Chapter 5: Immersive Extended Reality in Education: Adoption and Diffusion of Learning Technology

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Citation:
5. Immersive Extended Reality in Education: Adoption and Diffusion of Learning Technology

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Key Points:

- Advancements in extended reality technology and reductions in product costs allow for increased accessibility of this technology in the classroom.

- There are more applications tailored to use in the gaming and entertainment industry than for use in classroom education.

- Use of immersive extended reality is increasing in education, but has not reached widespread adoption or diffusion.

Abstract

The invention and development of eXtended reality (XR) technology hardware and software applications can be traced back through many decades. The distribution of an open source programming kit for augmented reality (AR) in 1999, developments in computer and smartphone capabilities that increase device access as well as computing and graphics capabilities, and the release of several consumer-priced AR and virtual reality (VR) head-mounted displays in 2016 led to a surge in the development and adoption of XR application in gaming and entertainment (Elmqaddem, 2019). Sales of AR and VR technology continue to climb (BCC Research, 2018). Most of the expenditures for XR technology are for gaming and military applications (Stevens, 2017), but the education market is the
fastest-growing sector (BCC Research). Non-immersive VR applications and AR applications are readily utilized in education for little or no cost through applications such as PhET simulation in Nearpod and Google Street View. While immersive XR technology can align with today’s constructivist pedagogy in education and promote increased learner engagement, diffusion of semi and fully immersive XR has not reached the mainstream level across educational levels and subject disciplines.

Introduction

Technology is omnipresent in our everyday lives. It impacts how business is conducted, healthcare is provided, communication is transmitted, and knowledge is gained. This is also true in the classroom, where the use of education technology can increase students’ collaboration, interest in learning, and transfer of knowledge (Nagasubramani, 2018). Students can now connect with students in other locations, search for information on a global network, explore areas they could not usually travel to on a field trip, participate in experiments that might be difficult to access in a real-world environment, and receive individualized resources for instruction. These immersive experiences can be achieved by incorporating virtual reality (VR) and augmented reality (AR) into the curriculum. Though the development of eXtended reality (XR) technology began decades ago, recent device capabilities coupled with the reduction in device cost have made this type of technology more available for various educational programs. However, technology advancement does not directly lead to adoption and diffusion in the mainstream classroom. This chapter will review the development of immersive technology, events that impacted diffusion and adoption of the media, the current use of immersive media in education, the impact of utilizing immersive media in education, and the infrastructure needed to impact successful technology adoption.
History and Definition of Terms

Definitions

It is difficult to discuss XR learning technology without defining the associated terms. Extended reality is an overarching term for immersive technology in that XR hardware and software provide sensory input to the user that alters reality. Within XR, different types of technology applications are related to the level of immersion and user interaction with the technology (Table 1).

Table 1.  
Type of Immersive Interfaces

<table>
<thead>
<tr>
<th>Interface</th>
<th>Description</th>
</tr>
</thead>
</table>
| Virtual Reality            | • The user is immersed in a virtual environment through the use of their senses. The actions of the user in the real world have an impact in the virtual environment (Dede et al., 2017).  
• Level of immersion in VR varies from non-immersive interaction with a screen and a mouse to fully immersive with the use of a head-mounted display (HMD) (Di Natale et al., 2020) |
| Multi-user Virtual Environment | • The user enters a simulated setting as an avatar. The digital avatar can interact with the environment and other users (Dede et al., 2017).                                                                 |
| Mixed Reality              | • Partial virtual environment achieved with wide field display and more realistic three-dimensional graphic.  
• May include mixed reality simulators that mixed real-world mechanisms with virtual environments.  
• The user remains connected to the physical environment and interacts through the use of a joystick or mouse. Similar to a flight simulator (Di Natale et al., 2020) |
Virtual reality refers to technology that immerses the user in an artificial environment through various media such as video, audio, and haptics (Figure 1). As the technology continues to advance, it allows for multiple types of user input such as hand movement, head position, body position, eye movement, and facial expression, with the potential for even e-smell (Scudellari, 2018) and e-taste (Ullah et al., 2022). According to Sherman and Craig (2018), there are five elements of VR: a virtual world, immersion, sensory feedback, interactivity, and information intensity. The user interacts with a virtual world based on rules developed by the program creator. The level of immersion may be psychological and physical.

