15. VIRTUAL REALITIES

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15.1 INTRODUCTION

Virtual realities are a set of newly emerging educational technologies, less than a decade old (Hamit, 1993; Aukstalnis & Blatner, 1992; Helsel, 1992a, 1992b, 1992c; Middleton, 1992; Pimentel & Teixiera, 1992; Helsel & Roth, 1991; Rheingold, 1991). 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 immersed in the present (Jacobson, 1993a). This technology was devised to enable people to deal with information more easily. YR 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. YR 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.

Virtual reality is a new type of computer tool that adds vast power to scientific visualization. Buxton (1992, p. 27) 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.

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; Hon, 1991; Dowding, 1991, 1992; Minsky, 1991; Marcus, 1994). 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 a very early stage of development. To date there is very little research, especially concerning the educational implications of this technology. However, some 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 already been initiated concerning this emerging technology and its potentials in education and training.

15.2 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; Harrison, 1972; W. Gibson, 1986; 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 3 decades. In the 1960s, Ivan Sutherland created one of the pioneering virtual-reality systems, which incorporated a head-mounted display (Sutherland, 1965, 1968) 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 simulate accurately and display the structure of molecules. Brooks's work developed into a major virtual-reality research initiative at the University of North Carolina (Hamit, 1993; Rheingold, 1991; Robinett, 1991).

In 1961, Mortin 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 1 960s and 1 970s, 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 SuperCockpit, which allows pilots to fly ultra-high-speed aircraft using only head, eye, and hand movements. The director of the SuperCockpit project, Tom Furness, is now the director of the Human Interface Technology Lab at the University of Washington, a leading YR R&D center, and VR research continues at Wright-Patterson Air Force Base (Auburn, 1993; Stytz, 1993, 1994). Flight simulators have been used extensively and effectively for pilot training since the 1920s (Lauber & Fouchee, 1981; Woolley, 1992; Bricken & Byrne, 1993).

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, 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, p. 149) 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.

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 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).

15.3 DIFFERENT KINDS OF VIRTUAL REALTY

There is more than one type of virtual reality. Furthermore, there are different schemas for classifying various types of virtual reality. Jacobson (1993a) suggests that there are four types of virtual realities: (1) immersive virtual reality, (2) desktop virtual reality (i.e., low-cost home-brew 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. 15-1). According to Thurman and Mattoon (1994, p. 57),

> 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 which correspond to natural laws. On the right side of the scale, VRs represent abstract ideas that are completely novel and may not even resemble the real world.

Thurman and Mattoon (1994) also identify an "integration dimension" that focuses on how human beings 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 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. 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.

15.3.1 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 that make it look and act real in terms of visual perception and, in some cases, aural and tactile perception (Brooks, 1988; Trubitt, 1990; Begault, 1991; Markoff, 1991; Minsky, 1991; Gehring, 1992). 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 GloveTM, used as an interface with Nintendo Games, is a low-cost design based on the DataGloveTM from VPL Research, Inc. The Power GloveTM failed as a toy, but it has achieved some success as

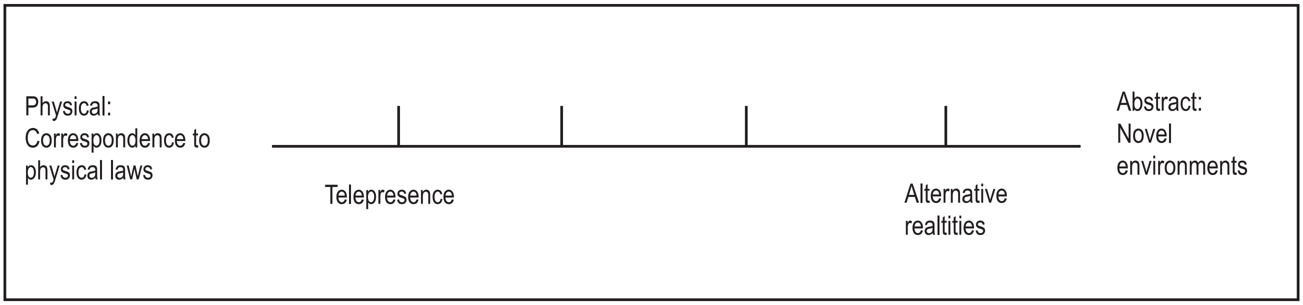

Figure 15-1. Thurston and Mattoon's verity scale for virtual reality. (Adapted from Thurston & Mattoon, 1994.)

