Virtual Reality and Augmented Reality in Education

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Abstract:

Virtual reality and augmented reality technology has existed in various forms for over two decades. However, high cost proved to be one of the main barriers to its adoption in education, outside of experimental studies. The creation and widespread sale of low-cost virtual reality devices using smart phones has made virtual reality technology available to the common person. This paper reviews how virtual reality and augmented reality has been used in education, discusses the advantages and disadvantages of using these technologies in the classroom, and describes how virtual reality and augmented reality technologies can be used to enhance teaching at the United States Military Academy.

Introduction

Google turned the virtual reality world upside down since it released Google Cardboard in 2014. Google Cardboard is an extremely low cost head-mounted virtual reality system which can be purchased for as little as $15. To keep the cost down, the user's own smart phone loads and runs a virtual reality app, and the Google Cardboard holds the smart phone and uses stereoscopic lenses to immerse the user in a virtual world. Although this is far less capable than high-end personal virtual reality devices such as the Oculus Rift or HTC Vive, the extremely low cost shifted the virtual reality market from the realm of technology enthusiasts to the common person. In 2016 alone, Google sold 84.4 million Cardboard headsets, over twenty times as many units sold as all other virtual reality devices combined (Korolov, 2016).

Virtual reality has long held promise as a tool to enhance education with immersive and interactive experiences in disciplines ranging from science and engineering to foreign languages and social sciences. Now that virtual reality devices are more affordable and widely available, the challenge has become finding ways to employ this technology effectively. This first section of this paper discusses what virtual reality and augmented reality are and how they have been used in education. The second part explores the advantages and disadvantages of using these technologies in the classroom and how they can be applied to teaching at West Point.

Virtual Reality and Augmented Reality Explained

Virtual reality has existed in various forms as far back as the 1960s when the first digital flight simulators were developed and employed by the world's major airlines and air forces (Pantelidis, 2010). These early simulators used a camera and projector to display the pilot's view and often employed motion to improve the realism and immersion of the simulation. As technology developed, "virtual reality" became the phrase to represent devices that create an immersive, interactive environment with visual realism (Rosenblum, 1997).

The least immersive type of virtual reality is considered Desktop VR (Merchant et al., 2014), in which a 3D virtual world is shown on a standard computer monitor. Although this is not a very immersive environment, it still serves as a window into a 3D virtual world and is much cheaper and more accessible than more immersive forms of virtual reality. Desktop VR emerged during the early 2000s because personal computers became powerful enough to simulate and render 3D virtual worlds. A common example of Desktop VR today is the 3D virtual worlds of Second Life. People can access Second Life through the Internet and they are represented in this virtual world with an avatar. Users can interact with text and audio, create 3D objects, and own their own "land" in the world. Other examples of Desktop VR include massively multiplayer online games such as World of Warcraft or EVE Online where thousands of people interact and coexist in a persistent virtual world.

An intermediate type of virtual reality is called CAVE (Cave Automatic Virtual Environment) which is characterized by projectors that show a virtual environment on walls surrounding the user. In some cases, users may wear stereoscopic glasses so they can see the virtual world in three dimensions and enhance immersion. Although expensive, a big advantage of CAVE VR is that it is easy for several people to share the same virtual reality experience yet interact with each other face-to-face.

The most immersive type of virtual reality uses a stereoscopic head mounted display with some form of motion tracking to determine where the user is looking. Their view of the outside world is completely blocked, creating a strong sensation of immersion while also providing an unobstructed view of the virtual world. Although head mounted displays have existed for decades, they have become available at the consumer level in 2014 with the introduction of the Oculus Rift. Today, consumer head mounted displays include the HTC Vive, Google Cardboard, and Samsung Gear VR among others.

Augmented reality is a hybrid form of visualization that combines the real and virtual worlds (Choi, 2016). Augmented reality became a part of popular culture in 2016 with the release of the smart phone game Pokemon Go, which has been downloaded over 500 million times. Augmented reality enhances the user's view of the real world with computer-generated elements, typically 2D or 3D graphics and text (Kamphuis et al., 2014). This enhanced view is typically visualized through mobile devices or head-mounted displays such as the Google Glass.