Psychological immersion relates to user engagement. In engagement research, this psychological concept is often referred to as flow, or an experience of absorption in an activity that is not prompted or forced (Nakamura & Csikzentmihalyi, 2014). Physical immersion relates to the sensory stimuli of the simulation. The experience should respond to user stimuli and change based on user input. The user should have an opportunity to manipulate items in the environment, such as picking up a stethoscope, adjusting the lighting, or moving to a new area in the video display.

The term Augmented Reality (AR) was coined in the 1990s and referred to head-mounted displays (HMD) worn by electricians that helped with an image overlay to assist with assembling wire harnesses (Elmqadden, 2019). This technology refers to an overlay of virtual items in a real environment (Figure 2). The user is not placed in a virtual environment, but their environment has additions from technology. When you use a smartphone app to see how a new piece of furniture will look in your room, you are using AR. AR usually has a tangible interface where the user can manipulate a physical object that has a digital effect, such as moving a mouse and having a cursor move on a computer screen (Dede et al., 2017).
The definitions of AR and VR vary by source and seem to intermingle and overlap. Dede et al. (2017) describe interface types as VR, mixed reality (MR), and multi-user virtual environment (MUVE). Conversely, Di Natale et al. (2020) classify MRs as a level of immersion instead of a type of interface. When I completed an Internet search on the history of the development of AR and VR technology, I found images of the same hardware as examples of both AR and VR. For this chapter, I will separate the types of interfaces that the student interacts with (Table 1).

In addition to different types of interfaces with XR, there are also a variety of types of immersion (Table 2). The level of immersion in the technology can help the user to suspend disbelief using sensory stimuli, actional, social, and narrative factors for psychological immersion. This component of XR technology is important to educational applications and the level of immersion is linked to
learner motivation while participating in the experience (Dede et al, 2017). The user interaction within the immersive environment may be limited to interaction within pre-programmed digital elements or allow collaboration with other users in multi-user virtual environments such as with PlayerUnknown or in health care simulations that allow multiple users to participate in patient care.

Figure 2.  
*Applied Instructional Augmented Reality*

*Note.* K-12 classroom using an AR application on a phone or tablet to view a dinosaur and a volcano on classroom desks.

**History**

Extended reality technology has existed for decades. As with the definition of what classifies AR or VR, there is also some conflict on who first developed XR technology. Sherman and Craig (2018) trace early conceptual and technical advancements in XR to the development of the Stereoscope in 1838 (Figures 3 and 4). Stereoscopic photos and viewers combined two images to create a
three-dimensional image that could be used as virtual tourism and a precursor to non-immersive VR. Arauza-Alba et al. (2022) trace the origins to 1957 with the development of Heiling’s Sensorama Simulator which placed an individual into a capsule that provided a widescreen with sounds, smells, body movement/tilting, and wind stimulation. Dede et al. (2017) classify the onset of XR technology in the 1960s with the development of flight simulators that provided an MR immersive experience. Lastly, Elmqaddem (2019) traces the origin of the first digital headset designed in the 1970s by Daniel Vickers that combined the use of two screens for visual input.

Table 2.
Levels of Immersion in XR

<table>
<thead>
<tr>
<th>Levels of Immersion</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-immersive VR</td>
<td>Interaction with a 3-D world on a 2D computer screen and user uses a joystick, mouse, or input device to interact such as a videogame or computer simulation.</td>
</tr>
<tr>
<td>Semi-immersive VR</td>
<td>Immersion in a partially virtual environment with an immersive display with a wide field of view, graphics have 3D depth/increased detail, includes simulators that partially replicate real-world mechanisms, user remains connected to physical surroundings and interaction through mouse/joy stick.</td>
</tr>
<tr>
<td>Fully immersive VR</td>
<td>Immersion in a fully virtual environment with high resolution of content with a full field of view with stereoscopic vision and head-tracking, uses hand sets for interaction, and example: HMD, CAVE systems</td>
</tr>
</tbody>
</table>

(Di Natale et al., 2020)
Figure 3.
Stereoscope Image

Note. Images such as these were inserted into a set of goggles to replicate a three-dimensional viewing experience.
Early models of immersive XR failed to reach mass adoption and diffusion with use during the 1970s to 1990s primarily in military training, industrial design, and healthcare purposes (Arauza-Alba et al., 2022). During this period, the development of the Data Glove allowed the capability for users to interact with XR through hand movement (Elmqadden, 2019). In 1999, AR programming moved closer to a larger market with the release of the ARToolKit which created an open-source library for AR applications.

