Virtual Reality in Education

Chapter · June 2010

DOI: 10.4018/978-1-60566-940-3.ch012

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ABSTRACT

Virtual Reality is produced by a combination of technologies that are used to visualize and provide interaction with a virtual environment. These environments often depict three-dimensional space which may be realistic or imaginary, macroscopic or microscopic and based on realistic physical laws of dynamics or on imaginary dynamics. The multitude of scenarios that VR may be used to depict make it broadly applicable to the many areas in education. A key feature of VR is that it allows multi-sensory interaction with the space visualized. Here we look at how this combination of multi-sensory visualization and interactivity make VR ideally suited for effective learning and try to explain this effectiveness in terms of the advantages afforded by active learning from experiences. We also consider some of the applications of VR in education and the draw-backs associated with this technology.

Keywords
Virtual Reality, Virtual Environments, VR, Education, Constructivism, Perception and Action

INTRODUCTION

Virtual Reality or VR allows a user to interact with a computer generated three-dimensional model or virtual environment. This environment may be realistic, in the sense that it is familiar to us at a macroscopic scale, it may be realistic in the sense that it depicts the physical world as known to science but which is not usually observable, or it may be used to visualize a world that is entirely imaginary. As such, VR is broadly applicable, and has been applied to, many different areas of education including the sciences, archeology, history and architecture. The advantage of VR over conventional methods of description is that the student is given the opportunity to *experience* subject matter that would be difficult if not impossible to illustrate or describe with conventional methods. We argue here that this experiential nature of VR together with its other key feature, interactivity, provides a valuable aid to conventional learning paradigms. In this chapter we give a brief description of common VR setups to give a feel for how a VR experience is provided. We also consider, from cognitive and sensory psychology points of view why learning may be facilitated by interactive multi-sensory systems and we provide some examples of the use of VR in educational contexts.

Modern education often requires a student to comprehend complex or abstract concepts or appreciate scenarios and situations that no longer exist. To this end, common mechanisms for teaching abstract concepts are the use of metaphor and analogy, especially within the sciences. By using an analogy we describe an event or abstract concept in terms of commonly observable reality. That is, we relate concepts to experience. The experience provides the material for the construction of a mental model of the concept, which in turn leads to the foundation of knowledge (Duffy & Jonassen, 1992). Humans learn by having experiences, by interacting with their environment and using their senses to derive information from the world. Virtual reality is a technology that replaces sensory input derived from the real world with sensory input created by computer simulation. It provides interactivity by responding to movements and the natural behaviors of humans in the real world. In this respect VR may prove to be a powerful resource that can help in teaching by providing an environment that allows the student to experience scenarios and situations rather than imagining them. The experiential nature of VR systems derives from three sources: immersion, interactivity and multi-sensory feedback. Immersion means being enveloped or surrounded by the environment. The benefit of immersion is that it ensures a sense of presence or the feeling that one is really in the depicted world (Schuemie et al., 2001). Interactivity is the ability to control events in the simulation by using ones body movements which in turn initiates responses in the simulation as a result of these movements. The multi-sensory nature of VR means that information can be derived from more than one sense and adds to the experience by making it more believable, engaging (adding to the sense of presence) and providing redundancy of information which reduces the potential for ambiguity and confusion. Sensory combination reinforces information from two or more sensory sources. The aim of VR is therefore to replace the real world with a virtual world and to allow the user to behave as if they were in the real world.

The experiential nature of VR supports a constructivist approach to learning (see Winn, 1993). Constructivism is a theory of knowledge acquisition that states that humans construct knowledge by learning from their experiences. As popularized by Jean Piaget the theory states that the learner attempts to assimilate new experiences within their already established world model. If the learner cannot successfully assimilate new detail they change their world view to accommodate the new experience. When we act on the expectation that the world operates according to our world model and it does not then we must accommodate the new experience by reframing our model of the way the world works; we learn from the experience. This implies that learning is a form of active hypothesis testing. This should be contrasted with the view that learning is a passive accumulation or acceptance of facts. VR provides an environment for this active hypothesis testing and thus provides a powerful medium for learning. In general, and as suggested by Bruner (1961), students who actively engage with new material are more likely to retain this material and recall it at a later stage.

Broad areas of application	Can be expensive and time consuming to set up
Provides a more engaging environment for learning	May in some cases result in simulation sickness
Utilizes interactivity & interactive learning	Learners may feel disorientated as first
Engages multiple senses.	Fidelity issues and lack of realism

Table 1 Advantages and disadvantages of using VR

Table 1 lists some of the advantages and potential disadvantages of using VR in an educational context. After reading this chapter, the reader will be able to appreciate how these issues impact on learning. We begin by giving a brief description of VR followed by an account of how interactivity and multi-sensory perception (key components of VR) provide a basis for learning.

We describe how the perceptual and cognitive processes responsible for learning benefit from interactivity and multi-sensory information. This section is then followed by a consideration of the building blocks of an operational VR system with details of the important components of a VR simulation and the various technologies that facilitate interaction and engagement. This is followed by a review of several application areas in educational contexts. We finish the chapter with a look at some of the draw-backs and potential problems associated with the use of VR in its present form.

WHAT IS VR?

