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VIRTUAL REALITIES

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17.1 INTRODUCTION

Virtual realities are a set of emerging electronic technologies, with applications in a wide range of fields. This includes education, training, athletics, industrial design, architecture and landscape architecture, urban planning, space exploration, medicine and rehabilitation, entertainment, and model building and research in many fields of science (Aukstalnis, & Blatner, 1992; Earnshaw, Vince, Guedj, & Van Dam, 2001; Hamit, 1993; Helsel, 1992a, 1992b, 1992c; Helsel & Roth, 1991; Hillis, 1999; Mayr, 2001; Middleton, 1992; Pimentel & Teixiera, 1992; Rheingold, 1991; Vince, 1998). Virtual reality (VR) can be defined as a class of computer-controlled multisensory communication technologies that allow more intuitive interactions with data and involve human senses in new ways. Virtual reality can also be defined as an environment created by the computer in which the user feels present (Jacobson, 1993a). This technology was devised to enable people to deal with information more easily. VR provides a different way to see and experience information, one that is dynamic and immediate. It is also a tool for model-building and problem solving. VR is potentially a tool for experiential learning. The virtual world is interactive; it responds to the user's actions. Virtual reality evokes a feeling of immersion, a perceptual and psychological sense of being in the digital environment presented to the senses. The sense of presence or immersion is a critical feature distinguishing virtual reality from other types of computer applications. An excellent extensive set of web links for companies involved with the production of virtual reality technologies, applications, and consulting services is available at http://www.cyberedge.com/4f.html.

Virtual reality is a new type of computer tool that adds vast power to scientific visualization. Buxton (1992) explains that "Scientific visualization involves the graphic rendering of complex data in a way that helps make pertinent aspects and relationships within the data more salient to the viewer. The idea is to tailor the visual presentation to take better advantage of the human ability to recognize patterns and see structures" (p. 27). However, as Erickson (1993) explains, the word "visualization" is really too narrow when considering virtual reality. "Perceptualization" is probably more appropriate. With virtual reality, sound and touch, as well as visual appearance, may be used effectively to represent data. Perceptualization involving the sense of touch may include both tactile feedback (passive touch, feeling surfaces and textures) and haptic feedback (active touch, where there is a sense of force feedback, pressure, or resistance) (Brooks, 1988; Delaney, 2000; Dowding, 1991; Hon, 1991, 1992; Marcus, 1994; McLaughlin, Hespanha, & Sukhatme, 2001; Minsky, 1991; Sorid, 2000). The key to visualization is in representing information in ways that can engage any of our sensory systems and thus draw on our extensive experience in organizing and interpreting sensory input (Erickson, 1993).

The term Virtual Reality was coined by Jaron Lanier one of the developers of the first immersive interface devices (Hall, 1990). Virtual often denotes the computer-generated counterpart of a physical object: a "virtual room," a "virtual glove," a "virtual chair." Other terms such as "virtual worlds," "virtual environments," and "cyberspace" are used as global terms to identify this technology. For example, David Zelter of the MIT Media Lab suggests that the term "virtual environments" is more appropriate than virtual reality since virtual reality, like artificial intelligence, is ultimately unattainable (Wheeler, 1991). But virtual reality remains the most commonly used generic term (although many researchers in the field vehemently dislike this term).

Virtual reality provides a degree of interactivity that goes beyond what can be found in traditional multimedia programs. Even a sophisticated multimedia program, such as the Palenque DVI program, which features simulated spatial exploration of an ancient Mayan pyramid, is limited to predetermined paths. With a virtual world you can go anywhere and explore any point of view.

Virtual reality emerged as a distinctive area of computer interfaces and applications only during the 1980s. Any assessment of this technology must keep in mind that it is at an early stage of development and the technology is evolving rapidly. Many exciting applications have been developed. Furthermore, researchers are beginning to collect valuable information about the usefulness of virtual reality for particular applications, including education and training. And a great deal of theory building has been initiated concerning this emerging technology and its potentials in education and training.

17.2 HISTORICAL BACKGROUND

Woolley (1992) explains that, "Trying to trace the origins of the idea of virtual reality is like trying to trace the source of a river. It is produced by the accumulated flow of many streams of ideas, fed by many springs of inspiration." One forum where the potentials of virtual reality have been explored is science fiction (Bradbury, 1951; W. Gibson, 1986; Harrison, 1972; Stephenson, 1992; Sterling, 1994), together with the related area of scenario building (Kellogg, Carroll, & Richards, 1991).

The technology that has led up to virtual reality technology—computer graphics, simulation, human-computer interfaces, etc.—has been developing and coalescing for over three decades. In the 1960s, Ivan Sutherland created one of the pioneering virtual reality systems which incorporated a head-mounted display (Sutherland, 1965, 1968). Sutherland's head-mounted display was nicknamed 'The Sword of Damocles' because of its strange appearance. Sutherland did not continue with this work because the computer graphics systems available to him at that time were very primitive. Instead, he shifted his attention to inventing many of the fundamental algorithms, hardware, and software of computer graphics (McGreevy, 1993). Sutherland's work provided a foundation for the emergence of virtual reality in the 1980s. His early work inspired others, such as Frederick P. Brooks, Jr., of the University of North Carolina, who began experimenting with ways to accurately simulate and display the structure of molecules. Brooks' work developed into a major virtual reality research initiative at the University of North Carolina (Hamit, 1993; Rheingold, 1991; Robinett, 1991).

In 1961, Morton Heilig, a filmmaker, patented Sensorama, a totally mechanical virtual reality device (a one-person theater) that included three-dimensional, full color film together with sounds, smells, and the feeling of motion, as well as the sensation of wind on the viewer's face. In the Sensorama, the user could experience several scenarios, including a motorcycle ride through New York, a bicycle ride, or a helicopter ride over Century City. The Sensorama was not a commercial success but it reflected tremendous vision, which has now returned with computer-based rather than mechanical virtual reality systems (Hamit, 1993; Rheingold, 1991).

During the 1960s and 1970s, the Air Force established a laboratory at Wright–Patterson Air Force Base in Ohio to develop flight simulators and head-mounted displays that could facilitate learning and performance in sophisticated, high-workload, high-speed military aircraft. This initiative resulted in the Super-Cockpit that allows pilots to fly ultra-high-speed aircraft using only head, eye, and hand movements. The director of the Super-Cockpit project, Tom Furness, went on to become the director of the Human Interface Technology Lab at the University of Washington, a leading VR R&D center with a strong focus on education. And VR research continues at Wright–Patterson Air Force Base (Amburn, 1993; Stytz, 1993, 1994). Flight simulators have been used extensively and effectively for pilot training since the 1920s (Bricken & Byrne, 1993; Lauber & Fouchee, 1981; Woolley, 1992).

In the 1960s, GE developed a simulator that was adapted for lunar mission simulations. It was primarily useful for practicing rendezvous and especially docking between the lunar excursion module (LEM) and the command module (CM). This simulator was also adapted as a city planning tool in a project at UCLA—the first time a simulator had been used to explore a digital model of a city (McGreevy, 1993).

In the 1970s, researchers at MIT developed a spatial data management system using videodisc technology. This work resulted in the *Aspen Movie Map* (MIT, 1981; Mohl, 1982), a recreation of part of the town of Aspen, Colorado. This "map" was stored on an optical disk that gave users the simulated experience of driving through the town of Aspen, interactively choosing to turn left or right to pursue any destination (within the confines of the model). Twenty miles of Aspen streets were photographed from all directions at 10-foot intervals, as was every possible turn. Aerial views were also included. This photo-based experiment proved to be too complicated (i.e., it was not user friendly) so this approach was not used to replicate larger cities, which entail a higher degree of complexity (Hamit, 1993).

Also in the 1970s, Myron Krueger began experimenting with human–computer interaction as a graduate student at the University of Wisconsin-Madison. Krueger designed responsive but nonimmersive environments that combined video and computer. He referred to this as Artificial Reality. As Krueger (1993) explains,

> . . . you are perceived by a video camera and the image of your body is displayed in a graphic world. The juxtaposition of your image with graphic objects on the screen suggests that perhaps you could affect the graphic objects. This expectation is innate. It does not need to be explained. To take advantage of it, the computer continually analyzes your image with respect to the graphic world. When your image touches a graphic object, the computer can respond in many ways. For example, the object can move as if pushed. It can explode, stick to your finger, or cause your image to disappear. You can play music with your finger or cause your image to disappear. The graphic world need not be realistic. Your image can be moved, scaled, and rotated like a graphic object in response to your actions or simulated forces. You can even fly your image around the screen. (p. 149)

The technologies underlying virtual reality came together at the NASA Ames Lab in California during the mid-1980s with the development of a system that utilized a stereoscopic head-mounted display (using the screens scavenged from two miniature televisions) and the fiber-optic wired glove interface device. This breakthrough project at NASA was based on a long tradition of developing ways to simulate the environments and the procedures that astronauts would be engaged in during space flights such as the GE simulator developed in the 1960s (McGreevy, 1993).

During the late 1980s and early 1990s, there was widespread popular excitement about virtual reality. But the great expense of the technology and its inability to meet people's high expectations at this early stage of development, led to a diminution of excitement and visibility that coincided with the emergence of the World Wide Web. Although the hype for this technology receded, eclipsed by enthusiasm for the World Wide Web, serious research and development has continued. Rosenblum, Burdea and Tachi (1998) describe this transition to a new phase:

Unfortunately, the excitement about virtual reality turned into unrealizable "hype". The movie *Lawnmower Man* portrayed a head-mounted display raising a person's IQ beyond the genius level. Every press report on the subject included the topic of cybersex (which still pervades TV commercials). Fox TV even aired a series called "VR5". Inevitably, the public (and, worse, research sponsors) developed entirely unrealistic expectations of the possibilities and the time scale for progress.

Many advances occurred on different fronts, but they rarely synthesized into full-scale systems. Instead, they demonstrated focused topics such as multiresolution techniques for displaying millions of polygons, the use of robotics hardware as force-feedback interfaces, the development of 3D audio, or novel interaction methods and devices. So, as time passed with few systems delivered to real customers for real applications, attention shifted elsewhere. Much of the funding for VR began to involve network issues for telepresence (or telexistence) that would enable remote users, each with their own VR system, to interact and collaborate. Medical, military, and engineering needs drove these advances.

As Rosenblum et al (1998) point out, the field of virtual reality faces difficult research problems involving many disciplines. Thus, it realistically, major progress will require decades rather than months. The area of systems, in particular, will require the synthesis of numerous advances. According to Rosenblum et al., "the next advance depends on progress by non-VR researchers. Thus, we may have to wait for the next robotics device, advanced flat-panel display, or new natural language technique before we can take the next step in VR."

As Rosenblum et al. (1998) explain, there have been important developments in the areas of multiresolution rendering algorithms, texture mapping, and image rendering. Both texture mapping and image rendering benefited from the dramatic improvements in computer processing speeds that took place over the past decade. Advances have also taken place in advances have taken place in lighting, shadowing, and other computer graphics algorithms for realistic rendering (Rosenblum et al., 1998). There have also been improvements in commercial software platforms for building VR computer application software. This includes SGI Performer, DIVE, Bamboo, Cavern, and Spline. In terms of VR display technologies, Rosenblum et al. report,

> The 1990s saw a paradigm shift to projective displays that keep viewers in their natural environment. The two most prominent of these, the Responsive Workbench and the CAVE, use see-though, stereoscopic shutter glasses to generate 3D images. Current advances in generating lighter, sharper HMDs let low-budget VR researchers use them. (p. 22)

Rosenblum et al. point out that R&D concerning other interfaces and nonvisual modalities (acoustics, haptics, and olfactory) has lagged behind (Delaney, 2000; Sorid, 2000). Improved navigational techniques are needed. Overall, Rosenblum et al. recommend,

> We know how to use wands, gestures, speech recognition, and even natural language. However, 3D interaction is still fighting an old war. We need multimodal systems that integrate the best interaction methods so that, someday, 3D VR systems can meet that Holy Grail of the human–computer-interface community—having the computer successfully respond to "Put that there."

17.3 DIFFERENT KINDS OF VIRTUAL REALITY

There is more than one type of virtual reality. Furthermore, there are different schema for classifying various types of virtual reality. Jacobson (1993a) suggests that there are four types of virtual reality: (1) immersive virtual reality, (2) desktop virtual reality (i.e., low-cost homebrew virtual reality), (3) projection virtual reality, and (4) simulation virtual reality.

Thurman and Mattoon (1994) present a model for differentiating between different types of VR, based on several "dimensions." They identify a "verity dimension" that helps to differentiate between different types of virtual reality, based on how closely the application corresponds to physical reality. They propose a scale showing the verity dimension of virtual realities (see Fig. 17.1). According to Thurman and Mattoon (1994),

> The two end points of this dimension—physical and abstract—describe the degree that a VR and entities within the virtual environment have the characteristics of reality. On the left end of the scale, VRs simulate or mimic real-world counterparts that correspond to natural laws. On the right side of the scale, VRs represent abstract ideas which are completely novel and may not even resemble the real world. (p. 57).

Thurman and Mattoon (1994) also identify an "integration dimension" that focuses on how humans are integrated into the computer system. This dimension includes a scale featuring three categories: batch processing, shared control, and total inclusion. These categories are based on three broad eras of human–computer integration, culminating with VR—total inclusion. A third dimension of this model is interface, on a scale ranging between natural and artificial. These three dimensions

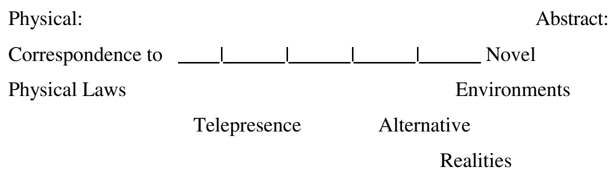

FIGURE 17.1. Thurston and Mattoon's verity scale for virtual reality (adapted from Thurston and Mattoon, 1994).

are combined to form a three-dimensional classification scheme for virtual realities. This model provides a valuable tool for understanding and comparing different virtual realities.

Another classification scheme has been delineated by Brill (1993, 1994b). This model will be discussed in detail here together with some new types of virtual reality that have emerged. Brill's model features seven different types of virtual reality: (1) Immersive first-person, (2) Through the window, (3) Mirror world, (4) Waldo World, (5) Chamber world, (6) Cab simulator environment, and (7) Cyberspace. Some of Brill's categories of virtual reality are physically immersive and some are not. The key feature of all virtual reality systems is that they provide an environment created by the computer or other media where the user feels present, that is, immersed physically, perceptually, and psychologically. Virtual reality systems enable users to become participants in artificial spaces created by the computer. It is important to note that not all virtual worlds are three-dimensional. This is not necessary to provide an enriching experience. And to explore a virtual world, the user doesn't have to be completely immersed in it: first-person (direct) interaction, as well as second-person and third-person interaction with the virtual world are all possible (Laurel, 1991; Norman, 1993), as the following discussion indicates.

The new types of virtual reality that will be discussed are: (1) the VisionDome, and (2) the Experience Learning System under development at the Institute For Creative Technologies (ICT) at the University of Southern California. Not everyone would agree that these technologies constitute virtual reality, but they all appear to be part of the initiative to implement computer-controlled, multisensory, immersive experiences. And these technologies all have important implications for education and training.

To summarize, we will be examining 10 types of virtual reality: (1) Immersive first-person, (2) Augmented reality (a variation of immersive reality), (3) Through the window, (4) Mirror world, (5) Waldo World (Virtual characters), (6) Chamber world, (7) Cab simulator environment, (8) Cyberspace, (9) the VisionDome, and (10) the Experience Learning System.

17.3.1 Immersive First-Person

Usually when we think of virtual reality, we think of immersive systems involving computer interface devices such as a head-mounted display (HMD), fiber-optic wired gloves, position tracking devices, and audio systems providing 3-D (binaural) sound. Immersive virtual reality provides an immediate, first-person experience. With some applications, there is a treadmill interface to simulate the experience of walking through virtual space. And in place of the head-mounted display, there is the BOOM viewer from Fake Space Labs which hangs suspended in front of the viewer's face, not on it, so it is not as heavy and tiring to wear as the head-mounted display. In immersive VR, the user is placed inside the image; the generated image is assigned properties which make it look and act real in terms of visual perception and in some cases aural and tactile perception (Begault, 1991; Brooks, 1988; Gehring, 1992; Isdale, 2000b; Markoff, 1991; McLaughlin, Hespanha, & Sukhatme, 2001; Minsky, 1991; Trubitt, 1990). There is even research on creating virtual smells; an application to patent such a product has been submitted by researchers at the Southwest Research Institute (Varner, 1993).

Children are already familiar with some of this technology from video games. Mattel's Power Glove^{TM}, used as an interface with Nintendo Games, is a low-cost design based on the DataGlove^{TM}from VPL Research, Inc. The Power Glove^{TM} failed as a toy, but it achieved some success as an interface device in some low-cost virtual reality systems in the early 1990s, particularly in what are known as "homebrew" or "garage" virtual reality systems (Jacobson, 1994). Inexpensive software and computer cards are available that make it possible to use the Power Glove^{TM} as an input device with Amiga, Macintosh or IBM computers (Eberhart, 1993; Hollands, 1995; Jacobson, 1994; Stampe, Roehl, & Eagan, 1993). Robin Hollands (1996) published *The Virtual Reality Homebrewer's Handbook*. In addition, there are many homebrew resources on the World Wide Web, including the web sites:

- http://www.cms.dmu.ac.uk/~cph/hbvr.html.
- http://www.geocities.com/mellott124/
- http://www.phoenixgarage.org/homevr/

Homebrew VR has expanded to include web-based resources such as VRML. The low cost of homebrew virtual reality makes it accessible to educators.

17.3.2 Augmented Reality

A variation of immersive virtual reality is **Augmented Reality** where a see-through layer of computer graphics is superimposed over the real world to highlight certain features and enhance understanding (Isdale, 2001). Azuma (1999) explains, "Augmented Reality is about augmentation of human perception: supplying information not ordinarily detectable by human senses." And Behringer, Mizell, and Klinker (2001) explain that "AR technology provides means of intuitive information presentation for enhancing the situational awareness and perception of the real world. This is achieved by placing virtual objects or information cues into the real world as the user perceives it."

