# Education Applications of 3D Technology

Aritra Ghosh
Center for eLearning
Florida Atlantic University
777 Glades Road, Boca Raton, FL 33431
aghosh2016@fau.edu

Victoria Brown
Center for eLearning
Florida Atlantic University
777 Glades Road, Boca Raton, FL 33431
vbrown22@fau.edu

Shihong Huang
Department of Computer & Electrical Engineering and Computer Science
Florida Atlantic University
777 Glades Road, Boca Raton, FL 33431
shihong@fau.edu

**Abstract:** Online learning has become an integral part of higher education. Although it is an extension of distance learning, the medium requires new modes of presentation and interaction to ensure high quality and student motivation. Virtual Reality (VR) has the potential to make distance learning truly interactive and flexible similar to the traditional face-to-face courses within a single platform. Students can interact with teachers and other fellow students and can perform experiments that bring the content to life. The virtual game-based experiment gives a better understanding of the subject matter, increases students' motivation and improves the attention level of the student. Providing appropriate VR technique for a particular educational requirement is challenging. This paper discusses the most common available virtual reality techniques used for educational purposes, and their implications. Different VR examples will help educators decide which techniques are best suited to their subject matter and pedagogical needs.

*Keywords:* Virtual reality, augmented reality, 3D interaction.

## Introduction

The history of the creation of three-dimension (3D) goes back to 1938 when Wheatstone (1938) described the first three-dimensional technique, called stereopsis or binocular vision, which gives a life-like representation of an object. This is a process where humans identify three dimensions (3D) from two identical, overlaid images. Virtual reality (VR) is a computer-generated simulation of 3D images or environments. VR can produce a life-like representation of an object or environment using special electronic devices. As a result, virtual reality is an advanced way to observe and experience any 3D environment.

Today, many students own several technological devices and use them regularly. Approximately, 90.1% of students have a computer, 85.3% possess at least one mobile phone, and 74.6% own handheld gaming devices (Bamford, 2011). Bamford (2011) indicated in his research that 86% of students showed improvements from the pre-test to the post-test in courses taught with 3D technology, compared to only 52% in courses infused with 2D technology. Individuals improved test scores by an average of 17% in the courses that used 3D technology, compared to only an 8% improvement in those inserted with 2D technology between pre-test and post-test. The teachers stated that the students in the 3D groups had a deeper understanding, increased attention, more motivation and higher engagement. The students reported higher levels of satisfaction in the courses infused with 3D technology. The use of 3D in the classroom changed students' behavior, communication patterns, and improved classroom interaction. Therefore, 3D and virtual reality has the potential to revolutionize how concepts are presented to students.

Below is a description of the most commonly available 3D techniques used for educational purposes with an analysis of the advantages and drawbacks of each technique. Included are suggestions for using VR in education to help educators decide what VR technologies will be best for their subject matter and pedagogical needs.

## Different 3D Interaction Techniques in Education

To understand the different 3D techniques the development of a taxonomy for interactions was important. The interaction in a 3D environment can be characterized in terms of three types of tasks (Hand, 1997). Navigation refers to the motor task of moving user's viewpoint through an environment; it includes a cognitive component – wayfinding. Selection and manipulation describe the techniques of choosing an object and specifying its position, orientation, and scale. System control creates communication between user and system which is not part of the virtual environment but important in understanding the development of the interaction within simulations.

Classification of the different types of 3D technology is closely linked to a continuum which places fully-immersive virtual reality on one end of the spectrum and physical reality (real life) on the other end of the spectrum (Milgram et al., 1994). Immersion is the degree to which the technology blocks out reality, replacing physical sensorial information with corresponding virtual stimuli. Therefore, a high-immersion environment is a fully virtual one while a low immersion environment is the mixture of virtual and real world.

### Virtual Reality

Virtual reality is the technique used to illustrate 3D, computer-generated environment which can be explored and interacted via human character. A person becomes part of this virtual world or is immersed within this environment and can manipulate objects or perform a series of actions. Figure 1 shows the taxonomy of virtual reality systems (Muhanna, 2015), based on two factors - the type of technology used in building the system and the level of immersion. A virtual reality system does not have to be fully immersive.