In the mid to late 1990s interest in AR and VR waned with a focus on the development of the World Wide Web. Interest in XR technologies was reborn in 2012 with the Oculus Kickstarter campaign for crowdfunding to build an affordable HMD, or head-mounted display (Sherman & Craig, 2018). Oculus was purchased by Facebook, now Meta, in 2014, and the Oculus VR was released to the public in 2016, the year when VR became an overnight success. Oculus VR was released along with Oculus Touch handsets that allowed user input from hand movements. That same year, HTC
released the Vive HMD with handsets, Daqir released the Smart Helmet, Microsoft developed the HoloLens AR HMD, and Sony released the PlayStation HMD for use with their game console and controllers. Several other companies, such as Google and Samsung, followed suit with affordable VR headsets made of inexpensive items such as cardboard that utilized advances in smartphone technology to pair the smartphone screen and computing capabilities with a device to hold the screen in front of the user (Elmqaddem, 2019). In the 2000s, several MUVE games allowed for user interaction and immersion in game play and virtual worlds, such as SecondLife. This period also saw the release and mass appeal of massive multiplayer online role-play games such as World of Warcraft (Dede et al., 2017).

Augmented reality development soared in the 2000s with the development of smartphone apps (Blippar, 2018). In 2000 after the release of the ARTookKit, AR Quake released their first AR game that combined the use of an HMD, with a backpack for a computer and gyroscope. In 2005 AR tennis was released for use on Nokia smartphones. Who could forget the release of Niantic and Nintendo’s Pokemon Go in 2016 (Figure 5)? This one app pushed AR into the mainstream with 500 million downloads in two months after it launched (Bauer, 2019). The use of this app was so great that social media giants Facebook, Twitter, Instagram, and Tinder reported declines in use in the first few weeks after Pokemon Go was released. With AR, smartphone users can see how furniture would look in their home before purchasing with the use of the IKEA place app, apply face filters in Snapchat, and use live mode in Google Maps to see virtual signs and direction arrows imposed over their view. New smart glasses released in 2021 from Snap, Lenovo, and Vusix have the potential to allow increased interaction such as hologram images placed in the user's environment to transform telephone calls into in-person conversations (Vizix, 2020).

Oculus continues to be a frontrunner in HMD technology in terms of sales (Aslop, 2022). Parent company Meta is developing technology to enhance user experience and decrease side effects associated with poor focus or image updating (Zuckerberg, 2022). New developments include HMDs that have increased retinal resolution, user ability to adjust focus from a near object to a far object based on eye tracking technology, adjustments to fix optical distortions, and enhanced image colors to mimic nature. Newer technology developments can increase
the comfort with use, but often with an increased initial price point for purchase.

Adoption and Diffusion of XR in Education

Education technology has the potential to do many things in the classroom. It might grab student attention and increase learner motivation. It could increase communication and collaboration with other students. It could clarify concepts or provide more flexibility in the timing of lessons to individual student needs. It seems like all learning technologies start with great promise for user results with use, but many education technology advancements often fail to reach mainstream use. Several theories help to explain why some innovations reach mass appeal and others fail to take off.
Figure 5.
*Pokemon Go Application and Groups of Users*