According to Isdale (2001), there are four types of augmented reality (AR) that can be distinguished by their display type, including:

1. Optical See-Through AR uses a transparent Head Mounted Display (HMD) to display the virtual environment (VE) directly over the real wold.
2. Projector Based AR uses real world objects as the projection surface for the VE.
3. Video See-Through AR uses an opaque HMD to display merged video of the VE with and view from cameras on the HMD.
4. Monitor-Based AR also uses merged video streams but the display is a more conventional desktop monitor or a hand held display. Monitor-Based AR is perhaps the least difficult to set up since it eliminates HMD issues.

Augmented reality has important potential in athletic training. Govil, You, and Neumann (2000) describe a video-based augmented reality golf simulator. The "Mixed Reality Lab" in Yokohama has developed an augmented reality hockey game (Satoh, Ohshima, Yamamoto, & Tamura, 1998). Players can share a physical game field, mallets, and a virtual puck to play an air-hockey game.

One important application of augmented reality is spatial information systems for exploring urban environments as well as planetary environments in space. In particular, a research initiative concerning "mobile augmented reality"—using mobile and wearable computing systems—is underway at Columbia University (Feiner, MacIntyre, Höllerer, & Webster, 1997; Höllerer, Feiner, & Pavlik, 1999; Höllerer, Feiner, Terauchi, Rashid, & Hallaway, 1999).

Another important application of augmented reality is in industrial manufacturing, where certain controls can be highlighted, for example the controls needed to land an airplane. Groups at Boeing are exploring these types of applications. Behringer, Mizell, and Klinker (2001) report that David Mizell has conducted a pilot experiment of an application of AR in the actual industrial airplane construction (specifically, the construction of wirebundle connections). This research found that with the aid of the AR system, a nontrained worker could assemble a wirebundle—faster than a trained worker who was not using this system. Behringer et al. (2001) report that Dirk Reiners developed an AR system that can be used for the car manufacturing process. Based on visual marker tracking, this system guides the user through an assembly sequence of a door-lock assembly process. Reiners' system requires an HMD and is running on a SGI O2 (180 MHz) for tracking and an SGI Onyx RE2 for rendering.

Many medical applications of augmented reality are under development (Isdale, 2001; Taubes, 1994b). Recently, for the first time, a surgeon conducted surgery to remove a brain tumor using an augmented reality system; a video image superimposed with 3-D graphics helped the doctor to see the site of the operation more effectively (Satava, 1993).

Similar to this, Azuma (1999) explains that

> . . . applications of this technology use the virtual objects to aid the user's understanding of his environment. For example, a group at UNC scanned a fetus inside a womb with an ultrasonic sensor, then overlayed a three-dimensional model of the fetus on top of the mother's womb. The goal is to give the doctor "X-ray vision," enabling him to "see inside" the womb. Instructions for building or repairing complex equipment might be easier to understand if they were available not in the form of manuals with text and 2D pictures, but as 3D drawings superimposed upon the machinery itself, telling the mechanic what to do and where to do it.

An excellent resource is the Augmented Reality web page at http://www.cs.rit.edu/~jrv/research/ar/.

Azuma (1999) reports,

> Unfortunately, registration is a difficult problem, for a number of reasons. First, the human visual system is very good at detecting even small misregistrations, because of the resolution of the fovea and the sensitivity of the human visual system to differences. Errors of just a few pixels are noticeable. Second, errors that can be tolerated in Virtual Environments are not acceptable in Augmented Reality. Incorrect viewing parameters, misalignments in the Head-Mounted Display, errors in the head-tracking system, and other problems that often occur in HMD-based systems may not cause detectable problems in Virtual Environments, but they are big problems in Augmented Reality. Finally, there's system delay: the time interval between measuring the head location to superimposing the corresponding graphic images on the real world. The total system delay makes the virtual objects appear to "lag behind" their real counterparts as the user moves around. The result is that in most Augmented Reality systems, the virtual objects appear to "swim around" the real objects, instead of staying registered with them. Until the registration problem is solved, Augmented Reality may never be accepted in serious applications. (p. 2)
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> Azuma's research is focused upon improving registration in augmented reality. He has developed calibration techniques, used inertial sensors to predict head motion, and built a real system that implements these improved techniques. According to Azuma, "I believe this work puts us within striking distance of truly accurate and robust registration." (p. 3).

For information about Azuma's research at the University of North Carolina, and copies of his publications (Azuma, 1993, 1997; Azuma & Bishop, 1994, 1995), go to http://www.cs.unc.edu/~azuma/azuma-AR.html. Milgram and Kishino (1994) present an excellent taxonomy of mixed reality. And Isdale's (2001) article, available on the web at http://www.vrnews.com/issuearchive/vrn0905/vrn0905tech.html, presents a comprehensive overview of developments in artificial reality/mixed reality.

17.3.3 Through the Window

With this kind of system, also known as "desktop VR," the user sees the 3-D world through the window of the computer screen and navigates through the space with a control device such as a mouse (Fisher & Unwin, 2002). Like immersive virtual reality, this provides a first-person experience. One low-cost example of a Through the window virtual reality system is the 3-D architectural design planning tool *Virtus WalkThrough* that makes it possible to explore virtual reality on a Macintosh or IBM computer. Developed as a computer visualization tool to help plan complex high-tech filmmaking for the movie *The Abyss, Virtus WalkThrough* is now used as a set design and planning tool for many Hollywood movies and advertisements as well as architectural planning and educational applications. A similar, less expensive and less sophisticated program that is starting to find use in elementary and secondary schools is *Virtus VR* (Law, 1994; Pantelidis, nd).

The Virtus programs are still available, but now a number of other low-cost virtual reality programs are available for educational applications. This includes web-based applications based upon the Virtual Reality Modeling Language (VRML) and other tools, including Java-based applications. It helps that computers have improved dramatically in power and speed since the early 1990s.

Another example of Through the window virtual reality comes from the field of dance, where a computer program called *LifeForms* lets choreographers create sophisticated human motion animations. *LifeForms* permits the user to access "shape" libraries of figures in sitting, standing, jumping, sports poses, dance poses, and other positions. *LifeForms* supports the compositional process of dance and animation so that choreographers can create, fine-tune, and plan dances "virtually" on the computer. The great modern dancer and choreographer Merce Cunningham has begun using *LifeForms* to choreograph new dances (Calvert, Bruderlin, Dill, Schiphorst, & Welman, 1993; Schiphorst, 1992). Using *LifeForms,* it is possible to learn a great deal about the design process without actually rehearsing and mounting a performance. The program LifeForms is now available commercially through Credo-Interactive (http://www.credo-interactive.com/products/index.html), which offers several different low-end VR software tools.

The field of forensic animation is merging with Through the window VR (Baird, 1992; Hamilton, 1993). Here, dynamic computer animations are used to recreate the scene of a crime and the sequence of events, as reconstructed through analysis of the evidence (for example, bullet speed and trajectory can be modeled). These dynamic visualizations are used in crime investigations and as evidence in trials. The London Metropolitan Police has used VR to document witnesses' descriptions of crime scenes. Similarly, the FBI has used *Virtus WalkThrough* as a training tool at the FBI Academy and as a site visualization tool in hostage crisis situations.

17.3.4 Mirror World

In contrast to the first-person systems described above, Mirror Worlds (Projected Realities) provide a second-person experience in which the viewer stands outside the imaginary world, but communicates with characters or objects inside it. Mirror world systems use a video camera as an input device. Users see their images superimposed on or merged with a virtual world presented on a large video monitor or video projected image. Using a digitizer, the computer processes the users' images to extract features such as their positions, movements, or the number of fingers raised. These systems are usually less expensive than total immersion systems, and the users are unencumbered by head gear, wired gloves, or other interfaces (Lantz, 1992). Four examples of a Mirror World virtual reality system are: (1) Myron Krueger's artificial reality systems such as VIDEOPLACE, (2) the Mandala system from the Vivid Group (http://www.vividgroup.com/), created by a group of performance artists in Toronto, (3) the InView system which has provided the basis for developing entertainment applications for children, including a TV game show, and (4) Meta Media's wall-sized screen applications such as shooting basketball hoops and experiencing what happens when you try to throw a ball under zero gravity conditions (Brill, 1995; O'Donnell, 1994; Wagner, 1994).

In Krueger's system, users see colorful silhouettes of their hands or their entire bodies. As users move, their silhouette mirror images move correspondingly, interacting with other silhouette objects generated by computer. Scale can be adjusted so that one person's mirror silhouette appears very small by comparison with other people and objects present in the VIDEOPLACE artificial world. Krueger suggests that, "In artificial realities, the body can be employed as a teaching aid, rather than suppressed by the need to keep order. The theme is not learning by doing in the Dewey sense, but instead doing is learning, a completely different emphasis" (Krueger, 1993, p. 152)."

The Mandala and InView systems feature a video camera above the computer screen that captures an image of the user and places this image within the scene portrayed on the screen using computer graphics. There are actually three components: (1) the scene portrayed (usually stored on videodisc), (2) the digitized image of the user, and (3) computer graphics-generated objects that appear to fit within the scene that are programmed to be interactive, responding to the "touch" of the user's image. The user interacts with the objects on the screen; for example, to play a drum or to hit a ball. (Tactile feedback is not possible with this technique.) This type of system is becoming popular as an interactive museum exhibit. For example, at the National Hockey Museum, a Mandala system shows you on the screen in front of the goalie net, trying to keep the "virtual" puck out of the net. Recently, a Mandala installation was completed for Paramount Pictures and the Oregon Museum of Science and Industry that is a simulation of Star Trek: The Next Generation's holodeck.

> Users step into an actual set of the transporter room in the real world and view themselves in the "Star Trek virtual world" on a large screen in front of them. They control where they wish to be transported and can interact with the scene when they arrive. For example, users could transport themselves to the surface of a planet, move around the location, and manipulate the objects there. Actual video footage from the television show is used for backgrounds and is controlled via videodisc. (Wyshynski & Vincent, 1993, p. 130)

Another application is an experimental teleconferencing project—"Virtual Cities"—for children developed by the Vivid Group in collaboration with the Marshal McLuhan Foundation (Mandala VR News, 1993). In this application, students in different cities around the world are brought into a networked common virtual environment using videophones.

The Meta Media VR system is similar to the Mandala and InView systems, but the image is presented on a really large wall-sized screen, appropriate for a large audience. Applications of this system, such as Virtual Hoops, are finding widespread use in entertainment and in museums (Brill, 1995). One fascinating aspect of this type of VR mirror world is that it promotes a powerful social dimension: people waiting in the bleachers for a turn at Virtual Hoops cheer the player who makes a hoop—it's very interactive in this way. And preliminary evidence suggests that learners get more caught up in physics lessons presented with this technology, even when they are only sitting in the audience (Wisne, 1994).

17.3.5 Waldo World (Virtual Characters)

This type of virtual reality application is a form of digital puppetry involving real-time computer animation. The name

"Waldo" is drawn from a science fiction story by Robert Heinlein (1965). Wearing an electronic mask or body armor equipped with sensors that detect motion, a puppeteer controls, in real-time, a computer animation figure on a screen or a robot. This type of technology has come to be known more commonly as "virtual characters" as well as "virtual animation" rather than Waldo World VR.

An early example of this type of VR application is the Virtual Actors™ developed by SimGraphics Engineering (Tice & Jacobson, 1992). These are computer-generated animated characters controlled by human actors, in real-time. To perform a Virtual Actor (VA), an actor wears a "Waldo" which tracks the actor's eye brows, cheek, head, chin, and lip movements, allowing them to control the corresponding features of the computer generated character with their own movements. For example, when the actor smiles, the animated character smiles correspondingly. A hidden video camera aimed at the audience is fed into a video monitor backstage so that the actor can see the audience and "speak" to individual members of the audience through the lip-synced computer animation image of the character on the display screen. This digital puppetry application is like the Wizard of Oz interacting with Dorothy and her companions: "Pay no attention to that man behind the curtain!"

The Virtual Actor characters include Mario in Real Time (MIRT), based on the hero of the Super Mario Nintendo games, as well as a Virtual Mark Twain. MIRT and the Virtual Mark Twain are used as an interactive entertainment and promotional medium at trade shows (Tice & Jacobson, 1992). Another Virtual Actor is Eggwardo, an animation character developed for use with children at the Loma Linda Medical Center (Warner, 1993; Warner & Jacobson, 1992). Neuroscientist Dave Warner (1993) explains:

> We brought Eggwardo into the hospital where he interacted with children who were terminally ill. Some kids couldn't even leave their beds so Eggwardo's image was sent to the TV monitors above their beds, while they talked to the actor over the phone and watched and listened as as Eggwardo joked with them and asked how they were feeling and if they'd taken their medicine. The idea is to use Eggwardo, and others like him, to help communicate with therapy patients and mitigate the fears of children who face surgery and other daunting medical procedures.

Another type of Waldo World has been developed by Ascension, using its Flock of Birds™ positioning system (Scully, 1994). This is a full-body waldo system that is not used in real time but as a foundation for creating animated films and advertisements.

Manners (2002) describes how this type of technology is used to create virtual characters for TechTV cable television (http://www.techtv.com). TechTV features two virtual characters, Tilde and Dash, that are driven by software developed by the French company MediaLab (http://www.medialabtechno.com). Manners explains that the performances constitute an impressive piece of choreographed collaboration between the body performers and the voice artists who read the scripts since the two must perform in coordination.

17.3.6 Chamber World

A Chamber World is a small virtual reality projection theater controlled by several computers that gives users the sense of freer movement within a virtual world than the immersive VR systems and thus a feeling of greater immersion. Images are projected on all of the walls that can be viewed in 3-D with a head-mounted display showing a seamless virtual environment. The first of these systems was the CAVE, developed at the Electronic Visualization Laboratory at the University of Illinois (Cruz-Nierna, 1993; DeFanti, Sandin, & Cruz-Neira, 1993; Sandin, Defanti, & Cruz-Nierna, 2001; Wilson, 1994). Another Chamber World system—EVE: Extended Virtual Environment—was developed at the Kernforschungszntrum (Nuclear Research Center) Karlsruhe in collaboration with the Institut fur Angewandte Informatik (Institute of Applied Informatics) in Germany (Shaw, 1994; Shaw & May, 1994). The recently opened Sony Omnimax 3-D theaters where all members of the audience wear a head-mounted display in order to see 3-D graphics and hear 3-D audio is another—albeit much larger—example of this type of virtual reality (Grimes, 1994).

The CAVE is a 3-D real-projection theater made up of three walls and a floor, projected in stereo and viewed with "stereo glasses" that are less heavy and cumbersome than many other head-mounted displays used for immersive VR (Cruz-Nierna, 1993; Rosenblum et al., 1998; Wilson, 1994). The CAVE provides a first-person experience. As a CAVE viewer moves within the display boundaries (wearing a location sensor and 3-D glasses), the correct perspective and stereo projections of the environment are updated and the image moves with and surrounds the viewer. Four Silicon Graphics computers control the operation of the CAVE, which has been used for scientific visualization applications such as astronomy.

17.3.7 Cab Simulator Environment

This is another type of first-person virtual reality technology that is essentially an extension of the traditional simulator. Hamit (1993) defines the cab simulator environment as:

> Usually an entertainment or experience simulation form of virtual reality, which can be used by a small group or by a single individual. The illusion of presence in the virtual environment is created by the use of visual elements greater than the field of view, three-dimensional sound inputs, computer-controlled motion bases and more than a bit of theatre. (p. 428).

Cab simulators are finding many applications in training and entertainment. For example, AGC Simulation Products has developed a cab simulator training system for police officers to practice driving under high-speed and dangerous conditions (Flack, 1993). SIMNET is a networked system of cab simulators that is used in military training (Hamit, 1993; Sterling, 1993). Virtual Worlds Entertainment has developed BattleTech, a location-based entertainment system where players in six cabs are linked together to play simulation games (Jacobson, 1993b). An entertainment center in Irvine, California called Fighter Town features actual flight simulators as "virtual environments." Patrons pay for a training session where they learn how to operate the simulator and then they get to go through a flight scenario.

17.3.8 Cyberspace

The term cyberspace was coined by William Gibson in the science fiction novel *Neuromancer* (1986), which describes a future dominated by vast computer networks and databases. Cyberspace is a global artificial reality that can be visited simultaneously by many people via networked computers. Cyberspace is where you are when you're hooked up to a computer network or electronic database—or talking on the telephone. However, there are more specialized applications of cyberspace where users hook up to a virtual world that exists only electronically; these applications include text-based MUDs (Multi-User Dungeons or Multi-User Domains) and MUSEs (Multi-User Simulated Environments). One MUSE, Cyberion City, has been established specifically to support education within a constructivist learning context (Rheingold, 1993). Groupware, also known as computer-supported cooperative work (CSCW), is another type of cyberspace technology (Baecker, 1993; Bruckman & Resnick, 1993; Coleman, 1993; Miley, 1992; Schrage, 1991; Wexelblat, 1993).

The past decade has seen the introduction of a number of innovations that are changing the face of cyberspace. The introduction of the World Wide Web during the early 1990s has extended the realms of cyberspace to include a vast area where, in addition to text, graphics, audio, multimedia, video and streaming media are all readily available throughout much of the world. And the increasing availability of wireless technologies and cable-based Internet access are extending access to cyberspace. For example, in Africa, where land-based telephone networks are not well developed, wireless cell phones offer an alternative. They have become very widespread in some parts of Africa. Wireless Internet access will not be far behind.

Habitat, designed by Chip Morningstar and F. Randall Farmer (1991, 1993) at Lucasfilm, was one of the first attempts to create a large-scale, commercial, many-user, graphical virtual environment. Habitat is built on top of an ordinary commercial on-line service and uses low-cost Commodore 64 home computers to support user interaction in a virtual world. The system can support thousands of users in a single shared cyberspace. Habitat presents its users with a real-time animated view into an online graphic virtual world. Users can communicate, play games, and go on adventures in Habitat. There are two versions of Habitat in operation, one in the United States and another in Japan.