Augmented reality is classified by the method used to determine how to augment the image. Marker-based augmented reality uses image processing to identify a point in the real world and display virtual content based on the marker. The marker is typically takes the form of a QR code, but could also be any easily identifiable object. The other type is called markerless augmented reality, which uses a combination of sensors to determine the location and orientation of the device, such as the GPS and compass on a smart phone, and enhances the original image with digital content based on the phone's location.

Applications for VR and AR in Education

Medical Education

Numerous surgery trainers and simulators employ virtual reality, including laparoscopy (Huber et al., 2015), temporal bone surgery (Fang et al., 2014), and even dental training (Steinberg et al., 2007). Some of these VR applications give haptic (i.e. tactile) feedback and they all allow students to practice their skills in a safe environment and without the expense of practicing on human or animal cadavers. Furthermore, virtual reality has been used to help medical students visualize anatomy in 3D, providing a much greater sense of context and scale than the cutaway diagrams and pictures common to anatomy textbooks (Satava, 1995; Falah et al., 2014).

Augmented reality has also been used to help visualize anatomy, lung dynamics, and laparoscopy (Kamphuis et al., 2014). For example, "Mirracle" is a system that uses a camera to mimic a mirror view of the user, but superimposes images from a CT scan giving the user a view of "their" anatomy. This determines where to show the image by creating an infrared-based depth image with a Microsoft Kinect sensor (Blum et al., 2012). ProMIS is an augmented reality laparoscopy simulator that uses a surgery dummy and superimposes labels and internal organs on the camera feed to both train and evaluate students (Botden, 2009).

Science

Early uses of virtual reality in science education focused on visualizing chemical reactions (Bell and Fogler, 1998) or learning about molecules by assembling them in a virtual environment (Byrne, 1996). More recent uses include marker-based augmented reality to visualize the process of respiration and human meiosis (Weng, 2016) and an astronomy application using a head-mounted display to explore the solar system and give students a grasp for its scale (Hussein and Nätterdal, 2015). Virtual reality and augmented reality make it possible to visualize concepts that are abstract or difficult to relate to real-world experiences, such as a marker-based augmented reality application that helps teach electromagnetism and the interaction between different circuit elements (Ibáñez, 2014).

Engineering

A variety augmented reality apps have been developed and tested in introductory electrical engineering courses (Martín-Gutiérrez et al., 2014). ElectARManual dispalys animations and instructions over electrical machines used in the lab to help students learn how to use the machines safely. ELECT3D is a markerless system that reads and interprets electrical diagrams. A third application is called ElectAR_notes, which is a study assistant that recognizes markers located on the course study notes and illustrates the concepts with video, animations, and more detailed information. Another study developed a virtual reality application to teach micro-controllers and Arduino boards with Google Cardboard headsets (Ray and Deb, 2016).

A university in Brazil modeled a complete charcoal mini-blast furnace with all of its sub-subsystems. Their application included additional information, videos, and 360-degree photos from real blast furnaces and was used to teach engineering students how the process works and how the various subsystems interact (Vieira et al., 2017).

History and Social Sciences

One of the greatest uses for virtual reality in the realm of history is to take virtual field trips to historical sites or witness historical events "first-hand" (Choi, 2006). The Google Expeditions Pioneer Program does exactly that: the students use Google Cardboard and their smart phones to journey to their virtual destination and explore. The teacher serves as the tour guide for the field trip and their app has the ability to highlight areas on their students' views to help direct their attention and contains extra information to explain certain landmarks in more detail (Ray and Deb, 2016). On live field trips to historical sites, augmented reality travel guides exist for mobile platforms to enrich the experience of the students and allow them to explore on their own (Olsson et al., 2013).

Behavioral studies have also been conducted using virtual reality to recreate scenarios that would otherwise be problematic or dangerous. For example, fire evacuation research used virtual reality simulations to record how people would react in a fire, providing more accurate results than traditional methods (Kinateder et al., 2014).

Foreign Languages

Virtual reality in foreign language education has been focused on allowing students to have interactions with native speakers through 3D virtual worlds using Desktop VR. A common 3D virtual world used as an educational tool is Second Life since it is free to access, allows voice and text interaction with other users, and is an open-ended world that any user can create content for (Baker et al., 2009). This bridges the gap of distance, allowing foreign language students to talk with native speakers from anywhere in the world (Jauregi et al., 2011; Ibáñez et al., 2011; Blasing, 2010).