an interface device in some low-cost virtual-reality systems, 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 GloveTM as an input device with Amiga, Macintosh, or IBM computers (Eberhart, 1993; Stampe, Roehl & Eagan, 1993; Jacobson, 1994; Hollands, 1995).

15.3.2 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. One application of augmented reality is in aviation, where certain controls can be highlighted, for example, the controls needed to land an airplane. And many medical applications are under development (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).

15.3.3 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. 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,* which 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,* directed by James Cameron, *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, n.d.).

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 (Schiphorst, 1992). Using *LifeForms,* it is possible to learn a great deal about the design process without actually rehearsing and mounting a performance.

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 use VR to document witnesses' descriptions of crime scenes. Similarly, the FBI uses *Virtus WalkThrough* as a training tool at the FBI Academy and as a site visualization tool in hostage crisis situations.

15.3.4 Mirror World

In contrast to the first-person systems described above, Mirror World (Projected Realities) provides 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, 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 video-phones.

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).

15.3.5 Waldo World

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.

One example of a Waldo World VR application is the Virtual ActorsTM 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" that tracks the actor's eyebrows, cheek, head, chin, and lip movements, allowing these features 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 & Jacobson, 1992; Warner, 1993). 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 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 BirdsTM 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.

15.3.6 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; 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; 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.

15.3.7 Cab Simulator Environment

This is another type of "first-person" virtual-reality technology that is essentially an extension of the traditional simulator (see 17.4). 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.

15.3.8 Cyberspace

The term *cyberspace* was coined by William Gibson in the science fiction novel *Neuromancer* (1986), that 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 (Schrage, 1991; Miley, 1992; Baecker, 1993; Bruckman & Resnick, 1993; Coleman, 1993; Wexelblat, 1993).

Habitat, designed by Chip Morningstar and F Randall Fanner (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 on-line 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; Moshell & Hughes, 1993, 1994a, 1994b). This system is built on 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.

CyberCity, an interactive graphical world, is currently being added as a section of CompuServe (Van Nedervelde, 1994). This is only one example of an increasing trend toward graphic interfaces in cyberspace, which is most clearly exemplified by graphical browses, such as MOSAIC. However, systems like CyberCity and Habitat are interactive virtual worlds rather than a hypertextual graphic user interface (GUI) system (see 21.4) like MOSAIC.

There is an electronically networked coffee house (Galloway & Rabinowitz, 1992). The Electronic Cafe International, headquartered in Santa Monica, California, links people at about 60 sites around the globe via video and computer for talk, music, and performance art conducted jointly by people at the various sites.

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 war games 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 also participants' actions in the virtual tanks are monitored, revised, and 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 changed for different war game scenarios (Hamit, 1993; Sterling, 1993).

15.3.9 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, children at different sites across the U.S. have the opportunity to teleoperate the unmanned submarine Jason, the namesake for this innovative science education project directed by Robert Ballard, a scientist at the Woods Hole Oceanographic Institute (EDS, 1991; Ulman, 1993; McLellan, 1995). 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 will go 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 U.S. can take turns driving the TROV in Antarctica.

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.