Similar to this, researchers at the University of Central Florida have developed ExploreNet, a low-cost 2-D networked virtual environment intended for public education (Moshell & Dunn-Roberts, 1993, 1994a, 1994b). This system is built upon a network of 386 and 486 IBM PCs. ExploreNet is a role-playing game. Students must use teamwork to solve various mathematical problems that arise while pursuing a quest. Each participant has an animated figure on the screen, located in a shared world. When one student moves her animated figure or takes an action, all the players see the results on the networked computers, located in different rooms, schools, or even cities. ExploreNet is the basis for a major research initiative.

Habitat and ExploreNet are merely early examples of graphical user environments. With the emergence of the World Wide Web, a wealth of applications have been developed, including a number of educational applications.

Online video games such as Ultima Online (http://www.uo.com/), are as well as other types of online communities designed with graphical user interfaces are now a big part of the Internet. Ultima Online provides a fascinating case study in how people respond to cyberspace—and how much cyberspace can be just like the real world—especially within the framework of virtual reality. Dell Computer Corporation (1999) explains that players buy the game software and set up an account at the Ultima Online Web site for a monthly fee. Players choose a home "shard," or city and create up to six characters, selecting the occupations, skills and physical appearance for each. Characters start off in relative poverty, having 100 gold pieces in their pockets. From there on, the characters are free to roam—to barter for goods, talk to other players (via text bubbles) or make goods to sell to get more gold—all the while building up their powers and strength to the point where they can, among other chivalrous duties, slay mystical beings. It takes time to develop a truly memorable character and to establish a virtual home and a thriving virtual business. To bypass the effort of establishing wealth and real estate online, players can make deals with other players in the real world, via the Ebay auction site, to buy virtual real estate for real money.

As Dell Computer Corporation (1999) explains:

> It started with a Texan firefighter named Dave Turner, who went by the online moniker Turbohawk. Turner decided he'd been spending too much time playing the game. So he put his account—his veteran character—up for sale on Ebay, asking for $39. It sold for $521. This was in early 1999. Within days, hundreds of other Ultima characters and property and, eventually, gold caches and other accessories were being bought and sold. One account went for $4,000.
>
> Daren Sutter, for one, put a large tower on the auction block last August. He made 600 bucks on the sale. He's been prospecting ever since. On any given day, he will have a couple of dozen items up for auction. These are mostly lump sums of gold in parcels of 500,000 or 1 million units. At present the market value is about $20 to $30 per half-million units. A "one million uo gold!" check sold recently for $71. (Buyers send Sutter hard currency, and Sutter leaves gold checks for them at virtual banks in Britannia.) This puts the exchange rate at around 15,000 to 25,000 Ultima Online gold units to the U.S. dollar, making a unit of Ultima gold nearly equal in value to the Vietnamese dong.
>
> It raises the question: who are these people who figure that a unit of currency in a fictional online world is worth about the same as actual Vietnamese money? Sutter says there are two kinds: impatient newcomers and upwardly mobile longtime players. The former, Sutter reckons, "just want to jump into the game with good weapons and armor and have a good-sized home for their character." The latter group is closer in mindset to that of overambitious parents. "A lot of people," says Sutter, "want to give their characters big homes and unique items that other characters don't have. Just like real life, people just want to get ahead."
>
> And if you're starting to think that the operative phrase here is "just like real life" (if you're wondering, that is, if maybe some of these 60-hours-a-week Ultima junkies no longer even notice the distinction), then check out the Sunday-real-estate-supplement jargon used in pitches

> for Ultima property. (Britannia, fantasy world or not, has a finite amount of land, so real estate is in particularly high demand.) "We all know real estate is hard to find," begins the description of one tower, "and a great house in a great location even harder to find." Another reads, "a hop skip from the city of Trinsic-perfect for all you miners out there." Elsewhere, a suit of "Rare Phoenix Armor" is described as a "status-symbol piece." It sold for $445. It was no aberration: there are literally hundreds of Ultima-related trades made every day, and the winning bids are in the hundreds of dollars as often as not. To be sure, this is not some ready-for-Letterman, stupid-human trick. Rather, it is a high-end niche market.

Another example of cyberspace is the Army's SIMNET system. Tank simulators (a type of cab simulator) are networked together electronically, often at different sites, and wargames are played using the battlefield modeled in cyberspace. Participants may be at different locations, but they are "fighting" each other at the same location in cyberspace via SIMNET (Hamit, 1993; Sterling, 1993). Not only is the virtual battlefield portrayed electronically, but participants' actions in the virtual tanks are monitored, revised, coordinated. There is virtual radio traffic. And the radio traffic is recorded for later analysis by trainers. Several battlefield training sites such as the Mojave Desert in California and 73 Easting in Iraq (the site of a major battle in the 1991 war) are digitally replicated within the computer so that all the soldiers will see the same terrain, the same simulated enemy and friendly tanks. Battle conditions can be change for different wargame scenarios (Hamit, 1993; Sterling, 1993). The Experience Learning System, to be described, shows the latest development in virtual military training. And there are many examples of how digital networks can be used to enhance military training and performance. The American soldiers in Afganistan in 2001–2002 relied heavily upon digital technologies to enhance their performance in the field in coordination with others.

17.3.9 Telepresence/Teleoperation

The concept of cyberspace is linked to the notion of **telepresence,** the feeling of being in a location other than where you actually are. Related to this, **teleoperation** means that you can control a robot or another device at a distance. In the Jason Project (http://www.jason.org), children at different sites across the United States have the opportunity to teleoperate the unmanned submarine Jason, the namesake for this innovative science education project directed by Robert Ballard, a scientist as the Woods Hole Oceanographic Institute (EDS, 1991; McLellan, 1995; Ulman, 1993). An extensive set of curriculum materials is developed by the National Science Teachers Association to support each Jason expedition. A new site is chosen each year. In past voyages, the Jason Project has gone to the Mediterranean Sea, the Great Lakes, the Gulf of Mexico, the Galapagos Islands, and Belize. The 1995 expedition went to Hawaii.

Similar to this, NASA has implemented an educational program in conjuction with the Telepresence-controlled Remotely Operated underwater Vehicle (TROV) that has been deployed to Antarctica (Stoker, 1994). By means of a distributed computer control architecture developed at NASA, school children in classrooms across the United States can take turns driving the TROV in Antarctica. NASA Ames researchers have focused on using telepresence-controlled scientific exploration vehicles to perform field studies of space-analog environments on the Earth including the Mars Pathfinder project.

Telepresence offers great potential for medicine (Coleman, 1999; SRI, 2002; Green, Hill, Jensen, & Shan, 1995; Satava, 1997; Shimoga & Khosla, 1994; Wong, 1996). A variety of telepresence medical devices are in use. Surgeon Richard Satava is pioneering telepresence surgery for gall bladder removal without any direct contact from the surgeon after an initial small incision is made—a robot does the rest, following the movements of the surgeon's hands at another location (Satava, 1992; Taubes, 1994b). Satava believes that telepresence surgery can someday be carried out in space, on the battlefield, or in the Third World, without actually sending the doctor. In conjunction with its series on *Twenty First Century Medicine,* PBS offers a teacher's guide to "cybersurgery," including learning activities, at http://www.pbs.org/safarchive/4_class/45_pguides/pguide-605/4565_cyber.html.

17.3.10 The VisionDome

The VisionDome from the Elumens Corporation (formerly ARC) is an immersive, multiuser, single projection Virtual Reality environment featuring a full-color, raster based, interactive display (Alternate Realities Corporation (ARC), 1998; Design Research Laboratory, 2001; Elumens Corporation, 2001). This differs from the chamber world type of virtual reality in that it does not require goggles, glasses, helmets, or other restrictive interface devices. Upon entering the VisionDome, the user views are into its hemispherical structure, which forms a fully immersive 180-degree hemispheric screen. The user sees vivid images that take on depth and reality inside the VisionDome. Combining computer generated 3-D models with advanced projection equipment, the VisionDome immerses users in a 360 degree by 180 degree virtual environment. As ARC (1998) explains,

> The tilted hemispherical screen is positioned so as to fill the field-of-view of the participants, creating a sense of immersion in the same way that large-screen cinemas draw the audience into the scene. The observer loses the normal depth cues, such as edges, and perceives 3D objects beyond the surface of the screen. The dome itself allows freedom of head motion, so that the observer can change their direction of view, and yet still have their vision fully encompassed by the image. (web publication, p. 3)

Three-dimensional immersive environments (3-D Models) are developed for the VisionDome in modeling applications such as AutoCad, 3D Studio Max, or Alias Wavefront. Models are exported in VRML or Inventor format. These interactive files types can be displayed over the Web by using a VRML plug-in with a Web browser.

Since this system does not require interface devices such as head-mounted displays for individual users, it is less expensive than immersive VR systems and it can accommodate a much larger audience. The VisionDome is available in several different models. For example, the V-4 model can accommodate from 1 to 10 people while the V-5 model can accommodate up to

45 people. The larger model is finding use in museums and trade shows. Both models are relevant to education. In addition, there is the smaller VisionStation that offers great potential ofr training and related applications. The projection system and 3-D images are scalable across the different VisionDome models so that content can be developed once and used on different models.

The VisionDome is highly interactive. For example, it allows designers and clients to interact in real-time with a proposed design. The spaces of a building or landscape plan can be visualized in a photo-realistic way.

The VisionDome can be used wherever an effective wide field-of-view immersive display is needed. Potential application areas include:

- Simulation and Training
- Research, commercial, military and academic
- Oil and gas exploration
- Product design, research and prototyping
- Marketing, presentation of products and services
- Medical, diagnosis, surgical planning and teaching hospitals
- Urban planning, geophysical research and planning
- Architectural presentation and walk-throughs
- Entertainment, arcades, museums, and theme parks

North Carolina State University was the first university to obtain a VisionDome in 1998. The Design Research Laboratory (DRL) at NCSU reports that it has plans to use the VisionDome for educational applications, research initiatives and projects in the fields of architecture, landscape architecture, industrial design, urban planning, engineering, chemistry, and biology. Projects are already underway concerning architectural planning and terrain visualization.

The Colorado School of Mines is installing a VisionDome at its new Center for Multidimensional Engineered Earth Systems which has an educational component to its mission. The Center will design software to project 4-D images of the earth's subsurface on a VisionDome. This facility is similar to a planetarium, with the viewer sitting inside the earth looking up at tectonic plate movements, migration of oil, environmental impact of natural seeps, or human exploitation of natural resources, etc. It will be used to educate people about energy literacy.

17.3.11 The Experience Learning System

The Institute for Creative Technologies (http://www.ict.usc.edu/) has recently been established at the University of Southern California to provide the Army with highly realistic training simulations that rely on advances in virtual reality, artificial intelligence and other cutting-edge technologies (Hafner, 2001; Kaplan, 1999). This research center at USC will develop core technologies that are critical to both the military and to the entertainment industry. Kaplan (1999) explains, "The entertainment industry is expected to use the technology to improve its motion picture special effects, make video games more realistic and create new simulation attractions for virtual reality arcades (p. 7)." According to Kaplan,

> The Army will spend $45 million on the institute during its first five years, making it the largest research project at USC. Entertainment companies are expected to contribute not only money but also their know-how in everything from computer special effects to storytelling. Altogether, the center could raise enough funds from entertainment companies and government sources to nearly double its budget. (p. 7)

According to the Institute for Creative Technologies (ICT) Web site,

> The ICT's work with the entertainment industry brings expertise in story, character, visual effects and production to the Experience Learning System. In addition, game developers, who bring computer graphics and modeling resources; and the computer science community bring innovation in networking, artificial intelligence, and virtual reality technology. The four basic research vectors of the ICT are: entertainment industry assets, photoreal computer graphics, immersive audio, and artificial intelligence for virtual humans.

The Web site also explains that the ICT is working closely with several of USC's schools, including the School of Cinema-TV, the School of Engineering and its Information Sciences Institute (ISI) and Integrated Media Systems Center (IMSC), and the Annenberg School of Communication.

The Institute for Creative Technologies, established in 1999, will develop a convergence of core technologies into "the experience learning system." This system will include:

- Artificial intelligence to create digital characters for military simulations that respond to situations like real people.
- Computer networks that can run simulations with hundreds—or even thousands—of participants who are spread around the globe.
- Technologies to create immersive environments for simulations, ranging from better head-mounted displays to force-feedback devices to surround-sound audio systems (Kaplan, 1999, p. 7).

Hafner (2001) explains that when these virtual learning simulations are ready, they will be used at bases around the country to train soldiers and officers alike to make decisions under stress. The ICT initiative highlights that the critical R&D challenge in developing virtual learning systems extends beyond the technology. Today's challenge is "to focus on the more unpredictable side of the human psyche, simulating emotions and the unexpected effects that panic, stress, anxiety and fear can have on actions and decisions when an officer or a soldier is deep in the fog of war" (Hafner, 2001). Hafner explains that the growing interest among researchers in these kinds of simulations comes with the rise in computer processing power and the growing sophistication of psychological theories.

To enhance the realism, the Institute for Creative Technologies has built a theater with a screen that wraps around roughly half the room. Three projectors and a sound system make the theater so realistic and directional that it can trick the listener into believing that a sound's source is coming from anywhere in the room. Several virtual learning exercises have been developed, including this one described by Hafner:

> On a quiet street in a village in the Balkans, an accident suddenly puts an American peacekeeping force to the test. A Humvee has hit a car, and a child who has been injured in the collision lies unmoving on the ground. A medic leans over him. The child's mother cries out. A crowd of local residents gathers in the background. How they will react is anyone's guess.
>
> A lieutenant arrives at the scene and is confronted by a number of variables. In addition to the chaos unfolding in the village, a nearby unit is radioing for help. Emotions—not only the lieutenant's own and those of his sergeant, but also those of the panicked mother and the restive townspeople—will clearly play a role in any decision he makes.
>
> This seven-minute situation is a simulation, generated on a large computer screen with sophisticated animation, voice synthesis and voice recognition technology. It is the product of about six months of work here by three research groups at the University of Southern California: the Institute for Creative Technologies, largely financed by the Army to promote collaboration among the military, Hollywood and computer researchers; the Information Sciences Institute; and the Integrated Media Systems Center.
>
> The only human player is the lieutenant. The rest of the characters, including the sergeant who has been conferring with the lieutenant, have been generated by the computer. (p. 34)

Hafner explains that as the simulation becomes more sophisticated, there will be more choices for the lieutenant, and software will put the story together on the fly.

17.4 INTRODUCTION TO VIRTUAL REALITY APPLICATIONS IN EDUCATION AND TRAINING

Virtual reality appears to offer educational potentials in the following areas: (1) data gathering and visualization, (2) project planning and design, (3) the design of interactive training systems, (4) virtual field trips, and (5) the design of experiential learning environments. Virtual reality also offers many possibilities as a tool for nontraditional learners, including the physically disabled and those undergoing rehabilitation who must learn (or relearn) communication and psychomotor skills (Delaney, 1993; Knapp, & Lusted, 1992; Loge, Cram, & Inman, 1995; Murphy, 1994; Pausch, Vogtle, & Conway, 1991; Pausch, & Williams, 1991; Powers & Darrow, 1996; Sklaroff, 1994; Trimble, 1993; Warner & Jacobson, 1992). Virtual reality has been applied to teaching foreign languages (Osberg, Winn, Rose, Hollander, Hoffman, & Char, 1997; Rose, 1995a, 1995b, 1996; Rose & Billinghurst, 1995; Schwienhorst, 1998). Virtual reality offers professional applications in many disciplines—robotics, medicine, scientific visualization, aviation, business, architectural and interior design, city planning, product design, law enforcement, entertainment, the visual arts, music, and dance. Concomitantly, virtual reality offers potentials as a training tool linked to these professional applications (Donelson, 1994; Dunkley, 1994; Earnshaw et al., 2001; Goodlett, 1990; Hughes, 1993; Hyde & Loftin, 1993; Jacobson, 1992).

Virtual reality offers tremendous potential in medicine, both as a tool for medical practice (Carson, 1999) and for training medical students, especially those training to become surgeons. There is an annual Medicine Meets Virtual Reality Conference (MMVR) where research concerning VR in medicine, including training applications, is presented. The Web site is http://www.nextmed.com/mmvr_virtual_reality.html. The U.S. Army has a Telemedicine & Advanced Technology Research Center (http://www.tatrc.org/). The VRepar Project (Virtual Reality Environments in Psychoneuro-physiological Assessment and Rehabilitation) has a useful Web site at http://www.psicologia.net/.

In terms of medical training, several companies have introduced surgical simulators that feature virtual reality, including both visual and tactile feedback (Brennan, 1994; Burrow, 1994; Hon, 1993, 1994; Marcus, 1994; McGovern, 1994; Merril, 1993, 1994, 1995; Merril, Roy, Merril, & Raju, 1994; Rosen, 1994; Satava, 1992, 1993; Spritzer, 1994; Stix, 1992; Taubes; 1994b; Weghorst, 1994). Merril (1993) explains:

> Anatomy is 3-dimensional and processes in the body are dynamic; these aspects do not lend themselves to capture with two dimensional imaging. Now computer technology has finally caught up with our needs to examine and capture and explain the complex goings-on in the body. The simulator must also have knowledge of how each instrument interacts with the tissues. A scalpel will cut tissue when a certain amount of pressure is applied; however, a blunt instrument may not—this fact must be simulated. In addition the tissues must know where their boundaries are when they are intersecting each other. (p. 35)

Virtual reality simulators are beginning to offer a powerful dynamic virtual model of the human body that can be used to improve medical education (Taubes, 1994b). In his autobiography, *The Big Picture,* Ben Carson (1999), the head of pediatric neurosurgery at the Johns Hopkins University Medical Center describes how a virtual reality system helped him prepare for an operation that successfully separated two Siamese twins joined at the head. The visualization was developed on the basis of CAT scans and other types of data that were integrated to create a three-dimensional, interactive model:

> However it worked, I can say it was the next best thing to brain surgery—at least in terms of my preparation and planning for the scheduled operation on the Banda twins. In a Johns Hopkins research lab in Baltimore, Maryland, I could don a special set of 3-D glasses and stare into a small, reflective screen which then projected an image into space so that I could virtually "see" inside the heads of two little Siamese twins who were actually lying in a hospital on another continent. Using simple hand controls I manipulated a series of virtual tools. A turning fork or spoke could actually move the image in space—rotating the interwoven brains of these two boys to observe them from any and all angles. I could magnify the image in order to examine the smallest details, erase outer segments of the brain to see what lay hidden underneath, and even slice through the brains to see what different cross-sections would reveal about the inner structure of the brains. This allowed me to isolate even the smallest of blood vessels and follow them along their interior or exterior surface without difficulty or danger of damaging the surrounding tissue. All of which, of course, would be impossible in an actual operating room.
>
> The chief benefit of all this was knowledge. I could observe and study the inner structure of the twins' brains before we opened them up and began the actual procedure on the operating table. I could note abnormalities ahead of time and spot potential danger areas—which promised to reduce the number of surprises we would encounter in the real operation. (p. 31)

Carson's account illustrates what a powerful tool virtual reality offers for medical practice—and for medical training.