Distance Learning

The Internet has made distance learning far more accessible and rich in content than ever before, but in many cases the only forum for discussion and interaction with classmates is through online message boards or e-mail. Virtual reality can improve distance learning by allowing easier and more natural class discussions in the distance learning setting. The simplest examples are giving lectures in a virtual classroom, such as in Second Life (Jarmon, 2009). Since participants are in the same virtual space as the teacher and their classmates, they can ask questions if a concept isn't clear, the teacher can employ classroom discussion techniques to foster critical thinking, and talk or coordinate with their classmates before and after class.

Greater challenges exist in distance learning for classes that require hands-on application in labs, such as science, engineering, or technology. One solution is to create a 3D virtual lab environment that the students can perform their activities in. Although virtual labs cannot completely replace the need for hands-on experience, virtual labs can be used to train basic skills which could reduce the frequency and amount of time needed in a physical lab (Potkonjak et al., 2016).

Advantages of Virtual Reality

Over the past two decades, numerous studies have shown the strengths of virtual and augmented reality use in the classroom. One of the most significant strengths is that they change the role of the teacher from the deliverer of knowledge into a facilitator who helps the students explore and learn (Yougnblut, 1998). This strongly complements the constructivist learning theory because the students feel empowered and engaged because they have control over the learning process (Dede, 2005; Antonietti et al., 2001). Students can learn experientially and proceed at their own pace since they are exploring a virtual environment, preventing situations where students are left behind during the lecture and spend the rest of the class trying to catch up (Jonassen et al., 1999).

Furthermore, virtual reality can help students learn abstract concepts because they can experience and visualize these concepts in the virtual environment (Sala 2013; Rosenblum, 1997). In contrast with the traditional learning process which is usually language-based, conceptual, and abstract, a virtual reality learning environment fosters active learning and helps students grasp abstract knowledge (Ray and Deb, 2016). Low-spatial ability learners particularly benefit from virtual reality because the visualizations help lower the extraneous cognitive load of the learning objectives (Lee and Wong, 2014).

Virtual reality allows the user to comprehend systems or objects that are of widely different scales. For example, the charcoal mini-blast furnace virtual reality application (Vieira et al., 2017) allows students to look at the big picture of how the entire system works and to explore the individual components of the system, all in a single, fluid experience. Studying human anatomy with virtual reality gives students a better grasp of the relative size of the different organs and parts. Furthermore, the additional context of visualizing where the organs are in the body and the surrounding parts makes it easier for students to commit the information to memory compared to rote memorization of names and terms (Falah et al., 2014).

Dangerous and rare situations can be simulated in virtual reality enabling students to learn in safety. Some examples include practicing surgery techniques (Ota et al., 1995) or learning how to use machine tools safely (Antonietti et al., 2001). Furthermore, in a simulated environment students can learn about the potentially dangerous consequences of failure from failing to follow procedures or exceeding design specifications without physical damage to equipment or loss of life (Potkonjak et al., 2016).

The ability to easily change the virtual world opens new possibilities in the realm of testing and design. For instance, digital prototypes can be copied, modified, and tested without the expense and time required to build and test physical prototypes. This allows the students to refine and test their design quickly and inexpensively before creating a physical version (Sala, 2013). Virtual reality also makes it easier to test different scenarios and hypotheses because the environment can be designed to prevent extraneous variables from disrupting the test results and the experimental variables can be precisely controlled (Kinateder et al., 2014).

Finally, the immersive nature of virtual reality can help block out other distractions so the students can focus on the learning objectives. Several virtual reality studies have revealed that students are more focused and show better concentration when using immersive virtual reality (Hussein and Nätterdal, 2015; Ibáñez, 2014). The interactive nature of virtual reality transforms students from passive learners into active learners, improving student motivation and their sense of control over their own learning (Pantelidis, 2010).

Limitations of Virtual Reality

As with any advancement in technology, virtual reality is a tool that must be employed properly in order to be effective. Despite the great promise of virtual reality and the advantages described above, there are some limitations that must be addressed when integrating virtual reality in an educational setting.

