I., Fuller, I., & Gaskin, S. (2006). Life without fieldwork: Some lecturers' perceptions of geography and environmental science fieldwork. *Journal of Geography in Higher Education*, *30*,161–171

Seppälä, K., Heimo, O. I., Korkalainen, T., Pääkylä, J., Latvala, J., Helle, S., ... & Viinikkala, L. (2016, September). Examining User Experience in an Augmented Reality Adventure Game: Case Luostarinmäki Handicrafts Museum. In *IFIP International Conference on Human Choice and Computers* (pp. 257-276). Springer, Cham.

Smith, C. C., Cihak, D. F., Kim, B., McMahon, D. D., & Wright, R. (2017). Examining augmented reality to improve navigation skills in postsecondary students with intellectual disability. *Journal of Special Education Technology*, *32*(1), 3-11.

Strickland, D., Marcus, L. M., Mesibov, G. B., & Hogan, K. (1996). Brief report: Two case studies using virtual reality as a learning tool for autistic children. *Journal of Autism and Developmental Disorders*, *26*(6), 651-659. http://doi.org/10.1007/BF02172354.

Sommerauer, P., & Müller, O. (2014). Augmented reality in informal learning environments: A field experiment in a mathematics exhibition. *Computers & Education*, *79*, 59-68.

Student Engagement. (2014). In S. Abbott (Ed.), *The glossary of education reform*. Retrieved from http://edglossary.org/student-engagement/

Thibaut, L., Ceuppens, S., De Loof, H., De Meester, J., Goovaerts, L., Struyf, A., ... & Hellinckx, L. (2018). Integrated STEM Education: A Systematic Review of Instructional Practices in Secondary Education. *European Journal of STEM Education*, *3*(1), 2-12.

Retrieved July 31, 2017, from https://www.nytimes.com/2016/07/12/technology /pokemon-go-brings-augmented-reality-to-a-mass-audience.html

Tobar-Muñoz, H., Baldiris, S., & Fabregat, R. (2017). Augmented reality game-based learning: Enriching students' experience during reading comprehension activities. *Journal of Educational Computing Research*, *0*(0) 1-36.

Tzanetakos, N., Papastergiou, M., Vernadakis, N., & Antoniou, P. (2017). Utilizing physically interactive videogames for the balance training of adolescents with deafness within a physical education course. *Journal of Physical Education and Sport*, *17*(2), 614.

Wingfield, N., & M. Isaac M. (2016). Pokémon go brings augmented reality to a mass audience. *The New York Times*. 11 July, 2016. Retrieved from https://www.nytimes.com /2016/07/12/technology/pokemon-go-brings-augmented-reality-to-a-mass-audience.html?_r=1

Woodcock, K. & Pole, J.D. (2007). Health profile of deaf Canadians. *Canadian Family Physician*, 53, 2140-2141

Wu, H. K., Lee, S. W. Y., Chang, H. Y., & Liang, J. C. (2013). Current status, opportunities and challenges of augmented reality in education. *Computers & education*, *62*, 41-49.

Yilmaz, R. M. (2018). *Augmented Reality Trends in Education between 2016 and 2017 Years.* Retrieved from https://cdn.intechopen.com/pdfs/59705.pdf

Zhang, K., & Liu, S. J. (2016, July). The application of virtual reality technology in physical education teaching and training. In *Service Operations and Logistics, and Informatics (SOLI), 2016 IEEE International Conference* (pp. 245-248). IEEE.