Virtual reality is under exploration as a therapeutic tool for patients. For example, Lamson (1994) and Carmichael, Kovach, Mandel, and Wehunt (2001) report that psychologists and other professionals are using virtual reality as tool with patients that are afraid of heights. Carmichael et al. (2001) also report that the Virtual Vietnam program is being used with combat veterans to help them overcome post-traumatic stress syndrome. Carmichael et al. also report that virtual reality techniques are proving useful with panicky public speakers and nervous golfers. The company Virtually Better, Inc. (http://www.virtuallybetter.com/) creates virtual reality tools for the treatment of various anxiety disorders.

Oliver and Rothman (1993) have explored the use of virtual reality with emotionally disturbed children. Knox, Schacht, and Turner (1993) report on a proposed VR application for treating test anxiety in college students.

A virtual reality application in dentistry has been developed for similar purposes: virtual reality serves as a "dental distraction," distracting and entertaining the patient while the dentist is working on the patient's teeth (Weissman, 1995). Frere, Crout, Yorty, and McNeil (2001) report that this device is "beneficial in the reduction of fear, pain and procedure time." The "Dental Distraction" headset is available for sale at http://www.dentallabs.co.uk/distraction.htm as well as other Web sites.

Originally designed as a visualization tool to help scientists, virtual reality has been taken up by artists as well. VR offers great potential as a creative tool and a medium of expression in the arts (Moser & MacLeod, 1997). Creative virtual reality applications have been developed for the audio and visual arts. An exhibit of virtual reality art was held at the Soho Guggenheim Museum in 1993 and artistic applications of VR are regularly shown at the Banff Center for the Arts in Canada (Frankel, 1994; Laurel, 1994; Stenger, 1991; Teixeira, 1994a, 1994b). This trend is expanding (Brill, 1995; Cooper, 1995; Krueger, 1991; Treviranus, 1993). Virtual reality has been applied to the theater, including a venerable puppet theater in France (Coats, 1994). And virtual reality has a role to play in filmmaking, including project planning and special effects (Manners, 2002; Smith, 1993). This has important implications for education.

One of VR's most powerful capabilities in relation to education is as a data gathering and feedback tool on human performance (Greenleaf, 1994; Hamilton, 1992; Lampton, Knerr, Goldberg, Bliss, Moshell, & Blau, 1994; McLellan, 1994b). Greenleaf Medical has developed a modified version of the VPL DataGlove™ that can be used for performance data gathering for sports, medicine, and rehabilitation. For example, Greenleaf Medical developed an application for the Boston Red Sox that records, analyzes, and visually models hand and arm movements when a fast ball is thrown by one of the team pitchers, such as Roger Clemens. Musician Yo Yo Ma uses a virtual reality application called a "hyperinstrument," developed by MIT Media Lab researcher Tod Machover, that records the movement of his bow and bow hand (Markoff, 1991; Machover, n.d.). In addition to listening to the audio recordings, Yo Yo Ma can examine data concerning differences in his bowing during several performances of the same piece of music to determine what works best and thus how to improve his performance. Other researchers at the MIT Media Lab have conducted research on similar interfaces. For a list of publications, go to http://www.media.mit.edu/hyperins/publications.html.

NEC has created a prototype of a virtual reality ski training system that monitors and responds to the stress/relaxation rate indicated by the skier's blood flow to adjust the difficulty of the virtual terrain within the training system (Lerman, 1993; VR Monitor, 1993). Flight simulators can "replay" a flight or battletank wargame so that there can be no disagreement about what actually happened during a simulation exercise.

In considering the educational potentials of virtual reality, it is interesting to note that the legendary virtual reality pioneer, Jaron Lanier, one of the developers of the DataGlove™, originally set out to explore educational applications of virtual reality. Unfortunately this initiative was ahead of its time; it could not be developed into a cost-effective and commercially viable product. Lanier explains, "I had in mind an ambitious scheme to make a really low-cost system for schools, immediately. We tried to put together something that might be described as a Commodore 64 with a cheap glove on it and a sort of cylindrical software environment" (quoted in Ditlea, 1993, p. 10). Subsequently, during the mid-1980s, Lanier teamed up with scientists at the NASA Ames Lab on the research and development project where immersive virtual reality first came together.

Another virtual reality pioneer, Warren Robinett, designed the educational software program *Rocky's Boots* (Learning Company, 1983) during the early 1980s. This highly regarded program, which provides learners with a 2-D "virtual world" where they can explore the basic concepts of electronics, was developed before virtual reality came into focus; it serves as a model for experiential virtual reality learning environments.

Newby (1993) pointed out that, "Education is perhaps the area of VR which has some of the greatest potential for improvement through the application of advanced technology" (p. 11). The Human Interface Technology Lab (the HIT Lab) at the University of Washington has been a pioneer in exploring educational applications of virtual reality for K–12 education. The HIT Lab publications (Bricken, 1990; Bricken & Byrne, 1992; Byrne, 1993, 1996; Emerson, 1994; Jackson, Taylor, & Winn, 1999; Osberg, 1993, 1994; Osberg, Winn, Rose, Hollander, Hoffman, & Char, 1997; Rose, 1995a, 1995b; Rose & Billinghurst, 1995; Taylor, 1998; Winn, 1993; Winn, Hoffman, Hollander, Osberg, Rose, & Char, 1997; Winn, Hoffman, & Osberg, 1995) are all available on the Web site. HIT Lab educational projects have included:

- **Chemistry World:** Chemistry world is a VR world in which participants form atoms and molecules from the basic building blocks of electrons, protons and neutrons. The world is a balance of theoretically real objects following the laws of chemistry along with symbolism to help participants interpret the information.
- **HIV/AIDS Project:** The HIT Lab collaborated with Seattle Public Schools for "Virtual Reality and At-Risk Youth—The HIV/AIDS Project." The goals were to motivate the students and to learn more about VR as an educational tool within a curriculum.

- **Learning Through Experiencing Virtual Worlds:** The Learning Center provided the Teacher/Pathfinder project an advanced technology component for their Internet resources for teachers. The Learning Center has developed a web site that that introduces teachers to virtual reality and world building, using the Global Change World as a model. Through this site teachers have the ability to review the world building process, experience a 3-D environment by "flying through" it, and provide feedback on the potential usefulness of building virtual worlds.
- **Puzzle World:** Puzzle World examines the use of VR to help students in developing spatial concepts and relationships through experience in multiperceptual alternative learning environments.
- **Pacific Science Center:** The Pacific Science Center sponsored projects that taught children to build and experience their own virtual worlds.
- **US West Virtual Reality Roving Vehicle Program (VRRV):** The VRRV program enables students in grades 4–12 to experience and use VR technology and provide and instructional unit for children to build their own VR worlds.
- **Zengo Sayu:** Zengo Sayu is the first functioning virtual environment ever created specifically to teach foreign language. The environment is a world of building blocks endowed with the power to speak. Students absorb and practice the target language—Zengo Sayu was originally designed to teach Japanese—as they move through the environment and interact with virtual objects (Rose, 1995).

For more information about these applications, go to Imprintit, on the Web at http://www.imprintit.com/CreationsBody.html.

The Virtual Reality and Education Lab (VREL) East Carolina University, in Greenville, North Carolina is one organization that provides leadership in promoting education in the schools (Auld & Pantelidis, 1994; Pantelidis, 1993, 1994). The Web site for VREL is http://www.soe.ecu.edu/vr/vrel.htm. VREL has as its goals, "to identify suitable applications of virtual reality in education, evaluate virtual reality software and hardware, examine the impact of virtual reality on education, and disseminate this information as broadly as possible" (Auld & Pantelidis, 1994, p. 29). Researchers at VREL have focused intensively on assembling and sharing information. For example, VREL regularly releases an updated bibliography concerning VR and education via the internet. Veronica Pantelidis, Co-Director of VREL, has prepared several reports, including: *North Carolina Competency-Based Curriculum Objectives and Virtual Reality* (1993), *Virtus VR and Virtus WalkThrough Uses in the Classroom,* and *Virtual Reality: 10 Questions and Answers*.

VR Learning from the Virtual Reality Education Company (http://www.vrlearning.com/index.html), provides software and curriculum modules for using virtual reality in the K–12 classroom. As the company Web site explains:

> VR Learning's mission is to provide software that promotes student achievement through virtual worlds, and meets the highest standards of classroom teachers and technology coordinators for K–12 software. Our products incorporate the following core principles:
>
> - use of virtual reality helps with visualization and spacial memory, both proven keys to learning.
> - the process of manipulating objects in virtual space engages students and promotes active learning.
> - classroom software should be teacher-created and teacher and student tested to improve learner outcomes.—classroom software should be available for all computing platforms.
> - classroom software should be cross-platform. That is, software and user-created files should function exactly the same on any platform.
> - classroom software that is Intranet and Internet accessible (works in standard web browsers) is more cost-effective for many schools to acquire and maintain than stand—alone software.
> - students should build on knowledge they discover by manipulating objects in virtual worlds, by reflecting on concepts and building their own virtual worlds.

This initiative started as a result of a project funded through the U.S. West Foundation, in partnership with the HIT Lab) designed to introduce virtual reality to the schools in and around Omaha Nebraska. Specifically, this was part of the HIT Lab's VRRV project described above.

As the VR Learning Web site explains, the staff from Educational Service Unit #3 took a fully immersive VR computer on loan from the HIT Lab on 1-day visits to over 60 schools and 4000 students experience immersive VR. The purpose of these visits was to expose the educational system to the VR concept, and start educators as well as students thinking about how virtual reality could be integrated into the curriculum. In addition, teachers were able to use the system to teach using one of five "Educational Worlds," including the Atom Building World and Hydrogen Cycle World. Teachers can see not only the technology, but also how to use the VR worlds to effectively teach content. For example, the Atom Building World teaches the structure of an atom by assembling a Neon atom one particle at a time. This application can be used in science classes, as well as computer-aided design (CAD) classes: a CAD teacher has used this system to show 3-D design in an immersive environment. The project featured low-end as well as high-end VR applications. The excitement generated by this funded project led to the formation of VR Learning in partnership with Educational Service Unit #3 to continue the momentum. VR Learning is focused on its home school district in Omaha, Nebraska, but its resources are available to all K–12 educators.

There have been other initiatives to explore the potential of virtual reality in the schools. For example, the Academy for the Advancement of Science and Technology in Hackensack, New Jersey, the West Denton High School in Newcastle-on-Tyne in Great Britain, and the Kelly Walsh High School in Natrona County, Wyoming have explored virtual reality in the K–12 classroom. Gay (1994a) describes how immersive virtual reality was implemented in Natrona County "on a school budget" using public domain software and other resources.

Museums are adopting virtual reality for displays as well as educational programs (Brill, 1994a, 1994b, 1994c, 1995; Britton, 1994; Gay, 1994b; Greschler, 1994; Holden, 1992; Jacobson, 1994b; Lantz, 1992; Loeffler, 1993; O'Donnell, 1994; Wagner, 1994; Wisne, 1994). In particular, the recently introduced VisionDome offers great potential in museums since it can accommodate up to 45 people without requiring individual head-mounted displays or other interfaces for each member of the audience.

Newby (1993) points out

> . . . that VR for education, even if developed and proven successful, must await further commitment of funds before it can see widespread use. This situation is common to all countries where VR research is being undertaken with the possible exception of Japan, which has followed through on an initiative to provide technological infrastructure to students. (p. 11)

So far most educational applications of virtual reality have been developed for professional training in highly technical fields such as medical education, astronaut and cosmonaut training (Stone, 2000), military training (Earnshaw et al., 2001; Eckhouse, 1993; Merril, 1993, 1995). In particular, military training has been an important focus for the development of virtual reality training systems since VR-based training is safer and more cost-effective than other approaches to military training (Amburn, 1992; Dovey, 1994; Fritz, 1991; Gambicki & Rousseau, 1993; Hamit, 1993; Sterling, 1993; Stytz, 1993, 1994). It is important to note that the cost of VR technologies, while still expensive, has substantially gone down in price over the last few years. And options at the lower end of the cost scale such as garage VR and desktop VR are expanding, especially via the World Wide Web.

NASA (http://www.vetl.uh.edu) has developed a number of virtual environment R&D projects. This includes the Hubble Telescope Rescue Mission training project, the Space Station Coupola training project, the shared virtual environment where astronauts can practice reconnoitering outside the space shuttle for joint training, human factors, engineering design (Dede, Loftin, & Salzman, 1994; Loftin, Engleberg & Benedetti (1993a) 1993). And NASA researcher Bowen Loftin has developed the Virtual Physics Lab where learners can explore conditions such as changes in gravity (Loftin, Engleberg, & Beneditti 1993a, 1993b, 1993c). Loftin et al. (1993a) report that at NASA there is a serious lag time between the hardware delivery and training since it takes time to come to terms with the complex new technological systems that characterize the space program. Virtual reality can make it possible to reduce the time lag between receiving equipment and implementing training by making possible virtual prototypes or models of the equipment for training purposes. Bowen Loftin and his colleagues have conducted extensive research exploring virtual reality and education (Bell, Hawkins, Loftin, Carey, & Kass, 1998; Chen, Kakadiaris, Miller, Loftin, & Patrick, 2000; Dede, 1990, 1992, 1993; Dede, Loftin, & Salzman, 1994; Harding, Kakadiaris, & Loftin, 2000; Redfield, Bell, Hsieh, Lamos, Loftin & Palumbo, 1998; Salzman, Dede, & Loftin, 1999; Salzman, Loftin, Dede, & McGlynn, 1996).

17.5 ESTABLISHING A RESEARCH AGENDA FOR VIRTUAL REALITIES IN EDUCATION AND TRAINING

Since virtual reality is a fairly new technology, establishing a research agenda—identifying the important issues for research—is an important first step in exploring its potential. So far, work in virtual reality has focused primarily on refining and improving the technology and developing applications. Many analysts suggest that VR research needs to deal with far more than just technical issues. Laurel (1992) comments, "In the last three years, VR researchers have achieved a quantum leap in the ability to provide sensory immersion. Now it is time to turn our attention to the emotional, cognitive, and aesthetic dimensions of human experience in virtual worlds." Related to this, Thurman (1993) recommends that VR researchers need to focus on instructional strategies, because "device dependency is an immature perspective that almost always gives way to an examination of the effects of training on learners, and thereby finetune how the medium is applied." To date, not much research has been conducted to rigorously test the benefits—and limitations—of learning and training in virtual reality. This is especially true of immersive applications. And assessing the research that has been carried out must take into consideration the rapid changes and improvements in the technology: improved graphics resolution, lighter head-mounted displays, improved processing speed, improved position tracking devices, and increased computer power. So any research concerning the educational benefits of virtual reality must be assessed in the context of rapid technological improvement.

Any research agenda for virtual realities must also take into consideration existing research in related areas that may be relevant. The Learning Environment systems project at the University of Southern California illustrates the importance of interdisciplinary expertise in developing virtual reality training systems. Many analysts (Biocca, 1992a, 1992b; Heeter, 1992; Henderson, 1991; Laurel, 1991; Pausch, Crea, & Conway, 1992; Piantanida, 1993, 1994; Thurman & Mattoon, 1994) have pointed out that there is a strong foundation of research and theory-building in related areas—human perception, simulation, communications, computer graphics, game design, multimedia, ethology, etc.—that can be drawn upon in designing and studying VR applications in education and training. Increasingly, research and development in virtual reality is showing an overlap with the field of artificial intelligence (Badler, Barsky, & Zeltzer, 1991; Taubes, 1994a; Waldern, 1994). And Fontaine (1992) has suggested that research concerning the experience of presence in international and intercultural encounters may be valuable for understanding the sense of presence in virtual realities. This example in particular gives a good indication of just how broad the scope of research relevant to virtual realities may be.

Furthermore, research in these foundation areas can be extended as part of a research agenda designed to extend our understanding of the potentials of virtual reality. For example, in terms of research related to perception that is needed to support the development of VR, Moshell and Dunn-Roberts (1993) recommend that theoretical and experimental psychology must provide: (1) systematic measurement of basic properties; (2) better theories of perception, to guide the formation of hypotheses—including visual perception, auditory perception, movement and motion sickness, and haptic perception (the sense of force, pressure, etc.); (3) careful tests of hypotheses, which result in increasingly valid theories; (4) constructing and testing of input and output devices based on empirical and theoretical guidelines, and ultimately (5) evaluation metrics and calibration procedures.

Human factors considerations will need careful attention (Pausch et al., 1992; Piantanida, 1993; Piantanida, 1994).

Waldern (1991) suggests that the following issues are vital considerations in virtual reality research and development: (1) optical configuration; (2) engineering construction; (3) form; (4) user considerations; (5) wire management; and (6) safety standards. According to Waldern, the single most difficult aspect is user considerations, which includes anthropometric, ergonomic and health and safety factors. Waldern explains: "If these are wrong, even by a small degree, the design will be a failure because people will choose not to use it." One issue that has come under scrutiny is the safety of head-mounted displays (HMDs), especially with long-term use. This issue will need further study as the technology improves. Wann, Rushton, Mon-Williams, Hawkes, and Smyth (1993) report, "Everyone accepts that increased screen resolution is a requirement for future HMDs, but equally we would suggest that a minimum requirement for the reduction of serious visual stress in stereoscopic presentations is variable focal depth."