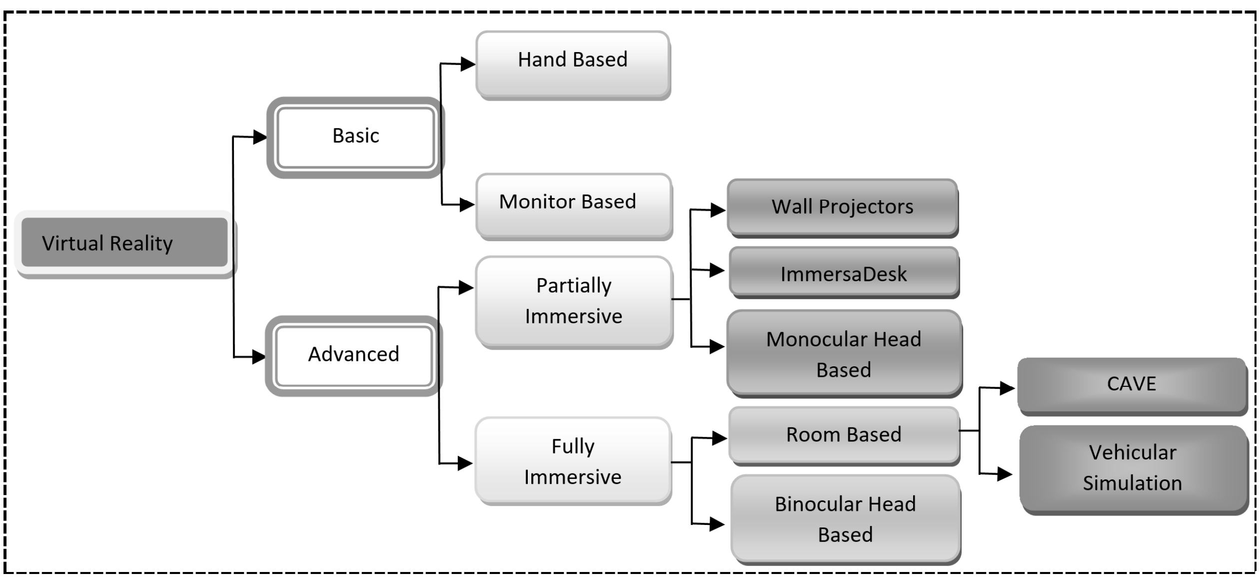


**Figure 1:** The Taxonomy of Virtual Reality Systems (Muhanna, 2015)

Basic VR techniques contain a lower level of immersion compared to the advanced systems. Systems without immersion are not classified as virtual. Basic VR systems do not need special input or output devices to display a virtual environment. These systems are screen-based and pointer-driven with 3D graphics (Heim, 2007). We can divide these systems into subcategories, such as the hand-based and the monitor-based virtual reality systems. In hand-based VR systems, hand-held devices, such as cell phones, personal digital assistants, ultra-mobile computers, and portable game consoles, provide the VR experience (Hwang et al., 2006). For example, by using a digital compass and a camera on a smartphone, this hand-based system can recognize landmarks, surroundings, and points of interests to augment helpful data for the users, on their phones. Another example, is the Sony PlayStation Portable which is a hand-based mobile learning platform where students can learn through games. Several secondary schools like Leeds Schools, Birmingham Schools etc. use this device to engage their students. Hand-held devices have a lower level of immersion when compared to desktop computing environments because of the limited field of view and display capabilities; however, its portability and widespread ownership make the devices an attractive platform. Monitor-based virtual reality systems are desktop computers displaying three-dimensional graphics on two-dimensional monitors. This display projects stereo images from the viewers' points of view, giving them the ability to see the third dimension on their two-dimensional desktop monitors. Because of the low level of immersion, and flexibility, the use of this technique is rare.

Advanced virtual reality systems require powerful devices for computing. These systems can provide partial or full immersion. Partially immersive VR systems use a single projector to display a virtual world on a large screen. Participants do not need to wear any goggles because this type of systems does not display scenes in three-dimensions. It uses special gloves which limit his or her degrees of freedom. For example, University of California, Davis developed Tiled Powerwall to create the 3D structure of the protein in their Institute for Data Analysis and Visualization lab (Keck, 2012).The University of California at Davis created a virtual quartz crystal with ImmersaDesk, another partially immersive VR system. A participant wears special goggles to see the contents of the projection display in a three-dimensional experience. The display provides two overlapping pictures or stereo images of the same content so that each eye of the participant receives the same scene but from a slightly different angle (Keck, 2012). This gives the participant the feeling of the third dimension coming out of the display. This system becomes cumbersome due to complex controller wires.