*Note.* Pokemon Go application using AR to project an image into real-world settings, and groups of Pokemon Go users congregating to capture game characters.
Rogers (2003) states that the four main components of diffusion of innovation advancement are the innovation itself, communication channels to spread the news of the advancement, time to adopt the innovation, and the structure of social systems using the new innovation. To enhance diffusion, the innovation must be perceived as an advantage over existing methods, compatible with existing values, relatively easy to implement or use, compatible with a trial of use, and demonstrate observable results with use. Rodgers notes that adoption takes place slowly at first with adoption by innovators who tend to be adventurous with an acceptance of risk who represent 2.5% of the population (Figure 6). From this point, early adopters, who represent 13.5% of the population and tend to be opinion leaders, see the big picture for use of the technology and tip the point of critical mass for sustained adoption. The rate of adoption at this point remains on a low slope on the adoption S curve. The adoption rate makes a steady increase as members of the early majority see the positive results of adoption by innovators and early adopters. The skeptical late majority represent 34% of the population and adopt the innovation after they are convinced by positive results from the adoption by 50% of the population. The final category of adopters, laggards, are very cautious of adopting innovations and only adopt after 84% of the population has taken the plunge.

Gartner Research (2018) defines a common pattern for adoption and diffusion of new technology in their Hype Cycle (see Figure 7). Similar to Rodger’s view on diffusion, this model starts with innovation. As hype spreads on the future possibilities of the technology, the technology becomes more visible, but expectations can exceed the limits of the technology leading to a period of disillusionment. During this period, visibility of the innovation decreases along with interest and often funding. The innovation may survive the period of disillusionment and enter the slope of enlightenment if some early adopters achieve success with the use and spread the word to others with increased visibility and interest. After enlightenment, the innovation reaches mainstream use rapidly.
Extended reality has been in development for over fifty years and yet is still described as an emerging or beginning technology (Southgate et al., 2019) with industry leaders continuing to discuss the possibility of XR to transform education (Klopfer & Squire, 2008). Some of this seems to relate to confusion of what the technology can do or what its purpose is. In 2019, the Dean of the School of Medicine at Case Western Reserve University claimed that XR will be a key component of healthcare education programs (Elmqadden, 2019). Two years later, a journalist for CNN proclaimed Meta’s Horizon World VR all as “ambitious” (para 1), “heart-pounding” (para 1), and “niche technology” (para 4) (Metz, 2021).

Sherman and Craig (2018) claim that immersive XR technology is in the Slope of Enlightenment of the Hype Cycle model (see Figure 7). They contend that the Technology Trigger phase is linked to several different events. The first was when Sutherland created the
first working HMD device, The Sword of Damocles, in 1968 at Harvard University. The second trigger was in 1989 when VPL Research, Inc. released an affordable VR technology for research laboratories. Sherman and Craig identify XR's period of Peak of Inflated Expectations between 1992-1995 when researchers hyped the technology but did not publicize information on the extended time that it would take to develop the technology. Immersive XR entered the trough of disillusionment from 1995 to 1998 when XR technology was too expensive for public use and the public focus shifted to the development of the World Wide Web. Technology advancements such as the development of smartphone technology, computing technology, and high-speed Internet pushed immersive XR technology to the Slope of Enlightenment (Elmqadden, 2019). Sherman and Craig also credit a 2012 Oculus Kickstarter campaign that became the first mass publicly affordable VR HMDs as a technology trigger, but this may have been a factor in getting from disillusionment to enlightenment.