Thurman and Mattoon (1994) comment,

> It is our view that VR research and development will provide a foundation for a new and effective form of simulation-based training. However, this can be achieved only if the education and training communities are able to conceptualize the substantial differences (and subsequent improvements) between VR and other simulation strategies. For example, there are indications that VR is already misinterpreted as a single technological innovation associated with head-mounted displays, or sometimes with input devices such as sensor gloves or 3-D trackballs. This is analogous to the mistaken notion that crept into the artificial intelligence (AI) and subsequently the intelligence tutoring system (ITS) community in the not too distant past. That is, in its infant stages, the AI and ITS community mistakenly assumed that certain computer processors (e.g., lisp machines) and languages (e.g., Prolog) constituted artificial intelligence technology. It was not until early implementers were able to get past the "surface features" of the technology and began to look at the "deep structure" of the concept that real inroads and conceptual leaps were made. (p. 56)

This is a very important point for VR researchers to keep in mind.

It will be important to articulate a research agenda specifically relating to virtual reality and education. Fennington and Loge (1992) identify the following issues: (1) How is learning in virtual reality different from that of a traditional educational environment? (2) What do we know about multisensory learning that will be of value in determining the effectiveness of this technology? (3) How are learning styles enhanced or changed by VR? and (4) What kinds of research will be needed to assist instructional designers in developing effective VR learning environments? Related to this, McLellan (1994b) argues that virtual reality can support all seven of the multiple intelligences postulated by Howard Gardner—linguistic, spatial, logical, musical, kinesthetic, interpersonal and intrapersonal intelligences. VR researchers may want to test this notion.

A detailed research agenda concerning virtual reality as applied to a particular type of training application is provided by a front-end analysis that was conducted by researchers at SRI International (Boman, Piantanida, & Schlager, 1993) to determine the feasibility of using virtual environment technology in Air Force maintenance training. This study was based on interviews with maintenance training and testing experts at Air Force and NASA training sites and at Air Force contractors' sites. Boman et al. (1993) surveyed existing maintenance training and testing practices and technologies, including classroom training, hands-on laboratory training, on-the-job training, software simulations, interactive video, and hardware simulators. This study also examined the training-development process and future maintenance training and testing trends. Boman et al. (1993) determined that virtual environments might offer solutions to several problems that exist in previous training systems. For example, with training in the actual equipment or in some hardware trainers, instructors often cannot see what the student is doing and cannot affect the session in ways that would enhance learning.

> The most cited requirements were the need to allow the instructor to view the ongoing training session (from several perspectives) and to interrupt or modify the simulation on the fly (e.g., introducing faults). Other capabilites included instructional guidance and feedback to the student and capture the playback of a session. Such capabilities should be integral features of a VE system. (V. II, pp. 26–27)

Boman et al. (1993) report that the technicians, developers, and instructors interviewed for this study were all in general agreement that if the capabilities outlined above were incorporated in a virtual environment training system, it would have several advantages over current training delivery methods. The most commonly cited advantages were availability, increased safety, and reduced damage to equipment associated with a simulated practice environment. Virtual reality was seen as a way to alleviate the current problem of gaining access to actual equipment and hardware trainers. Self-pacing was also identified as an advantage. For example, instructors could "walk through" a simulated system with all students, allow faster learners to work ahead on their own, and provide remediation to slower students. Boman et al. (1993) report that another potential benefit would be if the system enforced uniformity, helping to solve the problem of maintaining standardization of the maintenance procedures being taught.

Boman et al. (1993) report that some possible impacts of virtual environment simulations include: (1) portraying specific aircraft systems; (2) evaluating performance; (3) quick upgrading; (4) many hardware fabrication costs are avoided; (5) the computer-generated VR model can be disassembled in seconds; (6) the VR model can be configured for infrequent or hazardous tasks; and (7) the VR model can incorporate modifications in electronic form. Their findings indicate that (1) a need exists for the kind of training virtual reality offers and (2) virtual environment technology has the potential to fill that need. To provide effective VR maintenance training systems, Boman et al. (1993) report that research will be needed in three broad areas: (1) Technology development to produce equipment with the fidelity needed for VR training; (2) Engineering studies to evaluate functional fidelity requirements and develop new methodologies; (3) Training/testing studies to develop an understanding of how best to train using virtual reality training applications. For example, Boman et al. (1993) recommend the development of new methods to use virtual environment devices with simulations, including: (1) evaluating methods for navigating within a simulated environment, in particular, comparing the use of speech, gestures, and 3-D/6-D input devices for navigation commands; (2) evaluating methods for manipulating virtual objects including the use of auditory or tactile cues to detect object colision; (3) evaluating virtual menu screens, voice, and hand gesture command modes for steering simulations; (4) evaluating methods for interaction within multiple-participant simulations, including methods to give instructors views from multiple perspectives (e.g., student viewpoint, God's-eye-view, panorama); and (5) having the staff from facilities involved in virtual environment software and courseware development perform the studies on new methodologies.

In sum, virtual environments appear to hold great promise for filling maintenance and other technical training needs, particularly for tasks for which training could not otherwise be adequate because of risks to personnel, prohibitive costs, environmental constraints, or other factors. The utility of virtual environments as more general-purpose maintenance training tools, however, remains unsubstantiated. Boman et al. (1993) make a number of recommendations:

- Develop road maps for virtual environment training and testing research;
- Identify and/or set up facilities to conduct virtual environment training/testing research;
- Conduct experimental studies to establish the effectiveness of VE simulations in facilitating learning at the cognitive process level;
- Develop effective principles and methods for training in a virtual environment;
- Assess the suitability of VE simulation for both evaluative and aptitude testing purposes;
- Develop criteria for specifying the characteristics of tasks that would benefit from virtual environment training for media selection;
- Conduct studies to identify virtual environment training system requirements;
- Develop demonstration systems and conduct formative evaluations;
- Conduct studies to identify guidelines specifying when and where virtual environment or other technologies are more appropriate in the total curriculum, and how they can be used in concert to maximize training efficiency and optimize the benefits of both;
- Develop integrated virtual environment maintenance training system and curriculum prototypes; and
- Conduct summative evaluation of system performance, usablity, and utility, and of training outcomes. (V IV, pp. 12–16)

This study gives a good indication of the scope of the research still needed to assess the educational potentials of virtual realities. As this study indicates, a wide gamut of issues will need to be included in any research agenda concerning the educational potentials of VR. Virtual realities appear to hold great promise for education and training, but extensive research and development is still needed to refine and assess the potentials of this emerging technology.

Imprintit (n.d.) presents a valuable report on its approach to developing education virtual reality applications. This report is available at *http://www.imprintit.com/Publications/VEApp.doc*.

17.6 THEORETICAL PERSPECTIVES ON VIRTUAL REALITIES

Already there has been a great deal of theory building as well as theory adapting vis-à-vis virtual reality. Theorists have looked to a broad array of sources—theater, psychology, ethology, perception, communication, computer science, and learning theories—to try to understand this emerging technology and how it can be applied in education and other fields.

17.6.1 Ecological Psychology Perspective—J. J. Gibson

The model of ecological psychology proposed by J. J. Gibson (1986) has been particularly influential in laying a theoretical foundation for virtual reality. Ecological psychology is the psychology of the awareness and activities of indivduals in an environment (Gibson, 1986; Mace, 1977). This is a theory of perceptual systems based on direct perception of the environment. In Gibson's theory, "affordances" are the distinctive features of a thing which help to distinguish it from other things that it is not. Affordances help us to perceive and understand how to interact with an object. For example, a handle helps us to understand that a cup affords being picked up. A handle tells us where to grab a tool such as a saw. And door knobs tell us how to proceed in opening a door. Affordances provide strong clues to the operations of things.

Affordance perceptions allow learners to identify information through the recognition of relationships among objects or contextual conditions. Affordance recognition must be understood as a contextually sensitive activity for determining what will (most likely) be paid attention to and whether an affordance will be perceived. J. J. Gibson (1986) explains that the ability to recognize affordances is a selective process related to the individual's ability to attend to and learn from contextual information.

Significantly, Gibson's model of ecological perception emphasizes that perception is an active process. Gibson does not view the different senses as mere producers of visual, auditory, tactile, or other sensations. Instead he regards them as active seeking mechanisms for looking, listening, touching, etc. Furthermore, Gibson emphasizes the importance of regarding the different perceptual systems as strongly inter-related, operating in tandem. Gibson argues that visual perception evolved in the context of the perceptual and motor systems, which constantly work to keep us upright, orient us in space, enable us to navigate and handle the world. Thus visual perception, involving head and eye movements, is frequently used to seek information for coordinating hand and body movements and maintaining balance. Similar active adjustments take place as one secures audio information with the ear and head system.

J. J. Gibson (1986) hypothesized that by observing one's own capacity for visual, manipulative, and locomotor interaction with environments and objects, one perceives the meanings and the utility of environments and objects, i.e., their affordances. McGreevy (1993) emphasizes that Gibson's ideas highlight the importance of understanding the kinds of interactions offered by real environments and the real objects in those environments. Some virtual reality researchers (Ellis, 1991, 1992; McGreevy, 1993; Sheridan & Zeltner, 1993; Zeltner, 1992) suggest that this knowledge from the real world can inform the design of interactions in the virtual environment so that they appear natural and realistic, or at least meaningful.

Michael McGreevy, a researcher at the NASA Ames Lab, is studying the potential of virtual reality as a scientific visualization tool for planetary exploration, including virtual geological exploration. He has developed a theoretical model of the scientist in the virtual world as an explorer, based on J.J. Gibson's theory of ecological psychology. In particular, McGreevy links the Gibsonian idea that the environment must "afford" exploration in order for people to make sense of it to the idea that we can begin to learn something important from the data retrieved from planetary exploration by flying through the images themselves via immersive VR, from all different points of view. McGreevy (1993) explains:

> Environments afford exploration. Environments are composed of openings, paths, steps, and shallow slopes, which afford locomotion. Environments also consist of obstacles, which afford collision and possible injury; water, fire, and wind, which afford life and danger; and shelters, which afford protection from hostile elements. Most importantly, environments afford a context for interaction with a collection of objects. (p. 87).

As for objects, they afford "grasping, throwing, portability, containment, and sitting on. Objects afford shaping, molding, manufacture, stacking, piling, and building. Some objects afford eating. Some very special objects afford use as tools, or spontaneous action and interaction (that is, some objects are other animals)" (McGreevy, 1993, p. 87).

McGreevy (1993) points out that natural objects and environments offer far more opportunity for use, interaction, manipulation, and exploration than the ones typically generated on computer systems. Furthermore, a user's natural capacity for visual, manipulative, and locomotor interaction with real environments and objects is far more informative than the typically restricted interactions with computer-generated scenes. Perhaps virtual reality can bridge this gap. Although a virtual world may differ from the real world, virtual objects and environments must provide some measure of the affordances of the objects and environments depicted (standing in for the real-world) in order to support natural vision (perceptualization) more fully.

Related to this, Rheingold (1991) explains that a wired glove paired with its representation in the virtual world that is used to control a virtual object offers an affordance—a means of literally grabbing on to a virtual world and making it a part of our experience. Rheingold explains: "By sticking your hand out into space and seeing the hand's representation move in virtual space, then moving the virtual hand close to a virtual object, you are mapping the dimensions of the virtual world into your internal perception-structuring system" (p. 144).

And virtual reality pioneer Jaron Lanier (1992) has commented that the principle of head-tracking in virtual reality suggests that when we think about perception—in this case, sight—we shouldn't consider eyes as "cameras" that passively take in a scene. We should think of the eye as a kind of spy submarine moving around in space, gathering information. This creates a picture of perception as an *active* activity, not a *passive* one, in keeping with J. J. Gibson's theory. And it demonstrates a fundamental advantage of virtual reality: VR facilitates active perception and exploration of the environment portrayed.

17.6.2 Computers-as-Theater Perspective—Brenda Laurel

Brenda Laurel (1990a, 1990b, 1991) suggests that the principles of effective drama can be adapted to the design of interactive computer programs, and in particular, virtual reality. Laurel (1990) comments, "millennia of dramatic theory and practice have been devoted to an end that is remarkably similar to that of human–computer interaction design; namely, creating artificial realities in which the potential for action is cognitively, emotionally and aesthetically enhanced" (p. 6). Laurel has articulated a theory of how principles of drama dating back to Aristotle can be adapted to understanding human-computer interaction and the design of virtual reality.

Laurel's (1991) ideas began with an examination of two activities that are extremely successful in capturing people's attention: games and theater. She distinguishes between two modes of participation: (1) first-person—direct participation; and (2) third-person—watching as a spectator with the subjective experience is that of an outsider looking in, detached from the events.

The basic components of Laurel's (1991) model are:

1. Dramatic storytelling (storytelling designed to enable significant and arresting kinds of actions)
2. Enactment (for example, playing a VR game or learning scenario as performance)
3. Intensification (selecting, arranging, and representing events to intensify emotion)
4. Compression (eliminating irrelevant factors, economical design)
5. Unity of action (strong central action with separate incidents that are linked to that action; clear causal connections between events)
6. Closure (providing an end point that is satisfying both cognitively and emotionally so that some catharsis occurs)
7. Magnitude (limiting the duration of an action to promote aesthetic and cognitive satisfaction)
8. Willing suspension of disbelief (cognitive and emotional engagement)

A dramatic approach to structuring a virtual reality experience has significant benefits in terms of engagement and emotion. It emphasizes the need to delineate and represent human–computer activities as organic wholes with dramatic structural characteristics. And it provides a means whereby people experience agency and involvement naturally and effortlessly. Laurel (1991) theorizes that engagement is similar in many ways to the theatrical notion of the "willing suspension of disbelief." She explains: "Engagement involves a kind of complicity. We agree to think and feel in terms of both the content and conventions of a mimetic context. In return, we gain a plethora of new possibilities for action and a kind of emotional guarantee" (p. 115). Furthermore, "Engagement is only possible when we can rely on the system to maintain the representational context" (p. 115).

Magnitude and closure are two design elements associated with enactment. Magnitude suggests that limiting the *duration* of an action has aesthetic and cognitive aspects as well as physical ones. Closure suggests that there should be an end point that is satisfying both cognitively and emotionally, providing catharsis.

> In simulation-based activities, the need for catharsis strongly implies that what goes on be structured as a whole action with a dramatic "shape." If I am flying a simulated jet fighter, then either I will land successfully or be blown out of the sky, hopefully after some action of a duration that is sufficient to provide pleasure has had a chance to unfold. Flight simulators shouldn't stop in the middle, even if the training goal is simply to help a pilot learn to accomplish some midflight task. Catharsis can be accomplished, as we have seen, through a proper understanding of the nature of the whole action and the deployment of dramatic probability. If the end of an activity is the result of a causally related and well-crafted series of events, then the experience of catharsis is the natural result of the moment at which probability becomes neccesity. (Laurel, 1991, p.122)

Instructional designers and the designers of virtual worlds and experiences within them should keep in mind the importance of defining the "whole" activity as something that can provide satisfaction and closure when it is achieved.

Related to this theory of design based upon principles of drama, Laurel has recently introduced the concept of "smart costumes" to describe characters or agents in a virtual world. She has developed an art project, PLACEHOLDER, that features smart costumes—a set of four animal characters—crow, snake, spider, and fish (Frenkel, 1994; Laurel, 1994). A person visiting the PLACEHOLDER world may assume the character of one of these animals and thereby experience aspects of its unique visual perception, its way of moving about, and its voice. For example, snakes can see the infrared portion of the spectrum and so the system tries to model this: the space appears brighter to someone wearing this "smart costume." The "smart costumes" change more than the appearance of the person within. Laurel (1991) explains that characters (or "agents") need not be complex models of human personality; indeed, dramatic characters are effective precisely because the they are less complex and therefore more discursive and predictable than human beings.

Virtual agents are becoming an increasingly important area of design in virtual reality, bridging VR with artificial intelligence. For example, Waldern (1994) has described how virtual agents based on artificial intelligence techniques such as neural nets and fuzzy logic form a basis of virtual reality games such as *Legend Quest*. Bates (1992) is conducting research concerning dramatic virtual characters. And researchers at the Center for Human Modeling and Simulation at the University of Pennsylvania are studying virtual agents in "synthetic-conversation group" research (Badler et al., 1991; Goodwin Marcus Systems, Ltd., n.d. Taubes, 1994a). The virtual agent Jack™, developed at the Center for Human Modeling and Simulation, has been trade marked and is used as a 3-D graphics software environment for conducting ergonomic studies of people with products (such as cars and helicopters), buildings, and interaction situations (for example, a bank teller interacting with a customer) (Goodwin Marcus Systems, n.d.). Researchers at the MIT Media Lab are studying ethology—the science of animal behavior—as a basis for representing virtual characters (Zeltner, 1992).

Creative artists		**Performing artists**
	writer	storyteller
	speech writer	orator
	joke writer	comedian
	poet	bard
novelist	choreographer	dancer, mime
architect	composer	instrumentalist
sculptor	coach	athlete
painter	songwriter	singer
	playwright	stage actor
	filmmaker	film actor
user interface designer	dungeon master	D & D role player
	spacemaker	cyberspace player

FIGURE 17.2. Walser's media spectrum, including spacemaker and cyberspace player categories. Adapted from Walser (1991).

17.6.3 Spacemaker Design Perspective—Randal Walser

Randall Walser (1991, 1992) draws upon ideas from filmmaking, performance art, and role-playing games such as Dungeons and Dragons to articulate his model of "spacemaking."

> The goal of spacemaking is to augment human performance. Compare a spacemaker (or world builder) with a film maker. Film makers work with frozen virtual worlds. Virtual reality cannot be fully scripted. There's a similarity to performance art. Spacemakers are especially skilled at using the new medium so they can guide others in using virtual reality. (Walser, 1992)

Walser (1991) places the VR roles of spacemaker (designer) and cyberspace player (user) in the context of creative and performing artists, as shown in Fig. 17.2.