The head-based virtual reality system is another type of virtual reality. Participants wear a device on their heads, which provides visual and aural feedback. Head-based virtual reality systems can be either partially or fully immersive. Monocular head-based systems are examples of partially immersive virtual reality. A head-mounted display (HMD), or binocular head-based system are examples of a fully immersive VR systems which provides the participant with three-dimensional virtual scenes in a large field of view (Melzer and Moffitt, 1997; Sherman and Craig, 2003). Two small screens display the virtual scene to each of the participant's eyes. The binocular HMD systems can track the position of the head to provide feedback and interactivity to the participant. This technique is the most widely used in education because it is inexpensive and requires no additional space. Students can learn various subject matters such as physics, chemistry, history, geosciences, medicine, etc. using the head-based virtual reality systems.

Lower levels of 3D are becoming mainstream. Good examples are Google cardboard and Samsung Gear VR, two popular wireless head-mounted display (HMD) tools. Both are used to produce basic VR experiences. These devices only need the tool and VR app (easily developed by themselves or downloaded from Google Play/Apple store) installed on their smartphone. These devices are high latency and quickly drain the power of the smartphones. Some programs allow the user to interact with VR scenes through head movements. Due to the limitations for interaction, the primary use of the 3D is observational.

Oculus Rift and High Tech Computer (HTC) Vibe are two other examples of HMD devices, which are a little costlier and require a rather powerful personal computer (PC). These tools support a wider range of applications through hand controllers to interact with the scenes more efficiently. Carnegie Mellon University, Georgia Institute of Technology and many other educational organizations are using these techniques (Youngblut, 1998). They developed virtual Pompeii, virtual Egyptian Temple (History), virtual cell structure (Chemistry), NewtonWorld or MaxwellWorld (Physics) etc. to teach their students different subject matters.

The next level of 3D systems places participants into the virtual reality experience inside a room. For example, Flight Simulator or Light Vehicle Simulator is used for training purposes in civil, mechanical, automobile and aeronautical engineering. In flight simulator, the engineers artificially creates aircraft and the environment in which it flies. It trains the future pilots how aircraft fly, how they react to applications of flight controls, the effects of other aircraft systems, and how the aircraft reacts to external factors such as air density, turbulence, wind shear, cloud, precipitation, etc. In light vehicle simulator, the participants are trained on how to respond to emergency situations and the risks associated with driving light four-wheel drive vehicles on mine sites or in case of emergency situation (Light vehicle simulator, 2008). BikeSim, CarSim, TruckSim, SuspensionSim, etc. are well-known light vehicle simulators.

The Cave Automated Virtual Environment, or CAVE, was designed in response to the challenge of creating a one-to-many visualization tool that utilizes large projection screens. Pioneered by the University of Illinois Urbana-Champaign, the CAVE projection systems (Youngblut, 1998) are directed simultaneously at three to six walls of a room with different shapes. Projecting the scenes guarantee a more immersive environment through casting the shadows of the participants behind them. CAVE requires high graphics engine with powerful Graphics Processing Unit (GPU). Although a costly investment, the low-latency, durability and wide range of compatible applications make this technique effective.

Table 1 summarizes the proposed taxonomy in a tabular form.

| **Virtual Reality System** | **Special I/O devices** | **Drawbacks** | **3D stereo image** | **Level of immersion** | **Field of view** |
|---|---|---|---|---|---|
| Hand-based | N/A | Handheld | No | Low | Narrow |
| Monitor-based | N/A | N/A | Yes | Low | Narrow |
| Wall-projectors | Projector, gloves | Glove wires | No | Partial | Narrow |
| ImmersaDesk | Projector, goggles | Controller wires | Yes | Partial | Narrow |
| Monocular head-based | Helmet | Helmet weight | No | Partial | Narrow |
| Binocular head-based | HMD | Helmet weight | Yes | Full | Wide |
| Vehicle Simulators | Special setup | N/A | Yes | Full | Wide |
| CAVE | Special setup | Requires room | Yes | Full | Wide |