The Plateau of Productivity will settle in at a level dependent upon the size of the XR market. Sales of XR headsets are continuing to rise with $4.93 million in annual sales in 2020 and $6.1 million in 2021 (Alsop, 2022). The two largest sectors for sales of VR and AR technologies in the global market are entertainment, with 30.44% of sales, and the military, with 19.78% of sales (BCC Research, 2018). Consistently, immersive XR technology is deemed effective and mainstream in the military and consumer gaming (Stevens, 2017). The education market, with 14.84% of sales, is the fastest growing sector of AR and VR sales (BCC Research, 2018). Currently, there are fewer applications for AR and VR technology in education which will likely improve with increased sales and demand. However, there are more available options for using AR in education due to accessibility on smartphones and tablets and AR glasses. There were 37 million users of AR in the United States in 2018 with an expectation of 67 million users by 2020 by 2020 (Blippar, 2018).
Multiple surveys show that students, faculty, and parents have a favorable view of AR and VR in the classroom. A survey from Lenovo, as reported in Cureton, 2021, found that 54% of teachers and 41% of parents want to increase VR and AR use in the classroom. Vlasova (2020) reports on a survey that demonstrates that 90% of surveyed teachers believe that increased VR use in the classroom would provide personalized learning experiences for students and 97% of surveyed students indicated that they would like to attend a course that incorporated AR and VR. Dick (2021) adds additional summaries in support of AR and VR use in the classroom. A 2016 Samsung survey showed that 93% of teachers would like to incorporate AR and VR into the class with 83% indicating that their use would improve student learning outcomes. Seventy percent of 8 to 15 years olds and 64% of parents in a 2017 DigLitEY survey indicated that they are interested in VR learning.
With so much interest, is VR and AR prevalent in every classroom? There is limited data on the subject, but it seems to indicate that the use of XR in classrooms varies by subject and education level. As a parent and educator, I have witnessed many uses of non-immersive 2 dimensional VR immersion applications in classrooms. The immersion of semi and fully immersive experience tells a different story. A 2018 survey found that 50% of higher education institutions were partially or fully engaged in deploying AR or VR in the classroom (Dick, 2021). Similarly, Jisc (2019), a United Kingdom digital solution education research group, found that the most use was in higher education with 96% of universities indicating that they used AR or VR. However, this data only tells part of the immersion story. Use is limited to certain areas used by a few faculty members. While Jisc found that 96% of universities used immersive XR, only 9% of faculty actually used AR or VR technology in the classroom. The use of XR was typically limited to one or two departments (Jisc, 2021). Hamilton et al.’s (2020) literature review on XR in education found that of 29 published articles on learning outcomes, 25 were in higher education with 83% of the publications related to use in the subjects of science, engineering, and medicine (Figure 8). This is similar to findings from Jisc’s survey with most educational use related to the subjects of healthcare, engineering, and technology.
Benefits of Using XR in the Education

EXTended reality has great potential to transform education. Instead of watching field trips on *The Magic Schoolbus*, students can put on an HMD and go on a virtual field trip to inspect the flow through the circulatory system, explore the Grand Canyon, tour the White House, or visit a historic site all from their home or classroom. A medical student can safely practice surgical maneuvers repeatedly until they are perfected before performing them on a real patient who could be harmed by an error. Students can complete chemistry experiments without coming into contact with flames or the purchase of non-reusable lab supplies. Neurodiverse learners or those with a
language barrier can participate in class activities through accommodations afforded by XR (Vlaslova, 2020).

The research on learning outcomes with XR is limited, but available studies show promise. Like with use data on use in the K-12 environment, data on the effects of implementation in K-12 environments is limited (Araiza-Alba et al., 2022). Sherman and Craig (2018) content that early researchers were more concerned with pressure to develop the technology than research on its usefulness. There are a few studies indicating usefulness in children. Learning through manipulation of items, such as with XR, is enhanced over the learning while watching others use the tool, even in infancy (Sommerville et al., 2008). Additionally, children learn more from sensory input, like that provided by XR, over more traditional teaching methods (Duhaney et al., 2008). Findings outside of the K-12 environment indicate that compared to less immersive education strategies, XR can improve cognitive gains (Elmqadden, 2019; Hamilton et al., 2020) and improve procedural skills (Dede et al., 2017; Hamilton et al.). The use of XR increases learner engagement and motivation with up to 100% increased attention (Elmqadden, 2019) and increased enjoyment (Singhal et al., 2012) even with advanced concepts (Klopfer & Squire, 2008).

Interestingly, Lee et al. (2019) found that perceived enjoyment was one factor that could increase the intention to use XR in education. The use of XR in education fits the learner-centered paradigm as it offers new abilities to customize educational materials to learner needs and enhance learner engagement (Di Natale et al., 2020). The Constructivist paradigm encourages learner construction of knowledge from sensory input/interaction. The inclusion of XR is suitable for problem-based learning and can decrease the learner's cognitive load by eliminating distractions in the real-world environment (Vlasava, 2020). The inclusion of audio and visual input in immersive VR is consistent with guidelines set for use of multimedia to improve learning outcomes through dual coding (Mayer & Gallini, 1991). The use of three-dimensional images in XR, instead of two-dimensional images in non-immersion VR, decreased the extrinsic load of the lesson and allowed more focus on the lesson’s intrinsic load (Araiza-Alba et al., 2022). Wilson and Soranzo (2015) contend that when items that are three-dimensional in real life are presented in a two-dimensional format, the learner may have difficulty transferring the lesson for knowledge assimilation.
Factors Affecting Diffusion

Despite the potential for education and student benefits with the use of XR, its use remains somewhat limited in educational settings. There are several barriers to the technology that should be explored to help identify if adoption and diffusion are possible and what interventions may help to aid the process.