In a VR simulation a computer simulates and displays an environment through which we can walk and interact with objects and simulated people (commonly referred to as ‘agents’ or avatars). A virtual environment is depicted usually as a three-dimensional world and often virtual worlds try to replicate the real world both in appearance and in the way that objects behave (e.g. the simulation of gravity). It should be noted however, that there is no necessity that this virtual space be similar to the real world. Indeed, one of the virtues of virtual environments is that they can be used to depict entirely unrealistic scenarios. However, for training purposes virtual environments simulate the environment in which the student will eventually operate and provide a safe environment in which to test scenarios that would be either too difficult or dangerous to perform in real life.

There are many types of VR implementations and below we have listed 4 common setups:

1. Desktop VR (Monoscopic or Stereoscopic)
2. Immersive VR (HMD, CAVE, wide screen)
3. Collaborative Systems
4. Mixed or Augmented Reality

Desktop VR, as its name suggests, has the user seated in front of a desktop computer monitor with interaction provided by a controlling device such as a computer mouse. In immersive systems the users’ field of view is completely obstructed by the visualization display in the form of a helmet worn on the head. Collaborative systems may be either desktop based or immersive and involve the interaction between two or more avatars controlled by humans. A recent, and most successful implementation of a collaborative system is Second Life (www.secondlife.com). Attempts are also being made to harness the power of collaborative systems for research purposes (e.g. The Presenccia Project, www.presenccia.org). Mixed reality systems employ a combination of the real world viewed either directly or through a camera with overlaid computer generated content. Although relatively new, these systems have potential for training students in engineering and medicine.

MULTI-SENSORY INTERACTION – A SOUND BASIS FOR LEARNING

From infancy, a child learns through activity. With little control over its limbs, the process of learning about the world begins through exploration by reaching, touching, looking, smelling, and tasting whatever comes into its proximity. Through a combination of all the senses the child begins to associate different properties with different objects and through memorization is able to form distinct categories and concepts from the seemingly disparate and chaotic signals that it receives from the world. Even in maturity, perception and activity are crucial for learning. In this section we give a brief description of how we derive information through sensory perception and how the connection between perception and action can be exploited by VR technology for educational purposes.

The Senses

The five senses of vision, audition, touch, taste and olfaction provide different information for different purposes. We focus on vision, touch and audition as these senses are the ones primarily exploited in virtual reality. Of all the senses vision is the most versatile providing us with a wide range of information concerning ourselves and our surroundings. It also provides a means of communication and is used for recognition and identification. The visual system makes use of a wide variety of sensory cues. For example, for spatial perception (the perception of distances and shape) it utilizes stereopsis (the ability to fuse images from two eyes) to detect depth. When fused, the retinal images of the two eyes contain disparities or horizontal misalignments that scale with depth and the visual system uses these disparities to encode the relative depth of objects. Relative depth is also detected from motion parallax (images of objects *closer* to us move *faster* across the retina when they, or the head, moves). The visual system also makes use of so called ‘pictorial cues’ such as occlusion, shading, perspective etc. (Gregory, 1974) to get information regarding shape and relative depth. Under normal circumstances all of these visual cues are combined to allow us to navigate and understand the world.

Audition can also be used for spatial perception as well as for recognition and communication. For spatial perception auditory cues include inter-aural changes in loudness and pitch. For instance, one is able to localize a sound in the horizontal plane by the differences in sound intensity between the sounds reaching the two ears. This works particularly well if the source is less than a meter from the subject. It is also possible to differentiate the location of sound sources in the vertical plane when the source is the same distance from the two ears. The outer portion of the ear (the pinna) is thought to modulate sound frequency according to its location in the vertical plane thus serving as an auditory localization cue. Recent developments in sound simulation have utilized a Head Related Transfer Function (HRTF) which is a mapping of sound properties as a sound source is placed at different positions around a subject’s head. HRTFs are different for each individual (they depend on the shape of the head and body as well the shape of the outer ear). Despite this, generic maps have been created which provide compelling simulated sound with localization cues (see Burdea & Coiffet, 1994).

Touch is used to detect the presence of obstacles, as well as the shape of objects and their material properties. The properties of objects may be derived from two sources: cutaneous sensation and kinesthesia. It is customary to use the term haptics instead of touch to refer to the use and study of both of these sources of information. Cutaneous sensation is what we normally think of as touch and derives from receptors in the skin, not just of the hands but across the body. There are many different types of receptors located at various levels below the surface of the skin conveying the sensations of temperature, pain and movement/pressure. The latter are known as mechanoreceptors and different kinds of mechanoreceptors detect a range of stimuli ranging from transient vibrations to extended displacement of the skin. Kinesthetic sensation is used to detect force, position, direction and angles of the joints and is facilitated by the movements and tensions within muscles, joints and tendons located throughout the body. Whilst vibrotactile and electrotactile devices are being developed for use in VR systems the most successful devices have so far been kinesthetic devices which provide the user with haptic feedback my moving their finger or hand when it comes into contact with a virtual object (haptic devices are discussed below).