**Table 1:** A Comparison of the Different Types of Virtual Reality Systems.

## Augmented Reality

Augmented reality (AR) is a quickly expanding technology that combines real-world objects with virtual ones (Sherman and Craig, 2003). The user has the ability to see virtual and real objects combined, through transparent screens. The effect is created with one eye viewing the virtual objects and the real world with the other eye. Augmented reality is available to combine multiple inputs and outputs creating an immersive experience. Figure 2 and 3 illustrate the taxonomy of augmented reality inputs and outputs respectively (Gerard, 2011).

There are five categories of augmented reality. Vision is the most common type of augmented reality using three types of interfaces. Both handheld and head-mounted displays can be used everywhere, while spatial augmented reality is more stationary. With handheld devices, such as personal digital assistant (PDAs), mobile phones, students achieve visual augmented reality by using the cameras in those devices and instantly displaying images on the screen. There are two main types of HMDs: Optical see-through and video see-through. The first type projects the augmented objects onto a transparent surface. The second category replaces the glasses with tiny displays. Cameras in front of those displays perceive the reality and send it to a processing unit that adds the augmented objects before sending the images to those displays. In spatial augmented reality, augmented objects enter the life of the user without wearing any device at all. It is very immersive. The Z800 Pro AR HMD is a tool to experience augmented reality (Ng and Tan, 2011). Samsung announced their augmented reality glasses at the Mobile World Congress 2017 (Odom, 2017).

The visual augmented reality is much more advanced than those developed for the other human senses. However, some work has been done to simulate the other senses. Audio augmented reality targets our hearing. Museums frequently use headphones or speakers; the augmented information becomes an audio guide. Mobile AAR browser Toozla is the first audio AR browser available in the market (Gamper, 2014). Augmented touch, also called haptics, is a less common type of augmented reality. The haptic device translates a certain input into motion of some sort. Researchers from the University of Tokyo have developed 3D holograms that can be "touched" through haptic feedback using "acoustic radiation" to create a pressure sensation on a user's hands (Zyga, 2009). The last two categories are combined since smell influences taste. Taste and smell augmented reality is very uncommon. By releasing certain odors, the taste of eatable objects are altered. Researchers have found a way to merge the taste, feel and smell of food using atomizers, virtual reality headsets, devices that mimic chewing sounds, glasses with built-in sensors, specialized utensils, and 3D-printed food cubes. The goal is to trick the user's mind and palate into thinking they are experiencing something entirely different from what they are actually eating (Project nourished, n.d.).

The users need input devices to interact with augmented realities. Mouse and keyboard are the most traditional input devices. The global positioning system (GPS) or the radio-frequency identification (RFID) can track location. GPS is used on a global scale but loses accuracy when indoor. RFID requires several sensors but is more accurate. Motion detectors like the accelerometer, track how fast a device is moving. Speech can be tracked using speech recognition software. The user can give commands to the device or create noises to control the application. Interaction through vision is probably the most elaborate type of interaction because we can track all the possible attributes. Any combination of the inputs and outputs above is possible to create an augmented experience.