Cost to Implement

The cost to purchase XR hardware and software was also identified as the main barrier in Jice’s (2019) utilization survey. This is consistent with my own findings where cost was frequently cited as a barrier to XR use. To determine hardware costs, I performed an Internet search on July 23rd, 2022 to assess the price of popular AR and VR wearable technology (see Table 3). Prices ranged from $399.99 for a VR headset and headphones that required a separate purchase of a Samsung Galaxy smartphone for use to $3,500 for a Microsoft HoloLens 2 headset. Hamilton et al. (2020) found that the Oculus was the most common VR headset in their literature search, but they did not specify a version. In my search, Oculus HMDs range from $110 to $299. The second most common HMD was the HTC Vive which I found for $749. While the cost to purchase HMDs has decreased to a level that could improve consumer adoption, there are also additional costs related to the need to purchase software or software subscriptions, train faculty in how to use the technology in the classroom, provide support for faculty to incorporate XR in the curriculum, set up suitable space safe for use, and replace damaged hardware.

In an assessment of return on investment, change agents who are proponents of XR should assess if utilization of XR reduces other costs such as the reusable lab supplies that would no longer be needed or additional personnel to run a simulation who are replaced by VR avatars. Devices could be purchased to check out for use in multiple classrooms instead of attempting a 1:1 device approach. Free or open access software may be available to reduce costs and facilitate the adoption of XR through a range of XR modalities such as HMDs, computer 3D 360-degree explorations, or 3D glasses (see Table 3).
Table 3. 
*Purchase Prices for AR and VR Wearable Hardware*

<table>
<thead>
<tr>
<th>Wearable Hardware</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Echo Smart Glasses for audio immersion</td>
<td>$249</td>
</tr>
<tr>
<td>HTV Vive Elite ViR system</td>
<td>$749</td>
</tr>
<tr>
<td>Meta Quest 2 headset with handsets</td>
<td>$299</td>
</tr>
<tr>
<td>Microsoft HoloLens 2 AR headset</td>
<td>$3500</td>
</tr>
<tr>
<td>Oculus Go standalone VR system</td>
<td>$110</td>
</tr>
<tr>
<td>Oculus Rift S deadest with handsets</td>
<td>$369.99</td>
</tr>
<tr>
<td>Rokid Air AR glasses</td>
<td>$349</td>
</tr>
<tr>
<td>Samsung HMD Odyssey+ MR headset and handsets</td>
<td>$899.89</td>
</tr>
<tr>
<td>VR headset and headphones for use with Samsung Galaxy</td>
<td>$39.99</td>
</tr>
</tbody>
</table>

**Teacher Training and Curriculum Support**

To effectively implement XR in the curriculum, teachers must receive training in how to set up the technology, how to use the technology with students, and how to incorporate the technology into the curriculum. While faculty realized that there was an emphasis on utilizing technology in the classroom, they may have little skills or training in how to use it (Childs, 2016; Jensen & Konradsen, 2017; Jise, 2019). Childs also noted that the more expensive and complex the XR technology is, the steeper the learning curve is for its use.
<table>
<thead>
<tr>
<th>Application Name and URL</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anatomy 4D <a href="https://www.4danatomy.com/">https://www.4danatomy.com/</a></td>
<td>AR app that allows visualization of human anatomy with images that can be moved and dissected</td>
</tr>
<tr>
<td>BioDive <a href="https://www.biodive.science/">https://www.biodive.science/</a></td>
<td>VR software that immerses the middle school learner in a marine ecosystem to explore and track data on ecosystems of killer snails</td>
</tr>
<tr>
<td>eDrawings <a href="https://www.edrawingsviewer.com/">https://www.edrawingsviewer.com/</a></td>
<td>Contains AR and VR applications to transform engineering graphs into 3D models or to view designs in a real-world setting to assess impacts in the environment.</td>
</tr>
<tr>
<td>Exoplanet <a href="http://exoplanetapp.com/">http://exoplanetapp.com/</a></td>
<td>AR application with sky map to visualize planets. Provides 3D visualizations of space that are updated daily.</td>
</tr>
<tr>
<td>Google Arts and Culture <a href="https://artsandculture.google.com">https://artsandculture.google.com</a></td>
<td>VR application with virtual field trips and 360-degree experiences that allow exploration of artwork, historic events, historic figures, artists, and art movements on a 2D screen.</td>
</tr>
<tr>
<td>Lifeliqe VR Museum <a href="https://www.viveport.com/47590167-b266-41f8-a1cc-5a4b294425b1">https://www.viveport.com/47590167-b266-41f8-a1cc-5a4b294425b1</a></td>
<td>VR museum of over a thousand models for use in K-12 science and math education.</td>
</tr>
<tr>
<td>Nearpod <a href="www.Nearpod.com">www.Nearpod.com</a></td>
<td>Resource for developing classroom educational content. Contains a repository of 360-degree VR field trips and 2D interactive</td>
</tr>
</tbody>
</table>
PhET simulations.