15.4 INTRODUCTION TO VIRTUAL REALITY APPLICATIONS IN EDUCATION TRAINING

Virtual reality appears to offer educational potentials in the following areas: (1) data gathering and visualization, (2) project planning and design, (3) design of interactive training systems, (4) virtual field trips, and (5) 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 (Pausch, Vogtle & Conway, 1991; Pausch & Williams, 1991; Knapp & Lusted, 1992; Warner & Jacobson, 1992; Delaney, 1993; Trimble, 1993; Murphy, 1994; Sklaroff, 1994). 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—and concommitantly, virtual reality offers potentials as a training tool linked to these professional applications (Goodlett, 1990; Jacobson, 1992; Hyde & Loftin, 1993; Hughes, 1993; Donelson, 1994; Dunkley, 1994). For example, just as virtual reality is used as a tool by surgeons, it can be used by medical students training to become surgeons.

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. 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 (Stenger, 1991; Frenkel, 1994; Laurel, 1994; Teixeira, 1994a, 1994b). This trend is expanding (Krueger, 1991; Treviranus, 1993; Brill, 1995; Cooper, 1995). 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 (Smith, 1993). This has important implications for education, as demonstrated by Bricken and Byrne's (1993) research (described later in this chapter), as well as other projects.

One of VR's most powerful capabilities in relation to education is as a data-gathering and feedback tool on human performance (Hamilton, 1992; Greenleaf, 1994; Lampton, Knerr, Goldberg, Bliss, Moshell & Blau, 1994; McLellan, 1994b). Greenleaf Medical has developed a modified version of the VPL DataGloveTM 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). 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. 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 battle tank war game 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 DataGloveTM, 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* (see 12.3) (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, p. 11) points out that:

> Education is perhaps the area of VR which has some of the greatest potential for improvement through the application of advanced technology. The lack of funding to place VR systems (or, in many cases, more modest educational technology) in public K- 12 schools is the major impediment in this area. There are almost no articles in the literature describing research and potential applications in progress which fall clearly in the domain of education in K- 12 or college.

Nonetheless, a few secondary schools have started to use virtual-reality technology, including the Academy for the Advancement of Science and Technology in Hackensack, New Jersey, and the West Denton High School in Newcastleon-Tyne in Great Britain, and Kelly Walsh High School in Natrona County, Wyoming. Gay (1 994a) describes how immersive virtual reality was implemented in Natrona County "on a school budget" using public-domain software and other resources. And there have been experimental programs where children are introduced to virtual-reality technology, such as the programs by Bricken and Byrne (1993) and Merickel (1992), which are described later in this chapter. In addition, desktop VR applications featuring Virtus WalkThrough are used increasingly in K-12 schools.

East Carolina State University, in Greenville, North Carolina, has established a Virtual Reality and Education Lab (VREL), which 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 Walk-Through Uses in the Classroom,* and *Virtual Reality: 10 Questions and Answers.* Related to this, there are currently two Internet listservs concerning VR and education: listserv@mcmusemc.maricopa.edu (subscribe cbnvee your name) and listserv @juvm.stjohns.edu (subscribe VirtEd your name). In addition, there are several published reference guides to virtual reality, including *Information Sources for Virtual Reality: A Research Guide,* by Robert Carande (1993); *Virtual Reality: A Selected Bibliography,* by Hilary McLellan (1992); and *Virtual Reality: An International Directory of Research Projects,* edited by Jeremy Thompson (1993).

Many museums are adopting virtual reality for displays as well as educational programs (Lantz, 1992; Britton, 1994; O'Donnell, 1994; Greschler, 1994; Wagner, 1994; Wisne, 1994; Brill, 1994b, 1994c, 1995). The Boston Computer Museum carried out a research project, funded by NSF, to study learners in an experiential learning environment (Gay, 1994b; Greschler, 1994). This research will be discussed in detail in this chapter *(15.8.4).* And other museum projects are providing useful information concerning effective design and implementation of educational VR applications, such as the social dimension of the Virtual Hoops application discussed earlier. Kellogg, Carroll, and Richards (1991) present a brilliant scenario of "A Natural History Museum Cyberspace," describing how interactive VR museum displays can be designed to support learning. Carl Loeffler of Carnegie Mellon University directs a project featuring the Networked Virtual Art Museum, an art museum that joins telecommunications and virtual reality (Loeffler, 1993; Brill, 1994a: Jacobson, 1994b; Holden, 1992).