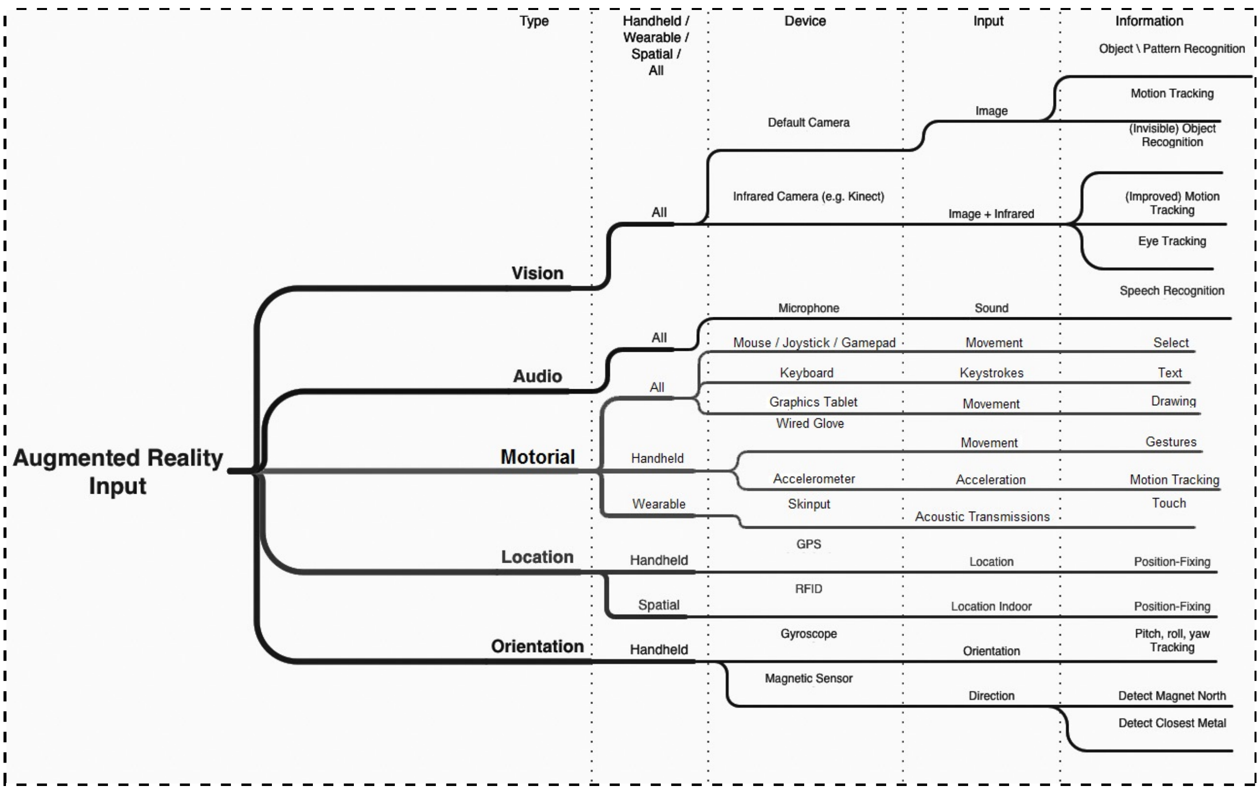


**Figure 2:** The Taxonomy of Augmented Reality Inputs (Gerard, 2011)

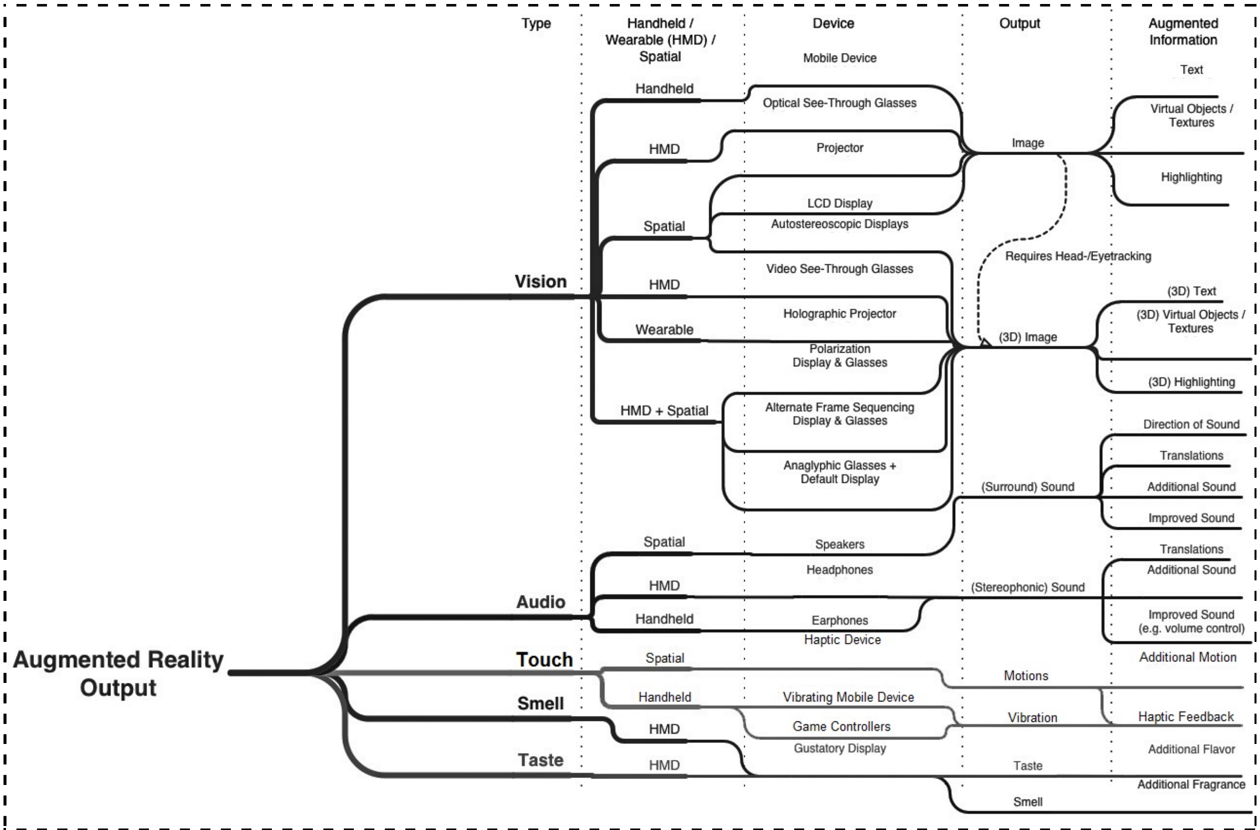


**Figure 3:** The Taxonomy of Augmented Reality Outputs (Gerard, 2011)

**Mixed Reality**

Mixed reality (MR), is the combination of actual and digital worlds to generate new environments and visualizations where physical and virtual objects co-exist and interact in real time. MR takes place not only in the physical world or the virtual world, but is a mix of reality and virtual reality, encompassing both augmented reality and augmented virtuality via immersive technology. Microsoft HoloLens, a pair of smart glasses gained popularity for being one of the first computers running MR platform (Hempel, 2015). Case Western Reserve University made revolution using HoloLens in their medical school anatomy and nursing classes (Gonzales, 2017).

## Educational Implications

The use of simulations is evolving with many different options becoming available. However, different types of simulations in 2D or 3D promote different types of learning. In this analysis, the technology for simulations has been grouped into five different categories based upon the type of equipment required for interactions (a) keyboard or joystick interactions, (b) basic goggle, (c) goggles with wearable sensors, (d) 3D space, and (e) others.

The keyboard and joystick simulations have been available. Using a keyboard or joystick provided many options for interaction with the simulations for learning. The learner is able to move around, interact with objects, and talk with characters. Input can be gathered from the learning using all of the keyboard options. This means input from questions can be with letters and numbers as well as the arrow keys and spacebar.