For many years, cost and the computing power necessary to produce realistic environments were the main barriers to using virtual reality in education (Merchant et al., 2014; Bell and Fogler, 1995). Furthermore, some virtual reality systems were difficult to use (Youngblut, 1998) and the equipment the user needed to wear was bulky and hindered immersion (Ray and Deb, 2016). Thankfully, the advances in technology for mobile devices have reduced the size of VR devices (Wu et al., 2013), and for some reduction in quality, mobile devices in inexpensive viewers such as Google Cardboard has made virtual reality extremely affordable.

An unavoidable drawback is that reliance upon virtual reality environments adds another point of failure that needs to be planned for. As with any computer, virtual reality devices can break or crash and the risk of any one malfunction occurring increases as more students use virtual reality devices (Choi, 2016; Wu et al., 2013). As a result, it would be helpful to keep backup devices on hand and backup lesson plans must be present in case technical issues, Internet outages, or other circumstances would prevent the entire class from using virtual reality. Furthermore, several participants in virtual reality studies have felt nausea, motion-sickness, or minor headaches while using the devices (Kinateder et al., 2014), reaching as high as 10-20% of users in one study (Hussein and Nätterdal, 2015).

There is also the additional time required for the students and teachers to learn how to use their virtual reality devices. For example, improperly adjusted head-mounted displays can cause the images and text to appear blurry (Hussein and Nätterdal, 2015), and the additional cognitive load of learning how to navigate and explore in the virtual world requires teachers to build time into their lesson plans to teach their students how to use their devices (Wu et al., 2013). Beyond using the tools, teachers or administrators need to procure or build the virtual worlds or simulations for their classes. Since most teachers do not have the time or the technical skills to create their own virtual reality applications, third parties will probably be needed to create and maintain these programs and the content with them (Choi, 2016). With that in mind, it is also important to ensure that the programs being used can be modified, customized, or updated easily by the instructors so they can cater to the needs of their individual classes and students (Klopfer and Squire, 2008; Kerawalla et al., 2006).

It is vital to remember that virtual reality technology does not reduce the importance of lesson planning or the role of the teacher in class instruction. Although the teacher’s role with virtual reality tools typically shifts to being a coach and a mentor (Zhang, 2013), the teacher’s guidance is still critical when using virtual reality systems (Lee et al., 2010). Furthermore, there need to be clear educational objectives and goals that virtual reality use support (Choi, 2016; Baker et al., 2009). There are some cases where virtual reality is not the best method for accomplishing a learning objective (Pantelidis, 2010) so it is essential to look at the course curriculum and determine where virtual reality can help, and where other teaching methods more appropriate.

Finally, we must remember that integrating virtual reality with a curriculum can be difficult and some teachers may be resistant to using the new technology (Huang, 2016). Some reasons center around the need to redesign the lesson plans from a teacher-centered, delivery-based focus to a student-centered lesson plans. It also may take more time to teach a topic with virtual reality than with traditional measures (Wu et al., 2013). If the virtual reality tools are difficult to use, this may discourage teachers from employing it in their classrooms (Choi, 2016). Also, since many teachers may not have been exposed to the capabilities or applications of virtual reality in the classroom, some form of professional education should be used so the teachers feel comfortable using the technology in their classroom and exploring the new possibilities that VR opens.

Augmented Reality vs. Virtual Reality

Most of the advantages and disadvantages listed above apply both to virtual reality and augmented reality devices. However, there are some particular areas in which augmented reality may be a better platform to pursue.

First and foremost, the scope of work in designing an augmented reality application is typically less than a similar application with virtual reality. In contrast with virtual reality applications that need to construct and model an entire virtual world, augmented reality applications are only modifying a picture of the real world with digital images or text. Although image processing algorithms and geolocation adds some complexity to the design, this is typically less time intensive than creating an entire virtual world.

The other main advantage of augmented reality is that it makes it easy for the users to interact with their surroundings as well as conduct face-to-face interaction with the people around them (Martín-Gutiérrez, 2015). For example, the ElectARManual system described earlier in the paper is used as a teaching assistant tool for electrical engineering labs; the importance of working with the actual machines made augmented reality a better choice than trying to create a virtual electrical engineering lab. Furthermore, teamwork between students is far easier with augmented reality since they can communicate face-to-face. Attempting to implement this level of communication in a virtual reality environment requires significant overhead, especially if modeling non-verbal communication such as body-language and gestures.