Newby (1993, p. 11) 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.

So far, most educational applications of virtual reality have been developed for professional training in highly technical fields such as medical education, astronaut training, and military training (Merril, 1993, 1995; Eckhouse, 1993). 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 (Auburn, 1992; Fritz, 1991; Gambicki & Rousseau, 1993; Hamit, 1993; Sterling, 1993; Stytz, 1993, 1994; Dovey, 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. Also, at least one virtual-reality software program, Sense8's WorldToolKit, can be ported between different computer systems.

NASA has developed a number of virtual environment R&D projects, including the Hubble Telescope Rescue Mission training project, the Space Station Coupola training project, and the shared virtual environment where astronauts can practice reconnoitering outside the space shuttle for joint training, human factors, and engineering design (Dede, Loftin & Salzrnan, 1994; Loftin, 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, Christopher Dede, and other researchers are working on further initiatives concerning VR and education at the Johnson Space Center (Dede, 1990, 1992, 1993; Dede, Loftin & Salzman, 1994).

In terms of medical training, several companies have introduced surgical simulators (see 17.4) that feature virtual reality, including both visual and tactile feedback (Satava, 1992; Stix, 1992; Satava, 1993; Hon, 1993, 1994; Marcus, 1994; Merril, 1993, 1994, 1995; Brennan, 1994; Burrow, 1994; McGovern, 1994; Merril, Roy, Merril & Raju, 1994; Rosen, 1994; Spritzer, 1994; Taubes; 1994b; Weghorst, 1994). Merril (1993, p. 35) explains:

> Anatomy is three-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.

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).

Related to this, virtual reality is under exploration as a therapeutic tool. For example, Lamson (1994) reports that the Kaiser-Permanente Medical Group in California is using virtual reality as a tool with patients who are afraid of heights. And 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 distractor," distracting and entertaining the patient while the dentist is working on the patient's teeth.

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

Since virtual reality is such a 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 3 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 fine-tunes 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. Many analysts (Henderson, 1991; Laurel, 1991; Biocca, 1992a, 1992b; Heeter, 1992; 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; Waldern, 1994; Taubes, 1994a). 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
5. Evaluation metrics and calibration procedures

Human factors considerations will need careful attention (Pausch, Crea & Conway, 1992; Piantanida, 1993, 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, p. 56) 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 (Al) 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.”

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? (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, and 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 capabilities included instructional guidance and feedback to the student and the capture of the playback of a session. Such capabilities should be integral features of a VE system (Vol. 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. Avoiding many hardware fabrication costs
5. Disassembling in seconds the computer-generated VR model
6. Configuring the VR model for infrequent or hazardous tasks
7. Incorporating the VR model modifications in electronic form

Their findings indicate that: (1) A need exists for the kind of training virtual reality offers, and (2) virtual envi-ronment 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, and (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 collision
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)
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, Vol. IV, pp. 12—16) 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 suitablity 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.
- Conduct summative evaluation of system performance, usability, and utility, and of training outcomes.

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.

15.6 THEORETICAL PERSPECTIVES ON VIRTUAL REALTIES

Already there has been a great deal of theory building as well as theory adapting vis-a-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.

15.6.1 Ecological Psychology Perspective— J. J. Gibson

The model of ecological psychology proposed by J. J. Gibson (1986) (see also 8.5) has been particularly influential in laying a theoretical foundation for virtual reality. Ecological psychology is the psychology of the awareness and activities of individuals in an environment (Mace, 1977; Gibson, 1986). 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 (see 8.5.2). 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 interrelated, 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, and 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 (McGreevy, 1993; Ellis, 1991, 1992; Zeltner, 1992; Sheridan & Zeltner, 1993) 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.

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 which is used to control a virtual object offers an affor-dance—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 perceptionstructuring 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.

15.6.2 Computers-as-Theater Perspective—Brenda Laurel

Brenda Laurel (1 990a, 1 990b, 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, p. 6) 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.