The goggle interface is the most restrictive for interaction. The low-level goggles allow the user to view a simulation in 2D or 3D. Learning activities are limited to view demonstrations or short movies. Some goggles are now using tracking devices. The learners can select options or target objects by moving their head. Simulation can be powerful for those concepts which do not promote comprehension in a flat paper format. For example, the fusion of the electrons and protons of different atoms to create molecules can facilitate an understanding of the fusion much better than reading words or viewing a 2D representation of the process.

The next step up in the simulation space is to add wearable sensors to the goggle. The sensors can do many things such as detect movement, temperature changes, heart rates, and so much more. Interactions with the simulation occur through the sensors. A glove with motion sensors can facilitate the manipulation of objects for example. The technology allows for the movement of objects from one location to another. Students could build an animal cell and compare it to a plant cell. Simulations are currently being designed that allow the user to have an interface over an object with directions on how to change the object. For example, fixing a leak in the plumbing or assembling a bike.

The more sophisticated 3D technology requires space. Two types of technology fit into this category. One is the 3D projection system. This system requires programming and a specialized projector. The projection system is best for a large group demonstration. One person manipulates the simulations while others in the group watch. This method is good for demonstrating how different systems function in the body for example. For a more personal approach, space can be created to allow the learner to move around safely. This requires external sensors to be located around the space. The learner then uses the goggles and sensory gloves to interact inside the space. Demonstrations of these types of products include connecting and interacting with other learners at different locations. The technology also allows for picking up and moving objects around the space.