|-----------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------

| Sharecare                                           | AR and VR application with videos to promote health, human anatomy AR explorations, and VR simulations. |
| https://www.sharecare.com/pages/vr                  |                                                                                                                                 |

| Smithsonian Institution                             | Web-based VR application that offers 3D models of items in the museum collection that can be manipulated and explored on a computer monitor. |
| https://3d.si.edu/collections/ar-experiences         |                                                                                                                                 |

| Touch Surgery                                       | AR application that allows learners to complete over 200 simulations of surgical procedures |
| https://www.touchsurgery.com/simulations             |                                                                                                                                 |

Facilitation of the adoption of XR in the curriculum should be coupled with professional development on best practices as well as practical skills for use and a support system to help troubleshoot use difficulties. Dicks (2021) called on policymakers in Congress to encourage the Department of Education to provide teacher resources for training and support in the use of AR and VR in classrooms. Felder and Proulix’s (n.d.) teaching resource guide on using VR for the New York Times provides a model for implementation with sample lesson plans that could be used as a guide for developing additional support measures.

Additionally, the classroom with XR use will need technology access and a model for effective adoption (Richards, 2017). The classroom should have access to high-speed internet and a low learner-to-computer ratio. The XR activities must be accessible in the classroom, instead of a separate laboratory, since this approach leads to decreased contact with the classroom teacher and has resulted in decreased use of educational technology. The XR activity should be aligned to the curriculum standards and linked to formative
assessments. The XR activities can be included as needed to fit the needs of individual learners in the classroom.

**Space for Safe Use**

Partially and fully immersive XR can decrease learner perceptions of their environment and increase the potential for injury. While Pokemon Go brought AR into the mainstream, it also brought a discussion on user injuries. Within four days of the launch of Pokemon Go, a subreddit thread on the game contained a large number of posts on actual injuries and near misses caused by falls and collisions with objects from distracted game players (Tsukâyama, 2016). In response, a medical school in Arizona sent out a student advisory warning students to capture Pokemon carefully and remain aware of their surroundings. Game developers included warnings in the application to warn users not to capture and drive, to remain aware of their surroundings, and to refrain from trespassing to capture Pokemon on private property.

Immersive XR use with partial or full immersion should be incorporated in a space that is safe for use. The user should have a space that is at least 6.5 feet by 6.5 feet set up with Guardian boundaries to warn the user when they are near the edge of the boundary (Melnick, 2020). There should be an additional 2.5 feet buffer zone between the Guardian boundaries and any walls or immovable objects. The floor inside the area should be free from obstacles, thus minimizing user safety concerns. Hardware use that is wired poses additional safety concerns as the user could become tangled and fall or drop and damage the hardware. Utilizing a backpack to carry the computer running the software and store any loose or excessive length of cable in one early solution.