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 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 necessity (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 on 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, PLACE-HOLDER, 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 (see 19.2.3.1). 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, Barsky & Zeltzer, 1991; Taubes, 1994a; Goodwin Marcus Systems, Ltd., n.d.). The virtual agent JackTM, developed at the Center for Human Modeling and Simulation, has been trademarked 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).

15.6.3 Spacemaker Design Perspective— Randal Walser

Randall Wailser (1991, 1992) draws on 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 filmmaker. Filmmakers 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 Figure 15-2.

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, Wailser 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 pro-

Creative artists		**Performing artists**
	writer	storyteller
	speechwriter	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 15-2. Walser’s media spectrum, including spacemaker and cyberspace player categories. (Adapted from Walser, 1991.)

poses that cyberspace is based on still another new paradigm, which is shown in Figure 15-3.

Walser (1992) is particularly concerned with immersive virtual reality. He explains that in the desktop paradigm, computers 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 cyberspace, 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 toinvent, communicate, and comprehend realities by "acting them out." Wailser explains that acting out roles or points of view is not just a form of expression, but a fundamental way of knowing.

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

Figure 15-3. Walser's (1992) comparison of the desktop and cyberspace paradigms of media design.

15.6.4 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 (see 7.3), 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 multisensory 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, thiaking 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 (see 24.3), 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 Figure 15-4. 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 being 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 be used to teach mathematics experientially.

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 15-4. William Bricken's (1990) comparison of the desktop and virtual-realty paradigms of media design.

15.6.5 Situated Learning Perspective— Hilary McLellan

McLellan (1991) has theorized that virtual reality—based learning environments can be designed to support situated learning (see 3.1.2, 7.4), the model of learning proposed by Brown, Collins, and Duguid (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 exemplify situated learning. LOFT was introduced in the early 1 980s in response to data showing that most airplane accidents and incidents, including fatal crashes, resulted from pilot error (Lauber & Foushee, 1981). Concommitently, these 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 copilots to work together so that an unexpected cascade of small problems on a flight do not 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 necessary 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 (VWE) 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, i.e., 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 on 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.

15.7 DESIGN MODELS AND METAPHORS

Developing design models and design metaphors will be an important aspect of theory building, research, and development (see also 7.2) in the emerging virtual-reality medium. A few models and design metaphors have emerged that are specifically for education and training.

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 Figure 15-5. 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, p. 4),

> 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.

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) on-line performance, (2) off-line training and rehearsal, (3) on-line 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.

	Less real	**More real**
1. **Dimensionality**	**2-D**	**3-D**
2. Motion	Static	Dynamic
3. Interaction	Open loop	Closed loop
4. Frame of reference	Outside-in (God's eye) World referenced	Inside-out (User's eye) Ego referenced
5. Multimodal interaction (Enhanced sensory experience)	Limited	Multimodal

Figure 15-5. Five components of virtual reality. (Adapted from Wickens & 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.

On-line performance refers to systems where the virtual environment is providing the operator with direct manipulation capabilities in a remote, or nonviewable, environment —for example, 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 database to obtain a particular item. Wickens and Baker (1994) suggest that three general human performance concerns are relevant in these environments: (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, p. *5),*

> 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.

In terms of on-line 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, p. 17) 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. 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).

These design considerations must be kept in mind as virtual-reality concepts are introduced into education. Wickens also recommends that 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 with 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, McCarthy, Pontecorvo & Stiles, 1991).

15.8 VIRTUAL REALITIES RESEARCH AND DEVELOPMENT

15.8.1 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 DatagloveTM. 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 also 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.

15.8.2 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 graphics images and the ability of children to solve spatially related problems (see Chapter 8). 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 graphics 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 DataGloveTM; 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 cyberspace modes. Each child was shown how the DataGloveTM and the head-mounted display would feel by having them first try 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, 3-D virtual realities. The DataGloveTM 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 DataGloveTM.