There are a few techniques available which are not popular yet and under research. Scientists are working on the forms of communication and entertainment that utilize multi-sensory touch, smell, and taste.

Table 2 summarizes the different interaction equipment with techniques in a tabular form.

| Interaction Equipment | Interaction Techniques | Interaction Medium | Examples |
|---|---|---|---|
| Keyboard or joystick interactions | Hand-held devices can recognize landmarks, surroundings, and points of interests to augment helpful data by using a digital compass, camera on a smartphone and/or motion sensors. | Vision | Cell phone, PDA, portable game console etc. |
| | Monitor-based devices display 3D graphics and project stereo images from a user point of view. | Vision | Desktop computers |
| Goggles | Simple goggles are used to produce basic VR experiences. These devices only need the tool and VR app installed on their smartphone. Some programs allow the user to interact with VR scenes through head movements. Due to the limitations for interaction, the primary use of the 3D is observational. | Vision | Google Cardboard, Samsung Gear VR are two widely used goggles with no additional sensors. |
| Goggles, wearable sensors, and hand controllers | In monocular and some advanced binocular head-based goggles, two small screens display the virtual scene to each of the participant's eyes. They can track the position of the head to provide feedback and interactivity to the participant. | Vision | Oculus Rift and High Tech Computer (HTC) Vibe are other two examples of HMD devices. Z800 Pro AR HMD is used for augmented reality visualization. |
| | ImmersaDesk - A participant wears special goggles to see the contents of the projection display to experience 3D. | Vision | ImmersaDesk creates virtual quartz crystal. |
| 3D space | Wall projectors display a virtual world on a large screen. Sometimes, students can use special gloves which limits their degrees of freedom. | Vision | Tiled Powerwall creates the 3D structure of the protein. |

| | | | |
|---|---|---|---|
| | Light vehicle simulator is used for training purpose in civil, mechanical, automobile, aeronautical engineering. Skills are developed progressively by subjecting the trainee to general, specific and emergency training scenarios. | Vision | BikeSim, CarSim, TruckSim, SuspensionSim etc. are well-known light vehicle simulators. |
| | CAVE has 3-6 walls in a room-sized cube where multiple projectors project images from different angles to create an immersive environment. | Vision | Many universities own CAVE systems like the University of Illinois Urbana-Champaign. |
| Headphones or speakers | Audio augmented reality targets our hearing. The augmented information becomes an audio guide. | Audio | Museums frequently use it. |
| Human body feels and senses through mouse, keyboard or touchscreen | Augmented touch or haptic device translates a certain input into motion of some sort. Haptic devices render mechanical signals (i.e., external force) which stimulate human touch and kinesthetic channels. | Touch | Researchers from the University of Tokyo have developed 3D holograms that can be "touched" through haptic feedback using "acoustic radiation" to create a pressure sensation on a user's hands. |
| Atomizers, virtual reality headsets, a device that mimics chewing sounds, a glass with built-in sensors, a specialized utensil, and a 3D-printed food cube | Smell influences taste. By releasing certain odors, the taste of a certain eatable object is altered. | Taste and smell | Researchers at Project Nourished have found a way to merge the taste, feel and smell of food. The goal is to trick the user's mind and palate into thinking they're experiencing something entirely different than what they're actually eating. |

**Table 2.** Different Simulation Technologies based on their Interaction Equipment.

## Evaluation and Conclusion

Our analyses and discussions of empirical studies in VR and AR indicated that while these techniques can be created by integrating multiple tools and has a great potential to support learning and teaching, there are various issues to consider when they are implemented in educational settings. Additionally, these empirical studies have limitations in terms of research design and evidential validity (Wu et al., 2013).