Multisensory Perception and Sensory Integration

There are many sources of perceptual information emanating from our surroundings. The neurophysiologist Sherrington categorized our sensations of the world into three groups:

1. Sensations coming from the outside world (exteroception)
2. Sensations describing the body's posture and action (proprioception)
3. Sensations emanating from within the body itself (interoception)

For our purposes, the first two types of sensation are most relevant and comprise what we shall refer to as the sensorimotor system. Exteroception uses the primary senses of vision, touch, taste, etc. as described above. Proprioception can be separated into two components: kinaesthesia and the vestibular sense (the vestibular system provides a sense of balance). Under normal circumstances these proprioceptive inputs influence, and are influenced by, the exteroceptive senses. Integrating inputs from the exteroceptive senses in particular helps disambiguate external stimuli and can help to speed up our responses.

As an example of sensory cooperation between exteroceptive and proprioceptive inputs, consider the illusion of self motion experienced when sitting on a train at a station. If there is a train next to us and it starts to move we often have the illusion that we are moving. The motion of a large part of the field of view is misinterpreted as self-motion. In some cases there is even an urge to change posture. It is only when the perceived movement of the self is not reinforced by expected proprioceptive inputs (from touch and the sensation of acceleration, for instance) that the illusion breaks down. This coupling between (vestibular and visual) sensory inputs was demonstrated by the experiments of Lee and Aronson (1974) with young children. After acclimatization within a room whose walls could be moved, the infant's balance when the walls were suddenly shifted towards them or away from them was assessed. In many cases the infants fell over in the direction of movement of the walls (compensation for perceived change in sway in the opposite direction) showing that postural (proprioceptive) senses can be overridden by visual (exteroceptive) inputs.

Many other demonstrations of this cooperation between the senses exist. For example, it is commonly known that under noisy conditions the ability to see a speaker's lips while they are talking enhances comprehension of what they are saying. Related to this is the McGurk effect (McGurk & MacDonald, 1976) in which seen lip movements alter the perceived phoneme that is heard (e.g. the sound of 'ba' can be heard as 'da' if the lip movement is that of 'ga'). In this case the two 'signals' (vision and sound) are fused to form a new percept that would not occur when either is presented in isolation. It seems therefore that multi-sensory integration is an important component of perception. A medium that provides multi-sensory information will therefore provide a richer experience than one that only delivers information through one sensory modality. In the absence of multiple sensory sources of information perception and learning may be slower and more prone to ambiguity (Calvert et al., 2004).

Perception, Action and Active Learning

In everyday situations action is coupled with changes in sensory input in the form of the perception/action loop (Figure 1). Our brains are adapted to exploit this coupling by setting up predictions as to what will happen given a particular input and what responses are appropriate. One evolutionary benefit of this coupling is that it makes responses to quickly changing events faster because it reduces the involvement of cognitive effort, which is relatively slow. Another benefit is that it provides for more concrete concept construction and thus facilitates learning. In this section we consider the theoretical basis of this assertion.

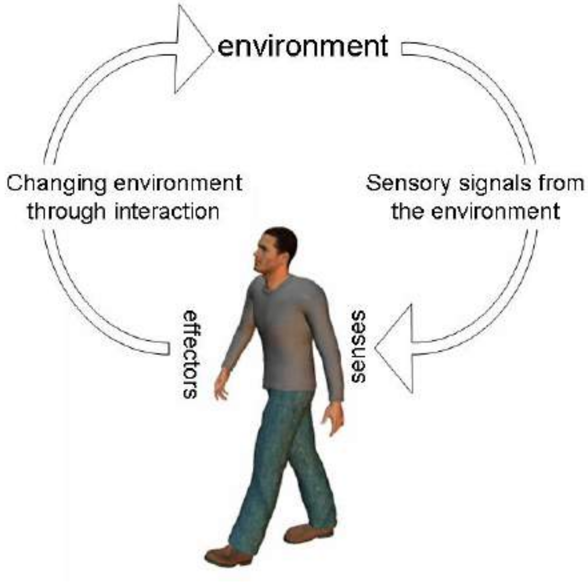

Figure 1. The Perception-Action loop.

Traditionally it was thought that perception is a passive process. A sensory stimulus, such as the visual sensation from an object, is projected to the retina and conveyed to the brain where it is matched against the contents of memory. Perception in some versions of this view involves a passive registration of sensory stimulation and learning involves becoming attuned to regularities in the environment (for example see Gibson, 1987). Another general view of the perceptual process considers perception as active, not passive. This view casts perception in an active role in which the perceiver performs particular actions in order to acquire the necessary information for perception to take place. As an example, consider an action we all perform when faced with a view of the world that is ambiguous. We usually move our heads from side to side in order to induce the cues of motion parallax that can separate object surfaces at different distances from us. This is a natural response that we rarely think about, but which suggests that we have learned action schemas for assisting and facilitating perception. Perception in this view is a top-down process that is guided by cognition. In cognitive psychology this view is encapsulated by the theories of Neisser (1976, 1987) and Gregory (1974). In particular, Neisser distinguished between seeing and thinking in the perceptual process. In ‘seeing’ the subject is making use of information in the world (as in Gibson’s view) and in ‘thinking’ the subject is applying top-down information to make sense of the world. This is a constructivist view in which attention, motivation and perceptual processes operate together to make sense of data arriving from all sense modalities but also in which the processes drive the pick-up of information. Neisser’s theory sees a perceiver as an active explorer of their environment guided by schemas already laid down in memory and who continually update these schemas based on their experiences. In Gregory’s view (e.g. Gregory, 1974) the perceptual process is one of generating and testing hypotheses. When sensory information is limited, the perceiver fills in the gaps with top-down knowledge about the world.