**User Age**

Immersive XR applications that run on a tablet or PC can be used with learners of many different ages. However, many of the HMDs state that the minimum age for use is 13 years old (Araiza-Alba et al., 2022). Furthermore, some HMDs may not fit a smaller, child-size head which could lead to discomfort and increase the risk of damage from a poorly fitting device falling on the floor.
There are a few types of XR developed for children to fit their size or limit the amount of immersion to help control negative side effects (Araiza-Alba et al., 2020). Google Cardboard uses a smartphone to provide the drive screen and computing technologies and can be sized for a child. Mattel manufactures a View-Master Delux VR that provides a less sophisticated immersion.

**Ethics**

Immersive XR can trick the brain into thinking that virtual experiences are real. Segovia and Bailenson (2009) found that some preschool-age children who participated in an immersion activity created false memories and remembered the event as if it happened in real life. Immersion experiences can also trigger real-world phobias such as a fear of spiders or a fear of heights (Araiza-Alba et al, 2022). Teachers who utilize XR in the classroom should consider the possible effects of use and plan for alternative experiences for users who are distressed by the immersion.

**Side Effects with Use of XR**

Users of high immersion XR may suffer discomfort from use. Cybersickness is a term given to motion sickness that can develop with immersion activities. Users may also complain of eye strain, headache, discomfort from wearing technology hardware, and injury falling due to a lack of spatial awareness (Jensen & Konradsen, 2017). Table 5 contains suggestions from Richards (2017) on measures that can be taken to improve the user experience in immersive XR and decrease discomfort. Those making a decision to adopt XR technology should preview the product to assess if images in VR disappear with head movement, or if the field of view is large enough with an HMD. They should plan to incorporate software that updates at a high-frequency rate, contains high-quality images, and reduces continuous movement.
Table 5.
*Measures to Enhance Comfort with Immersive Technology Use*

<table>
<thead>
<tr>
<th>Field of View</th>
<th>VR</th>
<th>AR</th>
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|               | ○  A wider field of view is more realistic  
|               | ○  Current HMDs support 90 degrees with the ability to look around for 360 degrees  
|               | ●  | ○  Software that allows objects to disappear if the user moves past the field of view, breaks the suspended disbelief and decrease learner immersion |

| Fast update of visual image | VR/AR require a speed of 90 frames per second  
|                            | CAVE AR systems require a speed of 30 frames per second  
|                            | MR requires a speed of 30 frames per second |

| Reduce motion sickness | Images that update quickly  
|                       | Use of high-quality images  
|                       | Software that minimizes continuous movement |

| MR registration | Project images onto high-contrast objects or utilize hardware that incorporates environmental scanning technology such as Lidar. |

| Fidelity of interaction | User movements should create accurate and crisp movement in immersion |

*Note.* From Richards, 2017
Conclusion

Immersive XR technology has the potential to transform education by providing a new way to interact with materials for constructivist learning in order to develop a deeper understanding, improve learning, build teamwork skills, travel to distant lands, and practice skills in a safe environment. Despite the potential, its adoption has mostly fallen into STEM, engineering, and health care subjects in higher education. Even with decades of technological advancements, partial and full XR immersion technology has failed to reach diffusion status, and its use in education remains mostly with innovators and early adopters. Barriers to adoption include technology costs, teacher training and curriculum support, space needed for safe use, discomfort for some users, young user age, limited educational software applications, and ethics related to tricks of the mind.

Immersive XR technology appears to be standing on the precipice of adoption and diffusion in education with an ever-increasing market share. A 2020 survey from Perkins Coie indicated that XR technology was poised to disrupt the education industry (Dick, 2021). Since that time, the Covid-19 pandemic produced a need for digital education solutions, and there are multiple reports of increased XR use with the need to move to reduced face-to-face learning (Cureton, 2021; Dick, 2021; Vlasova, 2020). Communication on the successes of XR use during hybrid and remote learning could be what this technology needs to jump the chasm between early adopters and the early majority to become mainstream.

To help push the use of XR technology forward, more support, technology development, and research are needed. Dicks (2021) called on the Department of Education to invest in research on the use of XR across the learning spectrum, provide resources for teacher support and training, and increase the development of age-appropriate software applications. Araiza-Alba et al. (2022) also called for the development of child-size HMDs and research on which specific XR applications improve learner performance as well as the effects of XR use on learner literacy and social engagement. If research is able to help share success stories of XR use and provide a structure for best practices, XR has a chance to become mainstream in education.
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