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 DataGloveTM 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 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 that visualization abilities and the ability to manipulate mentally 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.

15.8.3 Research on Cbildren's 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 collaborators. 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? (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 (see 7.4). This study featured an experimental program of weeklong 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 10 to 15 years old, 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 10 years old and older. A total of 59 students 10 to 15 years old 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-DTM, 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-DTM were converted over for use on more powerful computer workstations.)

Bricken and Byrne (1993) report that they wanted to see 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 primitives (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, p. 204) 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.

Bricken and Byrne (1993, p. 205) 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.

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 DataGloveTM 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 (Byrne, 1992; Bricken & Byrne, 1993). 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.

15.8.4 Research on Learners in Experiential Learning Environments

Recently, an exciting experiential learning environment was developed at the Boston Computer Museum, using immersive virtual-reality technology (Gay, 1993, 1994a, 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 x 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."

15.8.5 Research on Attitudes Toward Virtual Reality

Heeter (1992, 1994) has studied people's attitudinal responses to virtual reality. In one study, she investigated 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%. (One questionnaire was collected per person; at least 45% 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.
6. Be distinct from the everyday world ("paramount reality").

Heeter (1992, p. 67) 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.

According to Heeter (1992, p. 67),

> 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. Novices who pay to play BattleTech may feel intimidated by the complexity of the BattleTech controls, and some potential novices may even be so intimidated by that complexity that they are scared away completely. But among veterans and masters, 14% feel there are too many buttons and controls, while almost 40% 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 human beings in addition to virtual beings and environments in virtual reality. Just 2% of respondents would prefer to play against computers only. But 58% wanted to play against human beings only, and 40% wanted to play against a combination of computers and humans. Respondents preferred playing on teams (71%) rather than everyone against everyone (29%). 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."

Heeter (1992) reports that BattleTech players are mostly male. Masters are 98% male, veterans are 95% male, and novices are 91% 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. Specifically, 2% of masters, 5% of veterans, and 9% 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 versus 2.9) and *more embarrassing* (4.1 versus 2.0) than did male novices. Males were more aware of where their opponents were than females were (63% versus 33%) and of when they hit an opponent (66% versus 39%). Female BattleTech players enjoyed blowing people up less than males did, although both sexes enjoyed blowing people up a great deal (2.4 versus 1.5 out of 7, where I 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).* Of female novices, 57% said they would prefer that BattleTech cockpits have fewer than 100+ buttons and controls, compared to 28% 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% of the players were male." At FighterTown the proportion was 97%. 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% of the potential marketplace, or from a personal curiosity 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. Of the 203 respondents, 61% were male. The 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 human beings in virtual environments, be it virtual travel, virtual fitness, or other experiences. If they play a game, they want it to be based mostly 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 are collected from attendees at various conferences who try using the prototype.

15.8.6 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 (Pausch, Vogtle & Conway, 1991; Pausch & Williams, 1991;

Warner & Jacobson, 1992; Marcus, 1993; Middleton, 1993; Treviranus, 1993; Murphy, 1994). 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 three-dimensional 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." Murphy (1994, p. 59) 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.

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 who 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 wheel chairs (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 easily with those who do not speak sign language. Similar to this, Eberhart (1993) has developed a much less powerful noncommercial system that utilizes the Power GloveTM 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 DataGloveTM 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 DataGloveTM. The wearer of the GloveTalker speaks by signaling the computer with his or her personalized set of gestures. The DataGloveTM transmits the gesture signals through its fiber-optic sensors to the Voice Synthesis System, which speaks for the DataGloveTM 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) in which the goal is to develop a head-mounted video display system for the visually impaired that incorporates custom-prescribed, realtime 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 immmersive, 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 disabilities. 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).

15.9 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 less than a decade old, research and development are at a very, very 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. Research and development programs are underway throughout the world to study the potentials of virtual-reality technologies and applications (Thompson, 1992). As yet, however, very little research on virtual realities as a tool for learning has been carried out. Thus 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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