This view of perceptual processing feeds into the constructivist theory of epistemology and learning as propounded by Dewey, Piaget and Vigotsky among others (see Duffy 1992). In constructivism learning is a personal process of construction of meaning from a multitude of sensory information. In Neisser’s terms, the learner constructs their own schemas concerning how the world is and how it works and applies them to new encounters. Piaget saw the learner as one who tries to assimilate new experiences within schemas already laid down. If they cannot, they adjust their current knowledge to accommodate them. In such a theory, learning is facilitated when the learner is allowed to interact with sensory data and allowed to construct their own world view. A number of recent studies in cognitive psychology have investigated the potential benefits of active learning (e.g. Feldman & Acredolo, 1979; Christou & Bülthoff, 1999) and some of these have used VR technology specifically to decouple the various factors that are involved.

These considerations: the interaction between senses, the benefits of sensory integration and a constructivist view of learning, support the use of learning paradigms in which the learner is allowed to form knowledge through context and experience. VR is ideally suited for this. The use of VR provides a multi-sensory, interactive environment that is engaging and that allows learners to construct meaning from experience. For example, in the teaching of complex or abstract ideas it is useful because it provides a means of visualization and allows natural hypothesis making. In teaching historical events it sets these events within a multisensory context. VR provides the possibility of aiding learning by allowing the user to experience subject matter. In the next section we give a description of the inner workings of typical VR systems and of the technology that facilitates interactivity and multi-sensory stimulation.

HOW VR WORKS

Figure 2 is a schematic diagram of the possible components of a virtual reality simulation system and how they relate to each other.

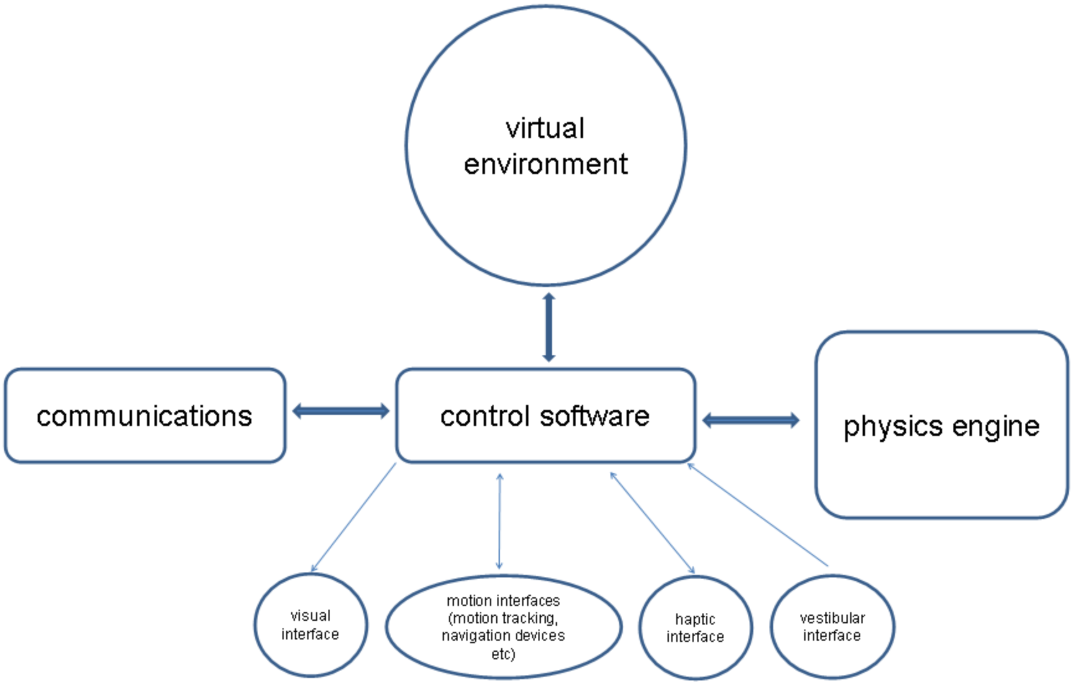

Figure 2. A schematic view of a VR system.

At the core of this system is the control software. This determines when the scene should be drawn on display devices (e.g. the haptic and visual interfaces) and handles communication between the interface layer and the virtual world updating the world appropriately when the user performs some action. The control software may also be used to communicate with the outside world via the internet; a feature that is important for collaborative or multi-user systems. The virtual environment module consists of the actual world model together with a representation of the entities within it. This representation includes not only appearance but also state and position information. These entities may be static objects or dynamic entities such as moving objects or even avatars. Dynamic entities must be updated within the virtual environment model on a constant basis. The virtual environment module is a database that stores the form, position and other properties of all constituents of the virtual world.