In this paper, we have summarized and discussed previous research on VR for 3D applications and their use in education. All VR techniques are not popular in teaching and learning; however, some techniques are common in research. Overall evaluation across the different research groups reported satisfactory outcomes because every institution develops their own scenarios based on different criteria. Still, some negative feedback from students and teachers were reported. Some students experienced difficulty using the menus in VR environments. Other struggled to navigate through the scenes. Hand gestures were unreliable in some projects. Few students expressed difficulty focusing the HMD optics. Most of the students and faculty members indicated slight to moderate level of eye strain and discomfort after using the application for over one hour (Youngblut, 1998).
It is important to note that the VR technology is continually evolving. However, all described techniques have advantages and drawbacks. In addition, VR technology and its application to education are still maturing. Existing research does suggest that this technology offers significant, positive support for education. Ideas in the conceptual stage a few years ago are now a reality. Imagination has no limit to what VR will be able to do in the future.

## References


Bamford, A. (2011). LiFE: Learning in future education. *Evaluation of Innovations in Emerging Learning Technologies*, in the press.

Gamper, H. (2014). Enabling technologies for audio augmented reality systems. *Aalto University Publication Series, doctoral dissertations.* Retrieved from *http://lib.tkk.fi/Diss/2014/isbn9789526056227/isbn9789526056227.pdf*.

Gerard, B. (2011). *The hitchhiker's guide to computer science.* Retrieved from https://bartgerard.wordpress.com/2011/11/01/founding-the-taxonomy.

Gonzales, P. (2017). HoloLens in medical education and training with Peter Campbell: Show 12. Retrieved from http://newschoolvr.com/hololens-medical-training/.

Hand, C. (1997). A survey of 3Dinteraction techniques. *Computer Graphics Forum, 16* (5), 269–281.

Heim, S. (2007). The resonant Interface: HCI foundations for interaction design. Addison-Wesley.

Hempel, J. (2015, January 21). Project HoloLens: Our exclusive hands-on with Microsoft's holographic goggles. Retrieved from https://www.wired.com/2015/01/microsoft-hands- on/.

Hwang, J., Jung, J., Yim, S., Cheon, J., Lee, S., Choi, S., Kim, G.J. (2006). Requirements, implementation, and applications of handheld virtual reality. *Internation Journal of Virtual Reality, 5*(2), 59–66.

Keck, W. M. (2012). Center for active visualization in the earth sciences. KeckCAVES, Retrieved from www.idav.ucdavis.edu/~okreylos/ResDev/KeckCAVES.

Light vehicle simulator launched to improve site safety. (2008, June 25). Retrieved from https://www.immersivetechnologies.com/news/news2008/news_2008_05.htm.

Melzer, J.E., Moffitt, K. (1997). Head mounted displays: Designing for the user. McGraw Hill.

Milgram, P., Takemura H., Utsumi A., Kishino F. (1994). Augmented reality: A class of displays on the reality-virtuality continuum. *Proceedings of Telemanipulator and Telepresence Technologies.* 2351–34.

Muhanna, A. M. (2015). Virtual reality and the CAVE: Taxonomy, interaction challenges, and research directions. *Journal of King Saud University – Computer and Information Sciences 27*, 344–361.

Ng, P.K., Tan, Y.G. (2011). ARTransform: Visualization of three-dimensional geometric transformations in augmented reality environment. WorldComp Proceedings. Retrieved from http://worldcomp-proceedings.com/proc/p2011/CGV8157.pdf

Odom, J. (2017). Samsung's 'monitorless' remote desktop smart glasses blur the line between virtual & augmented reality. Retrieved from https://augmented.reality.news/news/samsungs-monitorless-remote-desktop-smartglasses-blur-line-between-virtual-augmented-reality-0176310/.

Project nourished (n.d.) Retrieved from http://www.projectnourished.com/.

Sherman, W.R., Craig, A.B. (2003). Understanding virtual reality: Interface, application, and design, Morgan Kaufmann Publishers.

Wheatstone, C. (1838). Contributions to the physiology of vision. Part the first. On some remarkable, and hitherto unobserved, phenomena of binocular vision. *Philosophical Transactions of the Royal Society of London, 128*, 371-394.

Youngblut, C. (1998). Educational Uses of Virtual Reality Technology. *Institute for Defense Analyses.*

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.*

Zyga, L. (2009. August 6). Touchable Hologram Becomes Reality (w/ Video). Retrieved from https://phys.org/news/2009-08-touchable-hologram-reality-video.html