Walser (1992) places virtual reality (or cyberspace, as he refers to VR) in the context of a full spectrum of media, including film as well as print, radio, telephony, television, and desktop computing. In particular, Walser compares cyberspace with desktop computing. Just as desktop computing, based on the graphic user interface and the desktop metaphor, created a new paradigm in computing, Walser proposes that cyberspace is based on still another new paradigm, which is shown in Fig. 17.3.

Walser (1992) is particularly concerned with immersive virtual reality. He explains that in the desktop paradigm, computers

Desktop paradigm	Cyberspace paradigm
mind	body
ideas	actions
creative arts	performing arts
products	performances

FIGURE 17.3. Walser's (1992) comparison of the desktop and cyberspace paradigms of media design.

are viewed as tools for the mind — mind as dissembodied intellect. In the new cyberspace paradigm, computers are viewed as engines for worlds of experience where mind and body are inseparable. Embodiment is central to cybespace, as Walser (1992) explains:

> Cyberspace is a medium that gives people the feeling they have been bodily transported from the ordinary physical world to worlds of pure imagination. Although artists can use any medium to evoke imaginary worlds, cyberspace carries the various worlds itself. It has a lot in common with film and stage, but is unique in the amount of power it yields to its audience. Film yields little power, as it provides no way for its audience to alter screen images. The stage grants more power than film does, as stage actors can "play off" audience reactions, but the course of the action is still basically determined by a script. Cyberspace grants seemingly ultimate power, as it not only enables its audience to observe a reality, but also to enter it and experience it as reality. No one can know what will happen from one moment to the next in a cyberspace, not even the spacemaker (designer). Every moment gives each participant an opportunity to create the next event. Whereas film depicts a reality to the audience, cyberspace grants a virtual body and a role, to everyone in the audience.

Similar to Brenda Laurel, Walser (1992) theorizes that cyberspace is fundamentally a theatrical medium, in the broad sense that it, like traditional theater, enables people to invent, communicate, and comprehend realities by "acting them out." Walser explains that acting out roles or points of view is not just a form of expression, but a fundamental way of knowing.

17.6.4 Constructivist Learning Perspective—Meredith and William Bricken

Focusing primarily on immersive applications of VR, Meredith Bricken theorizes that virtual reality is a very powerful educational tool for constructivist learning, the theory introduced by Jean Piaget (Bricken, 1991; Bricken & Byrne, 1993). According to Bricken, the virtual reality learning environment is experiential and intuitive; it provides a shared information context that offers unique interactivity and can be configured for individual learning and performance styles. Virtual reality can support hands-on learning, group projects and discussions, field trips, simulations, and concept visualization; all successful instructional strategies. Bricken envisions that within the limits of system functionality, it is possible to create anything imaginable and then become part of it.

Bricken speculates that in virtual reality, learners can actively inhabit a spatial multi-sensory environment. In VR, learners are both physically and perceptually involved in the experience; they perceive a sense of presence within a virtual world. Bricken suggests that virtual reality allows natural interaction with information. In a virtual world, learners are empowered to move, talk, gesture, and manipulate objects and systems intuitively. And according to Bricken, virtual reality is highly motivational: it has a magical quality. "You can fly, you can make objects appear, disappear, and transform. You can have these experiences without learning an operating system or programming language, without any reading or calculation at all. But the magic trick of creating new experiences requires basic academic skills, thinking skills, and a clear mental model of what computers do" (Bricken, 1991, p. 3).

Meredith Bricken points out that virtual reality is a powerful context, in which learners can control time, scale, and physics. Participants have entirely new capabilities, such as the ability to fly through the virtual world, to occupy any object as a virtual body, to observe the environment from many perspectives. Understanding multiple perspectives is both a conceptual and a social skill; virtual reality enables learners to practice this skill in ways that cannot be achieved in the physical world.

Meredith Bricken theorizes that virtual reality provides a developmentally flexible, interdisciplinary learning environment. A single interface provides teachers and trainers with an enormous variety and supply of virtual learning "materials" that do not break or wear out. And as Bricken (1991) envisions it, virtual reality is a shared experience for multiple participants.

William Bricken (1990) has also theorized about virtual reality as a tool for experiential learning, based on the ideas of John Dewey and Jean Piaget. According to him, "VR teaches active construction of the environment. Data is not an abstract list of numerals, data is what we perceive in our environment. Learning is not an abstract list of textbook words, it is what we do in our environment. The hidden curriculum of VR is: make your world and take care of it. Try experiments, safely. Experience consequences, then choose from knowledge" (Bricken, 1990, p. 2).

Like his wife Meredith Bricken, William Bricken's attention is focused primarily on immersive virtual reality. William Bricken (1990) suggests that virtual reality represents a new paradigm in the design of human–computer interfaces. Bricken's model of the new virtual reality paradigm, contrasted with the "old" desktop computing paradigm, is presented in Fig. 17.4. This new VR paradigm is based on the transition from multiple points of view external to the human, to multiple points of view that the human enters, like moving from one room to another. Related to this, William Bricken and William Winn (Winn & Bricken, 1992a, 1992b) report on how VR can used to teach mathematics experientially.

17.6.5 Situated Learning Perspective—Hilary McLellan

McLellan (1991) has theorized that virtual reality-based learning environments can be designed to support situated learning, the model of learning proposed by Brown, Collins, and Duguid

Desktop paradigm (Old)	**Virtual reality paradigm (New)**
symbol processing	reality generation
viewing a monitor	wearing a computer
symbolic	experiential
observer	participant
interface	inclusion
physical	programmable
visual	multimodal
metaphor	virtuality

FIGURE 17.4. William Bricken's (1990) comparison of the desktop and virtual reality paradigms of media design.

(1989). According to this model, knowledge is situated; it is a product of the activity, context, and culture in which it is developed and used. Activity and situations are integral to cognition and learning. Therefore, this knowledge must be learned in context—in the actual work setting or a highly realistic or "virtual" surrogate of the actual work environment. The situated learning model features apprenticeship, collaboration, reflection, coaching, multiple practice, and articulation. It also emphasizes technology and stories.

McLellan (1991) analyzes a training program for pilots called Line-Oriented Flight Training (LOFT), featuring simulators (virtual environments), that exemplifies situated learning. LOFT was introduced in the early 1980s in response to data showing that most airplane accidents and incidents, including fatal crashes, resulted from pilot error (Lauber & Foushee, 1981). Concommitently, this data showed that pilot error is linked to poor communication and coordination in the cockpit under crisis situations. So the LOFT training program was instituted to provide practice in team building and crisis management. LOFT teaches pilots and co-pilots to work together so that an unexpected cascade of small problems on a flight doesn't escalate into a catastrophe (Lauber & Foushee, 1981).

All six of the critical situated learning components—Apprenticeship; Collaboration; Reflection; Coaching; Multiple practice; Articulation of learning skills—are present in the LOFT training program (McLellan, 1991). Within the simulated flight, the environmental conditions are controlled, modified, and *articulated* by the instructor to simulate increasingly difficult conditions. The learning environment is contextually rich and highly realistic. *Apprenticeship* is present since the instructor decides on what array of interlocking problems to present on each simulated flight. The pilots must gain experience with different sets of problems in order to build the skills neccesary for *collaborative teamwork and coordination*. And they must learn to solve problems for themselves: there is no instructor intervention during the simulated flights. *Reflection* is scheduled into the training after the simulated flight is over, when an instructor sits down with the crew to critique the pilots' performance. This involves *coaching* from the instructor as well. The simulation provides the opportunity for *multiple practice,* including practice where different factors are *articulated*. Related to this, it is noteworthy that many virtual reality game players are very eager to obtain feedback about their performance, which is monitored electronically.

The LOFT training program emphasizes stories: stories of real disasters and simulated stories (scenarios) of crisis situations that represent all the possible kinds of technical and human problems that a crew might encounter in the real world. According to Fouchee (1992), the pilots who landed a severely crippled United Airlines airplane in Sioux City, Iowa several years ago, saving many lives under near-miraculous conditions, later reported in debriefing that they kept referring back to their LOFT training scenarios as they struggled to maintain control of the plane, which had lost its hydraulic system. The training scenarios were as "real" as any other experience they could draw upon.

Another example of situated learning in a virtual environment is a program for corporate training in team building that utilizes the Virtual Worlds Entertainment games (BattleTech, Red Planet, etc.), featuring networked simulator pods (Lakeland Group, 1994; McLellan, 1994a). This is a fascinating example of how an entertainment system has been adapted to create a training application. One of the advantages of using the VWE games is that it creates a level playing field. These virtual environments eliminate contextual factors that create inequalities between learners, thereby interfering with the actual learning skills featured in the training program, that is, interpersonal skills, collaboration, and team-building. Thus, McGrath (1994) reports that this approach is better than other training programs for team building. The Lakeland team training program suggests that virtual reality can be used to support learning that involves a strong social component, involving effective coordination and collaboration with other participants. Since both LOFT and the Lakeland Group training program are based upon virtual environments (cab simulators), it remains to be seen how other types of virtual reality can be used to support situated learning. Mirror world applications in particular seem to offer potential for situated learning.

The new Experience Learning System at the University of Southern California (Hafner, 2001) appears to be informed by the situated learning perspective. The central role of stories is noteworthy. Of course stories are also central to the experience design perspective discussed below and to Brenda Laurel's "Computers-as-theater" perspective discussed above.

17.6.6 Experience Design Perspective

Experience design is an important emerging paradigm for the design of all interactive media, including virtual reality. Experience design draws upon the theory building in virtual reality concerning the concept of presence. It also builds on theory building in a range of other fields, including psychology (Csikszentmihalyi, 1990), economics (Pine & Gilmore, 1999) and advertising (Schmitt, 1999) as well as media design (Carbone & Haecke, 1998; Ford and Forlizzi, 1999; Shedroff, 2001).

According to Ford & Forlizzi (1999), experience is built upon our perceptions, our feelings, our thoughts. Experiences are usually induced not self-generated; they are born of something external to the subject. Experience is:

- A private event that occurs in response to some kind of stimulus, be it emotional, tactile, aesthetic, or intellectual.
- Made up of an infinite amount of smaller experiences, relating to other people, surroundings, and the objects encountered.
- The constant stream of thoughts and sensations that happens during conscious moments (Ford & Forlizzi, 1999).

Ford and Forlizzi (1999) suggest that "As designers thinking about experience, we can only design situations—levers that people can interact with—rather than outcomes that can be absolutely predicted."

Shedroff (2002) explains,

> One of the most important ways to define an experience is to search its boundaries. While many experiences are ongoing, sometimes even indefinitely, most have edges that define their start, middle, and end. Much like a story (a special and important type of experience), these boundaries help us differentiate meaning, pacing, and completion. Whether it is due to attention span, energy, or emotion, most people cannot continue an experience indefinitely; they will grow tired, confused, or distracted if an experience, however consistent, doesn't conclude.
>
> At the very least, think of an experience as requiring an *attraction,* an *engagement,* and a *conclusion*.

Shedroff explains that the attraction is necessary to initiate the experience. This attraction should not be synonymous with distraction. An attraction can be cognitive, visual, auditory, or it can signal any of our senses. Shedroff recommends that there need to be cues as to where and how to begin the experience.

Shedroff further explains that engagement is the experience itself. The engagement needs to be sufficiently different from the surrounding environment of the experience to hold the attention of the experiences. The engagement also needs to be cognitively important or relevant enough for someone to continue the experience.

According to Shedroff, the conclusion can come in many ways, but it must provide some sort of resolution, whether through meaning or story or context or activity to make an otherwise enjoyable experience satisfactory—and memorable. Shedroff refers to this factor that endures in memory as the *takeaway*. As Shedroff (2001) explains that takeaways help us derive meaning from what we experience. Narrative is becoming recognized as an increasingly important design element (Packer & Jordan, 2001). For example, Murray (1997) reports that increasingly, people want a story in their entertainment. Entertainment rides such as those at Universal Studios (a form of virtual reality) are designed with a story element. The traditional amusement ride with small surprises, hints of danger, and sensory experiences—they want a story to frame the experience.

Shedroff (2002) reports, "Most technological experiences—including digital and, especially, online experiences—have paled in comparison to real-world experiences and they have been relatively unsuccessful as a result. What these solutions require is developers that understand what makes a good experience first, and then to translate these principles, as well as possible, into the desired medium without the technology dictating the form of the experience." This is a very important design goal.

Psychologist Mihalyi Csikszentmihalyi has conducted extensive research exploring what makes different experiences optimally engaging, enjoyable, and productive. This research is a foundation for any understanding of experience design. Csikszentmihalyi (1991) explains, "The autotelic experience, or flow, lifts the course of life to a different level. Alienation gives way to involvement, enjoyment replaces boredom, helplessness turns into a feeling of control, and psychic energy works to reinforce the sense of self, instead of being lost in the service of external goals" (p. 69). Csikszentmihalyi has found that an optimum state of flow or "autotelic experience" is engaged when there is a clear set of goals requiring an appropriate response; when feedback is immediate; and when a person's skills are fully involved in overcoming a challenge that's high but manageable. When these three conditions are met, attention to task becomes ordered and fully engaged. A key element of an optimal experience is that it is an end in itself; even if undertaken for other reasons, the activity that engages us becomes intrinsically rewarding. This type of experience is fundamentally enjoyable.

Ackerman (1999) refers to this type of optimal experience as "deep play." As she explains, "play feels satisfying, absorbing, and has rules and a life of its own, while offering rare challenges. It gives us the opportunity to perfect ourselves. It's organic to who and what we are, a process as instinctive as breathing. Much of human life unfolds as play." Optimal experiences are the ultimate goal of experience design.

Economists Pine and Gilmore (1999) put this into a broader perspective (see Fig. 17.5). They hypothesize that we are moving from a service economy to an experience economy. "When a person buys a service, he purchases a set of intangible activities carried out on his behalf. But when he buys an experience, he pays to spend time enjoying a series of memorable events that a company stages—as in a theatrical play—to engage him in a personal way" (p. 2). In this context, experience type transactions occur whenever a company intentionally uses services as the stage and goods as props to engage an individual. "Buyers of experiences—we'll follow Disney's lead and call them guests—value being engaged by what the company reveals over a duration of time. Just as people have cut back on goods to spend more money on services, now they also scrutinize the time and money they spend on services to make way

Economic Offering	**Services**	**Experiences**
Economic Function	Deliver	Stage
Nature of Offering	Intangible	Memorable
Key Attribute	Customized	Personal
Method of Supply	Delivered on demand	Revealed over a duration
Seller	Provider	Stager
Buyer	Client	Guest
Factors of Demand	Benefits	Sensations

FIGURE 17.5. Economic distinctions between service and experience-based economic activities. Adapted from Pine and Gilmore (1999).

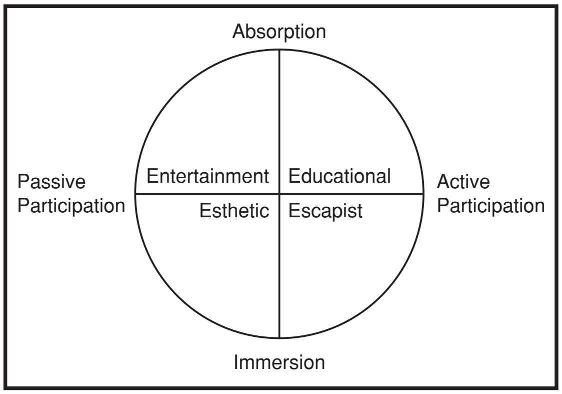

FIGURE 17.6. Realms of experience. Source: Pine and Gilmore (1999).

for more memorable—and more highly valued—experiences" (Pine & Gilmore, p. 12). While the work of the experience stager perishes, the value of the experience lingers, in contrast to service transactions.

Pine and Gilmore have proposed a model of different types of experience (Fig. 17.6). They recommend using this model as a framework for conceptualizing the aspects of each realm that might enhance the particular experience you wish to stage.

> The coupling of these dimensions defines the four "realms" of an experience—entertainment, education, escape, and estheticism—mutually compatible domains that often commingle to form uniquely personal encounters. The kind of experiences most people think of as entertainment occur when they passively absorb the experiences through their senses, as generally occurs when viewing a performance, listening to music, or reading for pleasure.

Pine and Gilmore emphasize that in setting out to design a rich, compelling, and engaging experience, it is not necessary to stay in just one realm or quadrant. While many experiences engage the audience primarily through one of the four realms, most experiences in fact cross boundaries, combining elements from all four realms: the key is to find the best balance for each type of experience. The designer's goal is to find "the sweet spot"—the ideal combination—for any compelling experience to create the optimum experience, one that is memorable and that people want to return to again and again.

17.7 DESIGN MODELS AND METAPHORS

Developing design models and design metaphors will be an important aspect of theory-building, research, and development in the emerging virtual reality medium. A few models and design metaphors have emerged that are specifically for education and training.

	Less Real	**More Real**
1. Dimensionality	2D	3D
2. Motion	Static	Dynamic
3. Interaction	Open Loop	Closed Loop
4. Frame of reference	Outside-In	Inside-Out
	(God's eye)	(User's Eye)
	World-Referenced	Ego-Referenced
5. Multimodal Interaction	Limited	Multimodal
(Enhanced sensory experience)		

FIGURE 17.7. Five components of virtual reality. Adapted from Wickens and Baker (1994). (1) Three-dimensional (perspective and/or stereoscopic) viewing vs. two-dimensional planar viewing. Three-dimensional viewing potentially offers a more realistic view of the geography of an environment than a 2-D contour map. (2) Dynamic vs. static display. A dynamic display appears more real than a series of static images of the same material. (3) Closed-loop (interactive or learner-centered) vs. open-loop interaction. A more realistic closed-loop mode is one in which the learner has control over what aspect of the learning "world" is viewed or visited. That is, the learner is an active navigator as well as an observer. (4) Inside-out (ego-referenced) vs. outside-in (world-referenced) frame-of-reference. The more realistic inside-out frame of reference is one in which the image of the world on the display is viewed from the perspective of the point of ego-reference of the user (that point which is being manipulated by the control). (5) Multimodal interaction (enhanced sensory experience). Virtual environments employ a variety of techniques for user input, including speech recognition and gestures, either sensed through a "data glove" or captured by camera.