For realistic simulations a physics engine is a required component *(*A physics engine is an important requirement to achieve realistic simulations). A physics engine embodies rules that govern the motion and interaction of dynamic objects. Common features of a physics engine include collision detection (calculating when one object intersects with another) and the simulation of the laws of Newtonian mechanics. Using physical laws they implement effects of gravity, friction and motion impulses. The latter effect (impulses) is important in collisions between entities. Collision detection is necessary to detect when two dynamic entities touch and collide with each other. If they do, the physics engine calculates the resulting velocity of both entities according to their simulated ‘physical’ properties such as their material, mass and velocity.

The sensory interface layer of the system provides input and output to and from the user. It is easily expandable and may include few or many components. Essential components include a visual interface that allows the user to see the world and some form of navigation device. Common visual interfaces include head mounted displays (HMDs) which are used for immersive simulations. HMDs are worn on the head and usually provide a stereoscopic view of the world by projecting a slightly different view of the virtual world to each eye. Other visual interfaces include large screen displays, such as the CAVE developed by the Electronic Visualization Laboratory at the University of Illinois in Chicago and the semi-circular cinema projection screen. The CAVE is a small room in which several people may stand. There are usually 4 projection surfaces (the ground and 3 walls) on which stereo images are projected. The semi-circular screen provides a smooth projection surface with a 180 degree field of view. Both of these require the user to wear stereo shutter glasses. These glasses are synchronized with the refresh of the two images comprising the stereo view of the world and provide a 3D experience.

There are many navigation devices that can be used for VR systems depending on what type of visual input device is used. In the CAVE for example, the user is free to walk around and their position in the virtual space is calculated by a head or body tracker. These trackers are usually electromagnetic devices that detect changes in an electromagnetic field depending on the position of a marker placed on the users' head or limbs. As well as using motion trackers, other common navigation devices include the SpaceMouse which allows 6 degrees of movement (3 for translation, and 3 for rotation) used for desktop systems and the 'data glove' which is a wired glove that tracks movements of the hand.

Additionally, the sensory interface may include a haptics device. Haptics devices allow the user to initiate movements of virtual hands or fingers in the environment (the hand or finger is represented in the environment) and provide haptic feedback to the user when the hand or finger 'touches' an object. Haptic interfaces operate through the use of servo motor combinations similar to those of robot arms used for industrial purposes. A popular haptics interface is the Phantom developed by Sensable Technologies (www.sensable.com) which consists of a stylus or finger thimble. The movement of the finger placed in the thimble is detected and is used to detect collisions between it and the virtual objects represented in the scene. When a collision is detected the motors provide a constraining force to the finger that is appropriate for the shape of the object and its material (hard, soft, liquid etc). Because this process is carried out at up to 1000 times a second it provides a convincing impression of solidity and impedance to motion and is able to simulate a wide range of materials including rubber, ice, glass and liquids as well as a range of dynamics effects such as gravity and other forces. Although haptic interfaces like the Phantom are used in small-scale VR applications (e.g. for desktop systems) large-scale devices have also been developed for use in Cave-like environments (Loscos et al., 2003, Christou et al., 2006).

Advanced virtual environment systems may even include a vestibular interface such as a motion platform. Such devices are often found in flight simulators. They physically respond to events in the simulated world and move the user's seat stimulating their sense of acceleration, orientation and position in the world.

A relative new development in the field of VR is in so called mixed, or augmented, reality. Mixed reality involves both a view of a real-world scenario (such as a desktop, car engine etc) overlaid with 3D virtual detail. In brief, the method works by using a visor through which a user can see a real scene and on which a computer is used to overlay a virtual scene. An initial calibration uses a camera pointed at the real scene to work out the orientation of visible surfaces with respect to the virtual world. If there is a one-to-one mapping between the real and virtual environments then it is possible for data, text, overlays and even virtual characters to be presented interacting with real objects. The usefulness of this for education and training purposes is far reaching because it combines the realism of real world scenarios with the informative detail of computer visualization. Uses include, for example, training for engineers in the functioning of complex mechanisms such jet engines and in medical applications.

APPLICATIONS OF VR IN EDUCATION

The multi-sensory, interactive, nature of VR has made it a popular with many researchers in education, rehabilitation and in cognitive neuroscience. For example, the fact that it can enable a child to interact with a 3D world that can be portrayed in many different forms made it popular with many cognitive psychologists studying how spatial awareness and spatial cognition may be improved in normal students and those with cognitive deficits (e.g. Foreman et al., 2003). This is because the virtual environment is more ‘controllable’ than the real world. We will restrict our discussion here to application areas within core educational schemes and in training. We give a brief overview of the fields of application of VR in educational contexts but we do not provide a complete listing of specific applications as these are numerous and changing. A thorough description of VR applications in education up to end of the last century is provided by Youngblut (1998). The educational application areas of VR may be categorized into 3 different types:

1. Application in schools and colleges to enhance core curriculum subjects.
2. Applications for museums, ‘edutainment’ and demonstrations.
3. Utilization for training (children or adults).