Furthermore, most mobile platform augmented reality devices require the user to hold the device with their hands. This can be awkward so a head-mounted augmented reality system might be more useful, or some sort of stand to hold the mobile device (Ibáñez et al., 2014). Furthermore, if augmented reality devices are being used outdoors, teachers need to account for adverse weather conditions which might damage electronic components, as well as the possibility of GPS errors impacting markerless AR programs (Dunleavy et al., 2009).

Application to Teaching at West Point

While virtual reality and augmented reality technology can be used at West Point in virtually every department to some extent or another, the military science and training aspects of the West Point curriculum can benefit in some very substantial ways.

The study of military history can take on an entirely new dimension by using virtual reality or augmented reality to conduct virtual staff rides of historic battlefields. A staff ride is a historical study of a campaign or battle that combines an academic study of the battle with a visit to the actual site of the battle to gain a better understanding of the terrain and the conditions that influenced the battle. Unfortunately, most staff rides from West Point are either to Civil War battlefields that are within a few hours driving range, or are only available for a limited number of cadets as summer Academic Individual Advanced Development (AIAD) opportunities. However, a virtual reality staff ride would enable any number of cadets to see the battlefield in three dimensions, from the viewpoints of the different units and commanders that fought as well as a bird's eye view to see how the battle as a whole progressed. Likewise, a marker-based augmented reality platform could be used on a topographic map of the battlefield with additional information and hyperlinks that cadets could use to explore the battlefield, the armies, and the equipment that took part in the battle.

Virtual reality simulations could also be used to enhance the military science classes that every cadet takes. Most cadets have never experienced combat first-hand and their closest conception comes from computer games or movies which usually eschew realism for the sake of drama or a good playing experience. Current Desktop VR simulations available to the Department of Military Instruction can be enhanced with head-mounted displays to give cadets an immersive experience of virtual combat. Furthermore, support assets such as artillery or air strikes can be modeled far more realistically than they are during summer training due to safety and financial constraints.

Cadets can take part in developing virtual reality applications as a part of their senior capstone projects. For example, the Department of Electrical Engineering and Computer Science, Department of History, and Department of Systems Engineering are currently taking part in an interdisciplinary capstone to create a Google Cardboard recreation of the D-Day landings at Omaha Beach. Creating virtual reality applications is an inherently interdisciplinary effort since the people desiring the tools need to work with the people capable of producing them (Sinclair, 2016). Although the quality of these products will likely fall short of professionally developed virtual reality applications, this still exposes the cadets to the capabilities and possibilities of virtual reality technology as well as broadening their horizons by working in a team with cadets with different educational backgrounds.

In order to successfully integrate virtual reality or augmented reality technology with a curriculum, one study recommends reviewing which course objectives can use a simulation or virtual reality, then determining what level of realism and type of immersion and interaction is required (Pantelidis, 2010). Based on these requirements, the appropriate hardware and delivery system can be chosen and a virtual environment constructed. Finally, this can be evaluated and refined using pilot groups and the target population.

It's essential for virtual reality to support specific learning objectives and to ensure that both the instructors and the students are given the time and training needed to use virtual reality technology. In order for the instructors to learn about virtual reality and how to apply it in the classroom, they should be given professional development classes that allow them to learn the capabilities of virtual reality through personal use as well as given time to consider how virtual reality or augmented reality technology can be applied to their courses and areas of interest.

Conclusions

The advent of affordable and widespread virtual reality technology and the proliferation of smart phones capable of supporting augmented reality has opened incredible opportunities for improving the way that we learn. Students can now experience the topics they are learning about. Use of virtual reality technology has been shown to increase student engagement and focus, while the immersive and interactive environment encourages the students to become active learners. Finally, the ability to visualize abstract concepts or simulate and experience rare or dangerous situations greatly enriches the possibilities that students can explore during class.

The spread of affordable virtual reality technology will impact the vast majority of the population in domains ranging from education and work to entertainment and leisure. Exposing students to this technology in the education system will help prepare them to use it productively outside the schoolhouse. Like all new tools, it takes time and effort to learn how to use and employ them properly. But once mastered, student and teacher alike can unlock doors to new possibilities and opportunities in the digital age.

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