Wickens (1993) and Wickens and Baker (1994) have proposed a model of virtual reality parameters that must be considered for instructional design. These analysts suggest that virtual reality can be conceptualized in terms of a set of five features, which are shown in Fig. 17.7. Any one of these five features can be present or absent to create a greater sense of reality. These analysts suggest that, based on these five elements, several justifications can be cited for using virtual reality as an educational tool. These justifications include: (1) Motivational value; (2) Transfer of learning environment; (3) Different perspective; and (4) Natural interface. According to Wickens and Baker (1994),

> We may conceptualize the features of VR in terms of two overlapping goals: that of increasing the naturalness of the interface to reduce the cognitive effort required in navigation and interpretation, and that of creating dynamic interaction and novel perspective. It is important to keep the distinctions between these goals clear as we consider the conditions in which VR can facilitate or possibly inhibit learning. Specifically, we argue that those features of an interface that may reduce effort and increase performance, may actually reduce retention. (p. 4)

Based on this model, these analysts discuss the cognitive issues involved in using virtual reality for task performance and for learning applications. They suggest that virtual reality may prove useful for four types of educational tasks: (1) online performance; (2) off-line training and rehearsal; (3) online comprehension; and (4) off-line learning and knowledge acquisition. These four categories, and the examples of each category that the authors present, clearly reflect emerging training needs linked to high technology, as well as more traditional training needs.

Online performance refers to systems where the virtual environment is providing the operator with direct manipulation capabilities in a remote, or nonviewable environment. One example of this is the operation of a remote manipulator, such as an undersea robot, space shuttle arm, or hazardous waste handler, the control of a remotely piloted vehicle, or the task of navigating through a virtual data base to obtain a particular item. Wickens and Baker (1994) suggest that three general human performance concerns are relevant in these environments. These include: (a) closed-loop perceptual motor performance should be good (that is, errors should be small, reactions should be fast, and tracking of moving targets should be stable); (b) situation awareness should be high; and (c) workload or cognitive efforts should be low.

Concerning off-line training and rehearsal, Wickens and Baker (1994) suggest that virtual environments may serve as a tool for rehearsing critical actions in a safe environment, in preparation for target performance in a less forgiving one. According to Wickens and Baker (1994), "This may involve practicing lumbar injection for a spinal or epidural anesthesia, maneuvering a space craft, carrying out rehearsal flights prior to a dangerous mission, or practicing emergency procedures in an aircraft or nuclear power facility. The primary criterion here is the effective transfer of training from practice in the virtual environment to the true reality target environment" (p. 5). In terms of online comprehension, Wickens and Baker (1994) explain that the goal of interacting with a virtual environment may be to reach insight or understanding regarding the structure of an environment. This type of application is particularly valuable for scientists and others dealing with highly abstract data. Finally, off-line learning and knowledge acquisition concerns the transfer of knowledge, acquired in a virtual environment, to be employed, later in a different more abstract form (Wickens & Baker, 1994).

Wickens (1994) cautions that the goals of good interface design for the user and good design for the learner, while overlapping in many respects, are not identical. He points out that

> a key feature in this overlap is the concern for the reduction in effort; many of the features of virtual reality may accomplish this reduction. Some of these features, like the naturalness of an interface which can replace arbitrary symbolic command and display strings, clearly serve the goals of both. But when effort-reduction features of virtual reality serve to circumvent cognitive transformations that are necessary to understanding and learning the relationships between different facets of data, or of a body of knowledge, then a disservice may be done. (p. 17)

Wickens also recommends that these design considerations should be kept in mind as virtual reality concepts are introduced into education. Also care should be taken to ensure redundancy of presentation formats, exploit the utility of visual momentum, exploit the benefits of closed-loop interaction, and use other principles of human factors design.

Wickens (1994) recommends that related human factors research concerning the characteristics of cognitive processes and tasks that may be used in a virtual environment should be taken into account. These factors include task analysis, including search, navigation, perceptual biases, visual-motor coupling, manipulation, perception and inspection, and learning (including procedural learning, perceptual motor skill learning, spatial learning and navigational rehearsal, and conceptual learning). And Wickens suggests that there are three human factors principles relevant to the design of virtual environments—consistency, redundancy, and visual momentum—which have been shown to help performance and, also, if carefully applied, facilitate learning in such an environment.

A design metaphor for representing the actions of the VR instructional developer has been proposed by researchers at Lockheed (Grant, McCarthy, Pontecorvo, & Stiles, 1991). These researchers found that the most appropriate metaphor is that of a television studio, with a studio control booth, stage, and audience section. The control booth serves as the developer's information workspace, providing all the tools required for courseware development. The visual simulation and interactions with the system are carried out on the studio stage, where the trainee may participate and affect the outcome of a given instructional simulation. The audience metaphor allows passive observation, and if the instructional developer allows it, provides the trainee the freedom of movement within the virtual environment without affecting the simulation. For both the instructional developer and the student, the important spatial criteria are perspective, orientation, scale, level of visual detail, and granularity of simulation (Grant et al., 1991).

17.8 VIRTUAL REALITIES RESEARCH AND DEVELOPMENT

17.8.1 Research on VR and Training Effectiveness

Regian, Shebilske, and Monk (1992) report on empirical research that explored the instructional potential of immersive virtual reality as an interface for simulation-based training. According to these researchers, virtual reality may hold promise for simulation-based training because the interface preserves (a) visual-spatial characteristics of the simulated world, and (b) the linkage between motor actions of the student and resulting effects in the simulated world. This research featured two studies. In one study, learners learned how to use a virtual control console. In the other study, learners learned to navigate a virtual maze. In studying spatial cognition, it is useful to distinguish between small-scale and large-scale space (Siegal, 1981). Small-scale space can be viewed from a single vantage point at a single point in time. Large-scale space extends beyond the immediate vantage point of the viewer, and must be experienced across time. Subjects can construct functional representations of large-scale space from sequential, isolated views of small-scale space presented in two-dimensional media such as film (Hochberg, 1986) or computer graphics (Regian, 1986). Virtual reality, however, offers the possibility of presenting both small-scale and large-scale spatial information in a three-dimensional format that eliminates the need for students to translate the representation from 2-D to 3-D. The resulting reduction in cognitive load may benefit training. Regian et al. (1992) investigated the use of immersive virtual reality to teach procedural tasks requiring performance of motor sequences within small-scale space (the virtual console) and to teach navigational tasks requiring configurational knowledge of large-scale space (the virtual maze). In these studies, 31 subjects learned spatial-procedural skills and spatial-navigational skills in immersive virtual worlds accessed with head-mounted display and Dataglove^{TM}. Two VR worlds were created for this research: a virtual console and a virtual maze. Both were designed to support analogs of distinctly different tasks. The first was a procedural console-operations task and the second was a three-dimensional maze-navigation task. Each task involved a training phase and a testing phase. The console data show that subjects not only learned the procedure, but continued to acquire skill while being tested on the procedure, as the tests provided continued practice in executing the procedure. The maze data show that subjects learned three-dimensional, configurational knowledge of the virtual maze and were able to use the knowledge to navigate accurately within the virtual reality.

17.8.2 Research on Learners' Cognitive Visualization in 2-D and 3-D Environments

Merickel (1990, 1991) carried out a study designed to determine whether a relationship exists between the perceived realism of computer graphic images and the ability of children to solve spatially related problems. This project was designed to give children an opportunity to develop and amplify certain cognitive abilities: imagery, spatial relations, displacement and transformation, creativity, and spatially related problem solving. One way to enhance these cognitive abilities is to have students develop, displace, transform and interact with 2-D and 3-D computer-graphics models. The goal of this study was to determine if specially designed 2-D and 3-D computer graphic training would enhance any, or all, of these cognitive abilities. Merickel reports that experiments were performed using 23 subjects between the ages of 8 and 11 who were enrolled in an elementary summer school program in Novato, California. Two different computer apparatuses were used: computer workstations and an immersive virtual reality system developed by Autodesk, Inc. The students were divided into two groups. The first used microcomputers (workstations) equipped with AutoSketch and AutoCAD software. The other group worked with virtual reality. The workstation treatment incorporated three booklets to instruct the subjects on how to solve five different spatial relationship problems. The virtual reality system provided by Autodesk that was used in the virtual reality treatment included an 80386-based MS-DOS microcomputer, a head-mounted display and a VPL DataGlove^{TM}, a Polhemus 6D Isotrak positioning and head-tracking device; Matrox SM 1281 real-time graphics boards; and software developed at Autodesk. The cyberspace part of the project began with classroom training in the various techniques and physical gestures required for moving within and interacting with cyperspace modes. Each child was shown how the DataGlove^{TM} and the head-mounted display would feel by first trying them on without being connected to the computer.

Merickel reports that after the practice runs, 14 children were given the opportunity to don the cyberspace apparatus and interact with two different computer-generated, 3D virtual realities. The DataGlove^{TM} had to be calibrated. Students looked around the virtual world of an office, and using hand gesture commands, practiced moving toward objects and "picked up" objects in the virtual world. Students also practiced "flying" which was activated by pointing the index finger of the hand in the DataGlove^{TM}.

The second cyberspace voyage was designed to have students travel in a large "outdoor" space and find various objects including a sphere, a book, a chair, a racquet, and two cube models—not unlike a treasure hunt. But this treasure hunt had a few variations. One was that the two cube models were designed to see if the students could differentiate between a target model and its transformed (mirrored) image. The students' task was to identify which of the two models matched the untransformed target model. Students were instructed to fly to the models and study them; they were also instructed to fly around the models to see them from different viewpoints before making a choice. Most students were able to correctly identify the target model. Merickel reports that during this second time in cyberspace, most students were flying with little or no difficulty. Their gestures were more fluid and, therefore, so was their traveling in cyberspace. They began to relax and walk around more even though walking movement is restricted by the cables that attach the DataGlove^{TM} and head-mounted display to the tracking devices. Students began to turn or walk around in order to track and find various items. They appeared to have no preconceived notions or reservations about "traveling inside a computer." In sum, these children had become quite proficient with this cutting-edge technology in a very short time.

Merickel reports that four cognitive ability tests were administered to the subjects from both treatment groups. The dependent variable (i.e., spatially related problem solving) was was measured with the Differential Aptitude Test. The three other measures (Minnesota Pager Form Board Test, Mental Rotation Test, and the Torrance Test of Creative Thinking) were used to partial out any effects which visualization abilities and the ability to mentally manipulate two-dimensional figures, displacement and transformation of mental images abilities, and creative thinking might have had on spatially related problem solving.

Merickel concluded that the relationships between perceived realism and spatially related problem solving were inconclusive based on the results of this study, but worthy of further study. Furthermore, Merickel points out that the ability to visualize and mentally manipulate two-dimensional objects are predictors of spatially related problem solving abilities. In sum, Merickel concluded that virtual reality is highly promising and deserves extensive development as an instructional tool.

17.8.3 Research on Children Designing and Exploring Virtual Worlds

Winn (1993) presented an overview of the educational initiatives that are either underway or planned at the Human Interface Technology Lab at the University of Washington: One goal is to establish a learning center to serve as a point of focus for research projects and instructional development initiatives, as well as a resource for researchers in kinesthesiology who are looking for experimental collaborator. A second goal is to conduct outreach, including plans to bring virtual reality to schools as well as pre- and in-service teacher training. Research objectives include the development of a theoretical framework, knowledge construction, and data-gathering about effectiveness of virtual reality for learning in different content areas and for different learners. Specific research questions include: (1) Can children build Virtual Reality worlds?, (2) Can children learn content by building worlds? and (3) Can children learn content by being in worlds built for them? Byrne (1992) and Bricken and Byrne (1993) report on a study that examined this first research issue—whether children can build VR worlds. This study featured an experimental program of week-long summer workshops at the Pacific Science Center where groups of children designed and then explored their own immersive virtual worlds. The primary focus was to evaluate VR's usefulness and appeal to students ages 10 to 15 years, documenting their behavior and soliciting their opinions as they used VR to construct and explore their own virtual worlds. Concurrently, the researchers used this opportunity to collect usability data that might point out system design issues particular to tailoring VR technology for learning applications.

Bricken and Byrne (1993) report that the student groups were limited to approximately 10 new students each week for 7 weeks. Participants were ages 10 years and older. A total of 59 students from ages 10 to 15 self-selected to participate over the 7-week period. The average age of students was 13 years, and the gender distribution was predominantly male (72%). The students were of relatively homogeneous ethnic origin; the majority were Caucasians, along with a few Asian Americans and African Americans. The group demonstrated familiarity with Macintosh computers, but none of the students had worked with 3-D graphics, or had heard of VR before coming to the VR workshops. The Macintosh modeling software package Swivel 3-D^{TM} was used for creating the virtual worlds. Each student research group had access to five computers for 8 hours per day. They worked in groups of two or three to a computer. They used a codiscovery strategy in learning to use the modeling tools. Teachers answered the questions they could, however, the software was new to them as well so they could not readily answer all student questions. On the last day of each session, students were able to get inside their worlds using VR interface technology at the HIT Lab (the desktop Macintosh programs designed by the children with Swivel 3-D^{TM} were converted over for use on more powerful computer workstations). Bricken and Byrne (1993) report that they wanted to see what what these students were motivated to do with VR when given access to the technology in an open-ended context. The researchers predicted that the participants would gain a basic understanding of VR technology. In addition, the researchers expected that in using the modeling software, this group might learn to color, cluster, scale, and link graphic primatives (cubes, spheres), to assemble simple geometric 3-D environments, and to specify basic interactions such as "grab a ball, fly it to the box, drop it in."

The participants' experience was designed to be a hands-on student-driven collaborative process in which they could learn about VR technology by using it and learn about virtual worlds by designing and constructing them. Their only constraints in this task were time and the inherent limitations of the technology. At the end of the week, students explored their worlds one at a time, while other group members watched what the participant was seeing on a large TV monitor. Although this was not a networked VR, it was a shared experience in that the kids "outside" the virtual world conversed with participants, often acting as guides. Bricken and Byrne (1993) report that the virtual worlds constructed by the students are the most visible demonstrations of the success of the world-building activity. In collecting information on both student response and system usability, Bricken and Byrne (1993) reported that they used three different information-gathering techniques. Their goal was to attain both cross-verification across techniques and technique-specific insights. They videotaped student activities, elicited student opinions with surveys, and collected informal observations from teachers and researchers. Each data source revealed different facets of the whole process. Bricken and Byrne (1993) reported that the students who participated in these workshops

> were fascinated by the experience of creating and entering virtual worlds. Across the seven sessions, they consistently made the effort to submit a thoughtfully planned, carefully modeled, well-documented virtual world. All of these students were motivated to achieve functional competence in the skills required to design and model objects, demonstrated a willingness to focus significant effort toward a finished product, and expressed strong satisfaction with their accomplishment. Their virtual worlds are distinctive and imaginative in both conceptualization and implementation. Collaboration between students was highly cooperative, and every student contributed elements to their group's virtual world. The degree to which student-centered methodology influenced the results of the study may be another fruitful area for further research. (p. 204)

Bricken and Byrne (1993) report that students demonstrated rapid comprehension of complex concepts and skills.

> They learned computer graphics concepts (real-time versus batch rendering, Cartesian coordinate space, object attributes), 3-D modeling techniques, and world design approaches. They learned about VR concepts ("what you do is what you get," presence) and enabling technology (head-mounted display, position and orientation sensing, 6-D interface devices). They also learned about data organization: Students were required by the modeling software to link graphical elements hierarchically, with explicit constraints; students printed out this data tree each week as part of the documentation process. (p. 205)

According to these researchers, this project revealed which of the present virtual reality system components were usable, which were distracting, and which were dysfunctional for this age group. The researchers' conclusion is that improvement in the display device is mandatory; the resolution was inadequate for object and location recognition, and hopeless for perception of detail. Another concern is with interactivity tools. This study showed that manipulating objects with the DataGlove^{TM} is awkward and unnatural. Bricken and Byrne (1993) also report that the head-mounted display has since been replaced with a boom-mounted display for lighter weight and a less intrusive cable arrangement. In sum, students, teachers, and researchers agreed that this exploration of VR tools and technology was a successful experience for everyone involved (Bricken & Byrne, 1993; Byrne, 1992). Most important was the demonstration of students' desires and abilities to use virtual reality *constructively* to build expressions of their knowledge and imagination. They suggest that virtual reality is a significantly compelling environment in which to teach and learn. Students could learn by creating virtual worlds that reflected the evolution of their skills and the pattern of their conceptual growth. For teachers, evaluating comprehension and competence would become experiential as well as analytical, as they explored the worlds of thought constructed by their students.

17.8.4 Research on Learners in Experiential Learning Environments

An experiential learning environment was developed and studied at the Boston Computer Museum, using immersive virtual reality technology (Gay, 1993, 1994b; Greschler, 1994). The Cell Biology Project was funded by the National Science Foundation. David Greschler, of the Boston Computer Museum, explains that in this case, the NSF was interested in testing how VR can impact informal education (that is, self-directed, unstructured learning experiences). So an application was developed in two formats (immersive VR and flat panel screen desktop VR) to study virtual reality as an informal learning tool. A key issue was: what do learners do once they're in the virtual world? In this application, participants had the opportunity to build virtual human cells and learn about cell biology. As Greschler explains, they looked at

> the basics of the cell. First of all the cell is made up of things called organelles. Now these organelles, they perform different functions. Human cells: if you open most textbooks on human cells they show you one picture of one human cell and they show you organelles. But what we found out very quickly, in fact, is that there are different kinds of human cells. Like there's a neuron, and there's an intestinal cell, and there's a muscle cell. And all those cells are not the same at the basic level. They're different. They have different proportions of organelles, based on the kinds of needs that they have. For instance, a muscle cell needs more power, because it needs to be doing more work. And so as a result, it needs more mitochondrias, which is really the powerhouse. So we wanted to try to get across these basic principles.