Application in Schools

VR applications in schools and colleges fall into two sub-categories; those in which teachers use pre-developed applications (Cell Biology, Virtual Gorilla Exhibit, MaxwellWorld, Atom World, Newton World, Greek Villa, and those in which students themselves build virtual worlds in order to test hypotheses (Virtual Stage, Wetland Ecology). Pre-developed applications consist of a virtual environment, supporting software and hardware in which students perform a required task. Previous implementations include MaxwellWorld which is part of a suite of three scientific applications called ScienceSpace developed for children aged 9-15 years by Dede and coworkers (Dede, et al., 1996). MaxwellWorld teaches students about electrostatic forces and electric fields by allowing them to position electrical charges and to see and interact with the resultant electromagnetic field. MaxwellWorld is a small-scale VR application occupying a 1 meter cube and with axes used to provide a reference frame. The space is presented in stereo using a HMD and menus are used for interaction. NewtonWorld, also part of ScienceSpace, similarly teaches students about forces in Newtonian Mechanics, and PaulingWorld is used for teaching atomic and molecular structure.

The educational uses of VR is also being investigated by the HITLab at the University of Washington. Previous projects of the HITLab include a HMD stereo system called Atom World which was used to aide teaching of atomic and subatomic particles to Grade 11 students and PhaseWorld used in Chemistry to teach students about state changes in matter and how this depends on volume and ambient temperature and pressure. Current projects of the HITLab are evaluating VR in several teaching areas including visualization in oceanography. Another producer of pre-developed VR systems is Cybernet Systems Corporation which has developed Astronomicon which is a HMD based visualization of the Solar System. Students make changes to planets etc. in order to answer specific questions. They have also developed Virtual Gorilla intended to allow students to reproduce the movements and behaviors of gorillas situated within a gorilla family and within an appropriate habitat.

Other fields where VR techniques are actively being applied for educational purposes are in Cultural Heritage and Archaeology. For example, Learning Sites has developed numerous desktop systems for exploration of Archaeological reconstructions of buildings and sites in Europe and the Middle East. One of these was Attica, Vari House which was developed as a desktop VR system and tested on grade 9 – 12 students. The virtual environment consisted of a reconstructed Hellenic House (modeled using details from excavations). Teaching components included set problem-solving tasks. Another organization that has also been active in the field of cultural heritage is the Institute for the Visualization of History which sells QTVR and VRML models of reconstructed sites such as the Acropolis in Athens. VRML stands for Virtual Reality Modeling Language and was used to quickly set up virtual environment models and the interaction environments in which they could be used. This has now been superseded by X3D which a web based standard that can be used in World Wide Web VR applications.

Museums and 'Edutainment'

A number of research projects have developed VR systems for 'edutainment' in the form of virtual museums. For example, The Exploratorium, which is a public science museum dedicated to teaching science using hands-on exhibits, has recently been ported to Second Life. Second Life (SL) is a large-scale, multiuser, three-dimensional online virtual world. We refer to this as a collaborative environment because multiple users inhabit and interact in the same space and it is displayed as a desktop system using a web browser. You visit this world as an avatar (a representation of oneself) and through the avatar's eyes explore areas and features using navigation controls from a keyboard (www.exploratorium.edu).

More research oriented projects have also built prototype virtual museums for this purpose. The CREATE project (Loscos et al. 2003), an EU funded research project, allowed users to reconstruct an archaeological site. The user's task involved the rebuilding of a temple piece by piece, in order to explore and examine alternative scenarios used in the original construction of the site. The selected site used in CREATE was a location in the ancient city of Messini, founded in 369 BC and located in the South West Peloponnese. Within this site, CREATE focused on the architectural complex of the Doric temple which is located at its centre and although this site is poorly preserved it is well documented, which aided the virtual reconstruction effort.

Training

The final application area of VR in education that we will mention is in training. We might consider training as a separate case of education because it usually entails teaching specific knowledge relating to manual tasks rather than general knowledge. VR training provides a safe environment for training tasks which would otherwise be unfeasible or even dangerous to perform in real life. VR training has been applied to the general fields of transportation, medicine, engineering and military & security. We give a brief overview of these next.

Transportation

Flight simulators were one of the first applications of VR technology. Training pilots to fly using grounded 'simulators' is almost as old as flying itself. Modern VR flight simulators use high resolution computer graphics providing 180 degrees field of view, real instrument panels and motion platforms capable of up to 6 degrees of freedom (translation and rotation). These motion platforms provide the vestibular motion cues which are correlated with auditory and visual events providing highly realistic feedback. Specific simulators are now used for specific aircraft types (e.g. the Airbus A320) allowing commercial pilots to be trained and retrained when transferring from one craft to another and databases of actual airports around the world providing realistic scenarios for take-off and landing. Pilot training is costly both from financial and environmental perspectives, as well as being dangerous. VR simulators therefore provide a commercially viable and safe alternative and can be used to prepare pilots to handling demanding and dangerous situations that would be hard if not impossible to stage in the real world. A leading developer of such systems is Evans & Sutherland (www.es.com); a company that has pioneered developments in computer graphics and VR since 1968.

VR simulators are also being used in other fields of transport. For example driving simulators can be used to train people to drive cars and to handle specific driving conditions including fog and heavy rain. These simulators are similar to flight simulators in that they may be housed on real cars situated on a motion platform to provide vestibular feedback. A number of car manufacturers are adopting this technology. For example, Daimler-Benz has opened its own VR centre for prototyping, ergonomics and for demonstrations.

Medicine

Like pilot training, medical training is an expensive process and involves risk to patients. Conventional medical training therefore required students to use cadavers in initial stages of say surgical training followed by lengthy sessions of overseeing qualified surgeons perform a particular task. Surgical training has benefited the most from developments in haptic feedback devices which provides a realistic sense of control and manipulation of soft body tissue. Most developments of VR in medicine are in training a new range of non-invasive or minimally invasive techniques of endoscopy. Endoscopy has many applications including laparoscopic (operations on the abdomen or pelvic cavity), thoracoscopic (key-hole surgery on the chest) and hysteroscopy (inspection and surgery within the uterine cavity). An endoscope is usually a flexible tube containing a camera and other instruments inserted into the body for visual inspection and for taking biopsies and removing growths and foreign objects. The method involves indirect access to the operation area and therefore causes a lot of disadvantages for the surgeon including restricted vision and difficult hand-eye coordination and handling of instruments with limited mobility. Surgeons require a lot of training and experience to execute an operation successfully and safely. VR endoscopic simulators, such as the Karlsruhe Endoscopic Surgery Trainer (Forschungszentrum Karlsruhe, www.fzk.de), have been developed to reduce the operative risks in training doctors. These systems are usually of the desktop type where real endoscopic equipment is used with a video camera feed being replaced with a computer generated display. The computer display shows simulated regions of the body, tissue membranes, organs etc. New developments include attaching the endoscope arm to a robot arm which provides haptic feedback. The endoscope therefore becomes a haptic end-effector which provides touch feedback when the simulated instrument comes into contact with internal surfaces of the simulated body. Again, this multi-sensory simulation increases the displayable realism and enhances learning by providing interactive control.

Military Training

The last area of application in training is for military purposes; primarily because it allows us to introduce an application of a multi-user 3D environment. These multi-user systems are otherwise known as a distributed interactive simulation (DIS). DIS is a standard for conducting real-time multi-platform war gaming using computers distributed worldwide and is especially used by military organizations. The standard was developed over a series of "DIS Workshops" at the Interactive Networked Simulation for Training symposium, held by the University of Central Florida's Institute for Simulation and Training (IST). The standard was fashioned after the SIMNET distributed interactive simulation protocol, developed in the mid 1980s for Defense Advanced Research Project Agency. SIMNET could potentially handle hundreds of online players and whereas realism, in the form of high fidelity graphics, was not available it was possible to have realistic interaction between 10s or even 100s of participants. For military purposes the benefits here are that users benefit from role playing, planning and operations within a safer environment.

ISSUES RELATING TO THE USE OF VR

Here we consider some of the key problems and drawbacks of using VR as an educational tool. We have identified the following three general and potentially serious drawbacks that have limited or restricted the general application of VR in education:

1. Potentially high financial costs of acquiring a system.
2. Lack of realism/fidelity/skill transfer issues.
3. Physical effects on end-users.

High Costs of Implementing VR Systems

The first of these relates to the high costs involved in developing and/or purchasing a VR system. As we have seen, VR systems consist of software for the control of the visualization, computers for running the software and technology for display and interaction. In the 1990s the relative novelty of the technology meant that relatively few ready-made systems existed and in order to develop a VR setup for an educational application one needed specialist knowledge for acquiring devices and integrating them and for developing control software. Display devices such as a head mounted displays were also expensive with relatively few manufacturers. The continued use of VR however has resulted in the economies of mass production and brought prices of some equipment down. Off-the-shelf educational systems also exist as we have noted and such systems are a cheaper and faster means of utilizing the technology because they do not require development time and development costs. While the technology is relatively new, however, it will remain a relatively expensive alternative to conventional methods of teaching.

Realism

In terms of realism and fidelity the question is how closely the VR simulation resembles the scenario being modeled or visualized. This issue relates both to visual realism and also realism of the dynamics and interaction. Initial visualizations used in VR were indeed rudimentary and lacked such realism. There were two reasons for this. Firstly, the techniques used to generate realistic graphics were quite limited and not fully developed. Secondly, in order to maintain interactivity, graphics display updates should be as high as possible (and certainly above 15 frames per second). However, the greater the realism displayed in the graphics, the greater the processing time required to render them. Most computer graphics methods use shaded polygonal approximations to represent smooth surfaces. To approximate a smooth surface we must therefore use many such polygons otherwise surfaces appear faceted and unrealistic. However, requiring a high polygon count means the computer must do more work and use more memory which in turn slows down the rate at which each frame of the simulation can be rendered. Slow update rates in turn result in sluggish display of movements and slow interactive feedback. Clearly there is a fine balance here between interactivity and realism and the original systems that were developed often sacrificed realism for interactivity.

Realism in visualization is important in as much as it can increase the engagement of the viewer, it can reduce perceptual ambiguity and it can provide redundancy of sensory information, resulting in a richer experience. Much progress has been achieved in the realism obtainable in graphical simulations recently and this is in most part due to the increasing popularity of computer games. The computer games industry has become extremely profitable and this has generated research and development in graphics algorithms and dedicated hardware for rendering graphics and simulating dynamics. This in turn has benefited VR simulations and VR systems. Indeed, while VR systems once required high-end computer support it is now possible to implement rendering, dynamics and interaction control on a single desktop machine. Where additional processing power is required (or the addition of haptics and 3D sound for example) clusters (connected groups) of computer workstations may be used. However, the balancing act between interactivity and realism in many respects still remains.