In the Cell Biology Virtual World, the user would start by coming up to this girl within the virtual world who would say, "Please help me, I need neuron cells to think with, muscle cells to move with, and stomach cells to eat with." So you would either touch the stomach or the leg or the head and "you'd end up into the world where there was the neuron cell or the muscle cell or the intestinal cell and you would have all the pieces of that cell around you and marked and you would actually go around and build." You would go over, pick up the mitochondria, and move it into the cell. As Greschler (1994) explains, "there's a real sense of accomplishment, a real sense of building. And then, in addition to that, you would build this person." Greschler reports that before trying to compare the different media versions of the cell biology world, "[the designers] sort of said, we have to make sure our virtual world is good and people like it. It's one thing to just go for the educational point of view but you've got to get a good experience or else big deal. So the first thing we did, we decided to build a really good world. And be less concerned about the educational components so much as a great experience." That way, people would want to experience the virtual world, so that learning would occur. A pilot virtual world was built and tested and improvements were made. Greschler reports,

> . . . we found that it needed more information. There needs to be some sort of introduction to how to navigate in the virtual world. A lot of people didn't know how to move their hand tracker and so on. So what we did is we felt like, having revised the world, we'd come up with a world that was . . . I suppose you could say "Good." It was compelling to people and that people liked it. To us that was very important.

They defined virtual reality in terms of immersion, natural interaction (via hand trackers), and interactivity—the user could control the world and move through it at will by walking around in the head mount (within a perimeter of 10 × 10 feet).

Testing with visitors at the Boston Computer Museum indicated that the nonimmersive desktop group consistently was able to retain more information about the cells and the organelles (at least for the short term). This group retained more cognitive information. However, in terms of level of engagement, the immersive VR group was much stronger with that. They underestimated the amount of time they were in the virtual world by, on average, more than 5 minutes, far more than the other group. In terms of conclusions, Greschler (1994) suggests that immersive virtual reality "probably isn't good for getting across factual information. What it might be good for is more general experiences; getting a sense for how one might do things like travel. I mean the whole idea [of the Cell Biology Project] is traveling into a cell. It's more getting a sense of what a cell is, rather than the facts behind it. So it's more perhaps like a visualization tool or something just to get a feel for certain ideas rather than getting across fact a, b, or c."

Furthermore, "I think the whole point of this is it's all new . . . We're still trying to figure out the right grammar for it, the right uses for it. I mean video is great to get across a lot of stuff. Sometimes it just isn't the right thing to use. Books are great for a lot of things, but sometimes they're just not quite right. I think what we're still trying to figure out is what is that 'quite right' thing for VR. There's clearly something there—there's an incredible level of engagement. And concentration. That's I think probably the most important thing." Greschler (1994) thinks that virtual reality will be a good tool for informal learning. "And my hope in fact, is that it will bring more informal learning into formal learning environments because I think that there needs to be more of that. More open-endedness, more exploration, more exploratory versus explanatory" (Greschler, 1994).

17.8.5 Research on Attitudes Toward Virtual Reality

Heeter (1992, 1994) has studied people's attitudinal responses to virtual reality. In one study, she studied how players responded to BattleTech, one of the earliest virtual reality location-based entertainment systems. Related to this, Heeter has examined differences in responses based on gender, since a much higher proportion of BattleTech players are males (just as with videogames). Heeter conducted a study of BattleTech players at the Virtual Worlds Entertainment Center in Chicago.

In the BattleTech study, players were given questionnaires when they purchased playing times, to be turned in after the game (Heeter, 1992). A total of 312 completed questionnaires were collected, for a completion rate of 34 percent. (One questionnaire was collected per person; at least 45 percent of the 1,644 games sold during the sample days represented repeat plays within the sample period.) Different questionnaires were administered for each of three classes of players: novices, who had played 1 to 10 BattleTech games ($n = 223$; veterans, who had played 11 to 50 games ($n = 42$); and masters, who had played more than 50 games ($n = 47$).

According to Heeter (1992), the results of this study indicate that BattleTech fits the criteria of Czikszentmihalyi's (1990) model of "flow" or optimal experience: (1) require learning of skills; (2) have concrete goals; (3) provide feedback; (4) let person feel in control; (5) facilitate concentration and involvement; and (6) are distinct from the everyday world ("paramount reality"). Heeter (1992) explains:

> BattleTech fits these criteria very well. Playing BattleTech is hard. It's confusing and intimidating at first. Feedback is extensive and varied. There are sensors; six selectable viewscreens with different information which show the location of other players (nearby and broader viewpoint), condition of your 'Mech, heat sensors, feedback on which 'Mechs are in weapon range (if any), and more. After the game, there is additional feedback in the form of individual scores on a video display and also a complete printout summarizing every shot fired by any of the six concurrent players and what happened as a result of the shot. In fact, there is far more feedback than new players can attend to. (p. 67).

According to Heeter (1992), "BattleTech may be a little too challenging for novices, scaring away potential players. There is a tension between designing for novices and designing for long term play. One-third of novices feel there are too many buttons and controls" (p. 67). Novices who pay to play BattleTech may feel intimidated by the complexity of BattleTech controls and some potential novices may even be so intimidated by that complexity that they are scared away completely, that complexity is most likely scaring other potential novices away. But among veterans and masters, only 14 percent feel there are too many buttons and controls, while almost 40 percent say it's just right.).

Heeter (1992) reports that if participants have their way, virtual reality will be a very social technology. The BattleTech data identify consistently strong desires for interacting with real humans in addition to virtual beings and environments in virtual reality. Just 2 percent of respondents would prefer to play against computers only. Fifty-eight percent wanted to play against humans only, and 40 percent wanted to play against a combination of computers and humans. Respondents preferred playing on teams (71 percent) rather than everyone against everyone (29 percent). Learning to cooperate with others in team play was considered the most challenging BattleTech skill by masters, who estimated on average that it takes 56 games to learn how to cooperate effectively. Six players at a time was not considered enough. Veterans rated "more players at once" 7.1 on a 10-point scale of importance of factors to improve the game; more players was even more important to masters (8.1). In sum, Heeter concludes that "Both the commercial success of BattleTech and the findings of the survey say that BattleTech is definitely doing some things right and offers some lessons to designers of future virtual worlds" (p. 67).

Heeter (1992) reports that BattleTech players are mostly male. Masters are 98 percent male, veterans are 95 percent male, and novices are 91 percent male. BattleTech is not a child's game. Significant gender differences were found in reactions to BattleTech. Because such a small percentage of veterans and masters were female, gender comparisons for BattleTech were conducted only among novices. (Significant differences using one-way ANOVA for continuous data and Crosstabs for categorical data are identified in the text by a single asterisk for cases of $p < .05$ and double asterisk for stronger probability levels of $p < .01$.) Specifically, 2 percent of masters, 5 percent of veterans, and 9 percent of novices were female. This small group of females who chose to play BattleTech might be expected to be more similar to the males who play BattleTech than would females in general. Even so, gender differences in BattleTech responses were numerous and followed a distinct, predictable stereotypical pattern. For example, on a scale from 0 to 10, female novices found BattleTech to be LESS RELAXING (1.1 vs. 2.9) and MORE EMBARRASSING (4.1 vs. 2.0) than did male novices. Males were more aware of where their opponents were than females were (63 vs. 33 percent) and of when they hit an opponent (66 vs. 39 percent). Female BattleTech players enjoyed blowing people up less than males did, although both sexes enjoyed blowing people up a great deal (2.4 vs. 1.5 out of 7, where 1 is VERY MUCH). Females reported that they did not understand how to drive the robot as well (4.6 compared to 3.1 for males where 7 is NOT AT ALL). Fifty-seven percent of female novices said they would prefer that BattleTech cockpits have fewer than its 100+ buttons and controls, compared to 28 percent of male novices who wanted fewer controls.

Heeter (1994) concludes, "Today's consumer VR experiences appear to hold little appeal for the female half of the population. Demographics collected at the BattleTech Center in Chicago in 1991 indicated that 93 percent of the players were male." At FighterTown the proportion was 97 percent. Women also do not play today's video games. Although it is clear that women are not attracted to the current battle-oriented VR experiences, what women DO want from VR has received little attention. Whether from a moral imperative to enable VR to enrich the lives of both sexes, or from a financial incentive of capturing another 50 percent of the potential marketplace, or from a personal curiousity about the differences between females and males, insights into this question should be of considerable interest.

In another study, Heeter (1993) explored what types of virtual reality applications might appeal to people, both men and women. Heeter conducted a survey of students in a large-enrollment "Information Society" Telecommunications course at Michigan State University, where the students were willing to answer a 20-minute questionnaire, followed by a guest lecture about consumer VR games. The full study was conducted with 203 students. Sixty-one percent of the 203 respondents were male. Average age was 20, ranging from 17 to 32. To summarize findings from this exploratory study, here is what women DO want from VR experiences. They are strongly attracted to the idea of virtual travel. They would also be very interested in some form of virtual comedy, adventure, MTV, or drama. Virtual presence at live events is consistently rated positively, although not top on the list. The females in this study want very much to interact with other live humans in virtual environments, be it virtual travel, virtual fitness, or other experiences. If they play a game, they want it to be based most on exploration and creativity. Physical sensations and emotional experiences are important. They want the virtual reality experience to have meaningful parallels to real life.

Heeter (1993) reported that another line of virtual reality research in the Michigan State University Comm Tech Lab involves the development of virtual reality prototype experiences demonstrating different design concepts. Data is collected from attendees at various conferences who try using the prototype.

17.8.6 Research on Special Education Applications of VR

Virtual reality appears to offer many potentials as a tool that can enhance capabilities for the disabled in the areas of communication, perception, mobility, and access to tools (Marcus, 1993; Murphy, 1994; Middleton, 1993; Pausch, Vogtle, & Conway, 1991; Pausch & Williams, 1991; Treviranus, 1993; Warner and Jacobson, 1992). Virtual reality can extend, enhance, and supplement the remaining capabilities of people who must contend with a disability such as deafness or blindness. And virtual reality offers potential as a rehabilitation tool. Delaney (1993) predicts that virtual reality will be instrumental in providing physical capabilities for persons with disabilities in the following areas:

1. Individuals with movement restricting disabilities could be in one location while their "virtual being" is in a totally different location—this opens up possibilities for participating in work, study, or leisure activities anywhere in the world, from home, or even a hospital bed
2. Individuals with physical disabilities could interact with the real world through robotic devices they control from within a virtual world
3. Blind persons could navigate through or among buildings represented in a virtual world made up of 3-D sound images—this will be helpful to rehearse travel to unfamiliar places such as hotels or conference centers
4. Learning disabled, cognitively impaired, and brain injured individuals could control work processes that would otherwise be too complicated by transforming the tasks into a simpler form in a VR environment
5. Designers and others involved in the design of prosthetic and assistive devices may be able to experience the reality of a person with a disability—they could take on the disability in virtual reality, and thus experience problems firsthand, and their potential solutions.

At a conference on "Virtual Reality and Persons with Disabilities" that has been held annually in San Francisco since 1992 (sponsored by the Center on Disabilities at California State University Northridge) researchers and developers report on their work. This conference was established partly in response to the national policy, embedded in two separate pieces of legislation: Section 504 of the Rehabilitation Act of 1973, and the Americans with Disabilities Act (ADA). Within these laws is the overriding mandate for persons with disabilities to have equal access to electronic equipment and information. The recently-enacted American Disabilities Act offers potential as a catalyst for the development of virtual reality technologies. Harry Murphy (1994), the Director of the Center on Disabilities at California State University Northridge, explains that "Virtual reality is not a cure for disability. It is a helpful tool, and like all other helpful tools, television and computers, for example, we need to consider access" (p. 59). Murphy (1994) argues that, "Virtuality and virtual reality hold benefits for everyone. The same benefits that anyone might realize have some special implications for people with disabilities, to be sure. However, our thinking should be for the general good of society, as well as the special benefits that might come to people with disabilities" (p. 57). Many virtual reality applications for persons with disabilities are under development, showing great promise, but few have been rigorously tested. One award-winning application is the Wheelchair VR application from Prairie Virtual Systems of Chicago (Trimble, 1993). With this application, wheelchair-bound individuals "roll through" a virtual model of a building such as a hospital that is under design by an architect and tests whether the design supports wheelchair access. Related to this, Dean Inman, an orthopedic research scientist at the Oregon Research Institute is using virtual reality to teach kids the skills of driving wheelchairs (Buckert-Donelson, 1995).

Virtual Technologies of Palo Alto, California has developed a "talking glove" application that makes it possible for deaf individuals to "speak" sign language while wearing a wired glove and have their hand gestures translated into English and printed on a computer screen, so that they can communicate more easily with those who do not speak sign language. Similar to this, Eberhart (1993) has developed a much less powerful non-commercial system that utilizes the Power Glove^{TM}toy as an interface, together with an Echo Speech Synthesizer. Eberhart (1993) is exploring neural networks in conjunction with the design of VR applications for the disabled. Eberhart trained the computer to recognize the glove movements by training a neural network.

Newby (1993) described another much more sophisticated gesture-recognition system than the one demonstrated by Eberhart. In this application, a DataGlove^{TM} and Polhemus tracker are employed to measure hand location and finger position to train for a number of different hand gestures. Native users of American Sign Language (ASL) helped in the development of this application by providing templates of the letters of the manual alphabet, then giving feedback on how accurately the program was able to recognize gestures within various tolerance calibrations. A least-squares algorithm was used to measure the difference between a given gesture and the set of known gestures that the system had been trained to recognize.

Greenleaf (1993) described the GloveTalker, a computer-based gesture-to-speech communication device for the vocally impaired that uses a modified DataGlove™. The wearer of the GloveTalker speaks by signaling the computer with his or her personalized set of gestures. The DataGlove™ transmits the gesture signals through its fiber optic sensors to the Voice Synthesis System, which speaks for the DataGlove™ wearer. This system allows individuals who are temporarily or permanently impaired vocally to communicate verbally with the hearing world through hand gestures. Unlike the use of sign language, the GloveTalker does not require either the speaker or the listener to know American Sign Language (ASL). The GloveTalker itself functions as a gesture interpreter: the computer automatically translates hand movements and gestures into spoken output. The wearer of the GloveTalker creates a library of personalized gestures on the computer that can be accessed to rapidly communicate spoken phrases. The voice output can be sent over a computer network or over a telephone system, thus enabling vocally impaired individuals to communicate verbally over a distance. The GloveTalker system can also be used for a wide array of other applications involving data gathering and data visualization. For example, an instrumented glove is used to measure the progress of arm and hand tremors in patients with Parkinson's disease.

The Shepherd School, the largest special school in the United Kingdom, is working with a virtual reality research team at Nottingham University (Lowe, 1994). The Shephard School is exploring the benefits of virtual reality as a way of teaching children with complex problems to communicate and gain control over their environment.

Researchers at the Hugh Macmillan Center in Toronto, Canada are exploring virtual reality applications involving Mandala and the Very Nervous System, a responsive musical environment developed by artist David Rokeby that is activated by movement so that it "plays" interactive musical compositions based on the position and quality of the movement in front of the sensor; the faster the motions, the higher the tones (Treviranus, 1993). Rokeby has developed several interactive compositions for this system (Cooper, 1995).

Salcedo and Salcedo (1993) of the Blind Children Learning Center in Santa Ana, California report that they are using the Amiga computer, Mandala software, and a videocamera to increase the quantity and quality of movement in young children with visual impairments. With this system, children receive increased feedback from their movements through the musical sounds their movements generate. Related to this is the VIDI MICE, a low-cost program available from Tensor Productions which interfaces with the Amiga computer (Jacobs, 1991).

Massof (1993) reports that a project is underway (involving collaboration by Johns Hopkins University, NASA, and the Veterans Administration) where the goal is to develop a head-mounted video display system for the visually impaired that incorporates custom-prescribed, real-time image processing designed to enhance the vision of the user. A prototype of this technology has been developed and is being tested.

Nemire, Burke, and Jacoby (1993) of Interface Technologies in Capitola, California report that they have developed a virtual learning environment for physics instruction for disabled students. This application has been developed to provide an immersive, interactive, and intuitive virtual learning environment for these students.

Important efforts at theory building concerning virtual reality and persons with disabilities have been initiated. For example, Mendenhall and Vanderheiden (1993) have conceptualized two classification schemes (virtual reality versus virtual altered reality) for better understanding the opportunities and barriers presented by virtual reality systems to persons with disabilites. And Marsh, Meisel, and Meisel (1993) have examined virtual reality in relation to human evolution. These researchers suggested that virtual reality can be considered a conscious reentering of the process of evolution. Within this reconceptualization of the context of survival of the fittest, disability becomes far less arbitrary. In practical terms, virtual reality can bring new meaning to the emerging concepts of universal design, rehabilitation engineering, and adaptive technology.

Related to this, Lasko-Harvill (1993) commented,

> In Virtual Reality the distinction between people with and without disabilities disappears. The difference between Virtual Reality and other forms of computer simulation lies in the ability of the participant to interact with the computer generated environment as though he or she was actually inside of it, and no one can do that without what are called in one context "assistive" devices and another "user interface" devices.

This is an important comparison to make, pointing out that user interfaces can be conceived as assistive technologies for the fully abled as well as the disabled. Lasko-Harvill explains that virtual reality can have a leveling effect between abled and differently abled individuals. This is similar to what the Lakeland Group found in their training program for team-building at Virtual Worlds Entertainment Centers (McGrath, 1994; McLellan, 1994a).

17.9 IMPLICATIONS

This emerging panoply of technologies—virtual realities—offers many potentials and implications. This chapter has outlined these potentials and implications, although they are subject to change and expansion as this very new set of educational technologies, virtual realities, develops. It is important to reiterate that since virtual realities as a distinct category of educational technology are little more than a decade old, research and development are at an early stage. And rapid technological improvements mean that existing research concerning virtual realities must be assessed carefully since it may be rapidly outdated with the advent of improved technological capabilities such as graphics resolution for visual displays, increased processing speed, ergonomically enhanced, lighter-weight interface design, and greater mobility. The improvements in technology over the past decade give testament to the speed of technological improvements that researchers must keep in mind. Research and development programs are underway throughout the world to study the potentials of virtual reality technologies and applications, including education and training. There is a wealth of possibilities for research. As discussed in this chapter, the agenda for needed research is quite broad in scope. And as many analysts have pointed out, there is a broad base of research in related fields such as simulation and human perception that can and must be considered in establishing a research agenda for virtual reality overall, and concerning educational potentials of virtual reality in particular. Research can be expected to expand as the technology improves and becomes less expensive.

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