We believe that viewers can tolerate reduced graphics as long as the simulation is smooth and that there are no delays in interactivity. There are a number of reasons for this. Most importantly, it appears that viewers in a dynamic simulation can make use of dynamics cues (for example head movements) to provide supplementary cues (from motion parallax etc) whenever the depicted scene is ambiguous because of low quality graphics. Original computer games also employed rudimentary graphics and yet the dynamics of the game and absorption into the task made users disregard the low quality graphics. The decision, however, depends on the application. In surgical training, for example, fidelity and realism are of paramount importance. This is counteracted by that fact that the visual environments used in such training are relatively small scale, requiring smaller scenes and are therefore faster to generate and render.

Health Related Issues

Lastly, we consider human factors and physical side effects. These usually manifest themselves in immersive environments and in particular those in which the viewer has to wear a head mounted display. Original HMDs were so heavy that wearers had to be seated to use them. Modern HMDs are much lighter and less invasive and obtrusive although they are significantly heavier than, for example, stereo shutter glasses. HMD's usually consist of two small cathode ray tubes for stereo viewing together with supported optics that magnify the images in front of each eye. Original systems suffered from low resolution as well as heaviness although improvements in resolution are forthcoming. Some of the health related effects of wearing a HMD have been documented by Cobb and coworkers (Cobb et al., 1999). The heaviness of the HMD means that there is the possibility of head shifts within the device itself resulting is misaligned viewing. There is also the potential for fatigue after a user wears the display for a long period of time and, although the lenses in a HMD are close to the eye, there is also a reduced field of view which means that the wearer has to make more head movements than normal. Another issue is that of eye strain resulting from poor adjustments of the optics and other effects such as flicker in the display. Again this is significant only after prolonged usage and the only solution is to limit the amount of time the user spends wearing a HMD.

Another significant health related issue that is not limited to the use of HMD is that of simulator sickness. Simulation sickness, which includes nausea, disorientation and fatigue, usually arises where there is a mismatch between the subject's visual perception and their sense of movement (i.e. derived from the vestibular system). This can occur in wide screen displays as well as with HMDs. Ironically, the better the simulation graphics, the more likely it is that some people will experience simulator sickness. This is because higher quality graphics give a better feeling of movement and thus will be more likely to stimulate the vestibular reflex responses to this perceived movement. Although there is no definitive explanation for simulator sickness, or a remedy for its effects, studies have shown that duration of exposure should be kept to a minimum and that the probability of occurrence is reduced after repeated exposure (Kennedy et al., 2000). Other basic precautions that can be taken include reducing abrupt movements and avoiding changes to the pitch and roll of the visual field.

CONCLUSION

In this chapter we have attempted to convey the usefulness of VR as a technology suitable for education and training purposes. This usefulness is derived from the fact that VR systems are allow the student to experience a wide range of scenarios including those that are physically impossible to set up in the classroom. The range of subject matter that may be taught is enormous; ranging from the sciences and mathematics to history, archaeology and cultural heritage. VR provides the opportunity to visualize the macroscopic world as well as the microscopic world at a human scale thus providing the opportunity to instill an understanding that would be otherwise impossible to achieve using conventional methods.

We have seen that the experiential nature of VR is compatible with a constructivist view of education in which the student is encouraged to explore and experiment in order to form new ideas and concepts and in order to reformulate old ones. VR is a multi-sensory interactive medium which replaces the normal sensory inputs of the subject with artificial sensory signals generated by a computer. These aspects of VR make it ideal for users to initiate similar behaviors in learning as they would in the real world. We have seen that the normal method of deriving information from the world and in forming concepts is multi-sensory in nature with the different senses working together to maximize sensory input and reduce ambiguity. It is increasingly accepted that the provision of multi-sensory inputs allows for disambiguation in real life. Multi-sensory depiction moreover provides a richer environment for the formation of concepts. By using interactive multi-sensory visualization (in the broad sense), complex and abstract concepts may be taught to students. Furthermore, these concepts may be introduced at an even earlier age than is normally possible.

The potential of VR in education is demonstrated by the interest it has generated from researchers and organizations in this field. We have described several examples of the use of VR in educational contexts to give a flavor of the types of application and the subject matter covered. These are not exhaustive with many new applications being currently developed. As well as development of new systems for applied educational purposes, basic research is also being carried out on the effectiveness of using virtual environments and VR on learning and on other cognitive abilities such as memorization, spatial awareness and perception.

As with the introduction of all new technologies, the use of VR has revealed health related issues that have to be addressed. These include adverse effects that can potentially occur with long exposure or continued use. Original systems using HMDs were indeed uncomfortable, especially after continued use. There are also problems regarding simulator sickness. Although the latter occurs infrequently it must be addressed and basic guidelines for reducing its effect are being developed and will be improved in time. Other serious drawbacks include high costs and reduced realism. The former will constrain the general application of VR in schools at least until the technology becomes widespread and thus cheaper. As for realism, there have been many improvements in computer graphics over recent years that will permeate eventually into VR applications. As the technology improves we expect such issues will become less significant and allow for the more general application of this powerful medium.

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