Virtual Reality Learning Environments: Potentials and Challenges

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Abstract

This paper addresses the unique characteristics of emerging Virtual Reality (VR) technology and the potential of virtual worlds as learning environments. I describe several key attributes of VR environments and discuss them in relationship to educational theory and pedagogical practice. I then identify three challenges that must be met before VR can be integrated into educational settings: cost, usability, and fear of the technology.

Introduction

Computer graphics technology enables us to create a remarkable variety of digital images and displays that, given the right conditions, effectively enrich education [Clark 1983]. Real-time computer graphics are an essential component of the multi-sensory environment of VR.The practical potential of VR is still being explored.

Using a head-mounted audio-visual display, 6-D position sensors, and tactile interface devices, we can inhabit computer-generated environments. We can see, hear, and touch virtual objects. We can create, modify, and manipulate them in much the same way we do physical objects, but without those pesky real-world limitations. VR is not only virtual; we can meet real people in virtual worlds, we can tele-exist in real places all over the world and beyond, and we can superimpose virtual displays onto the physical world.

Of the many application areas that suggest themselves, education is clearly worth immediate investigation. VR was *devised* to enable people to deal with information more easily, and it has been successfully developed to facilitate learning and task performance for over 20 years in the U.S. Air Force [Furness 1978]. Public education and training applications are a natural extension of this work.

The national mandate for educational improvement is based on increasingly grim statistics. Between 25%-30% of our children don't graduate from high school, and of those who do, at least 700,000 are functionally illiterate. Our students rank at the bottom of 19 industrial nations in reading, writing, and arithmetic. "One thing is for certain: the information revolution is changing our lives, and we need to prepare ourselves to cope with its promise and potential." [Gore 1991] How might VR help?

Virtual Reality as a Learning Environment

VR offers teachers and students unique experiences that are consistent with successful instructional strategies: hands-on learning, group projects and discussions, field trips, simulations, and concept visualization. Within the limits of system functionality, we can create anything imaginable and then become part of it. The VR learning environment is experiential and intuitive; it is a shared information context that offers unique interactivity and can be configured for individual learning and performance styles.

"If there are limits on the human ability to respond to learning environments, we are so far away from the limits as to make them presently inconsequential. Throughout human history to date, it has been the environments, not the human beings, that have run up against limitations." [Leonard 1968]

VR is experiential. We actively inhabit a spatial multi-sensory environment. We are both physically and perceptually involved in the experience; we feel a sense of presence within a virtual world. "We are immersed in a very high bandwidth stream of sensory input, organized by our perceiving systems, and out of this bath of sensation emerges our sense of being in and of the world." [Zeltzer 1990] We

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experience the environment as if it were real, while still fully aware that it is computer-generated.

Educational theorists have agreed on the fundamental importance of experiential learning for over a hundred years:

"Learning is the development *of* experience *into* experience." [James 1892]

"Knowledge begins with enaction." [Bruner 1962]

"To learn is to make sense out of experience." [Silberman 1970]

"If you can *be* a gear, you can understand how it turns by projecting yourself into its place and turning with it...As well as connecting with the formal knowledge of mathematics, it also connects with the body knowledge, the sensory-motor schemata of a child. It is this double relationship--both abstract and sensory--that gives a transitional object the power to carry mathematics into the mind." [Papert 1980]

Text, oral, and screen-based presentations address subsets of human capacity. In contrast, the VR learning environment is a context that includes the multiple nature of human intelligence: verbal/linguistic, logical/mathematical, auditory, spatial, kinesthetic, interpersonal and intrapersonal.

The importance of affective learning has been carefully explored [Kohlberg 1968, Rogers 1969]. It is apparent that we must consider the whole learner in his or her effort to attain educational goals [Belkin 1977]. VR's experiential computing environment allows "purposeful movement that coordinates the cognitive, the psychomotor, and the affective domains" [Harrow 1972]. VR provides a context for both cognitive and affective learning by engaging us in a process that is rational and emotional, practical and whimsical, organized and spontaneous.

VR allows natural interaction with information. The technology is designed to fit human architecture. A virtual world empowers us to move, talk, gesture, and manipulate objects and systems intuitively: to move an object, you reach out your hand and pick it up; to see what you hear going on behind you, you turn around and look. The skills needed to function within a virtual world are the same skills we've been practicing in the physical world since birth. This method of representing and interacting with information is fundamentally different from the way we are now using computers [W. Bricken 1990a]. Novices require minimal accommodation time [M. Bricken 1990]. Skilled users can represent and manipulate increasingly complex information in forms that are easy to interpret and remember [Furness 1988].

The motivation to learn hinges on interest, and most people find VR a very interesting experience. It has a magical quality, which fascinates children of all ages. 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 experience requires basic academic skills, thinking skills, and a clear mental model of what computers do.

VR is a shared experience. A personal computer is designed for solitary operation; there is one keyboard, one mouse, and one display. Virtual worlds can be both individual and social contexts. Networked VR allows multiple participants to interact simultaneously in the same audiovisual environment, sharing control naturally while conversing with augmented capability (I'll show you what I mean, and it sounds like this...).

Research in collaborative learning abounds with evidence of its educational value:

"The learner tends to be more productive in a group situation than working in isolation. Ongoing discussion involves the active participation of students in the teaching-learning process; attention is then directed toward the learning activity." [Belkin 1977]

"Children solve practical tasks with the help of their speech, as well as with their eyes and hands...Human learning presupposes a specific social nature and a social process by which children grow into the intellectual life of those around them." [Vygotsky 1978]

For the most part, our schools exist separately from the world that they teach about. Virtual worlds can be linked to the physical world through telepresence; distance learning networks can be expanded to allow students and teachers to share worldwide learning environments. Through virtual participation in local and international activities, students become active in the process of culture, and can see more clearly their relationship to the whole of humanity. Students can learn about different electronic communication and information networks through participation. They can learn how to deal with different forms of electronic data, building computer skills and data management skills. Real-time access to a multitude of people and information sources opens the virtual world -- and the classroom -- to the world at large:

"When heterogeneous students interact within a context characterized by positive goal interdependence, a process of acceptance is promoted, resulting in increased interaction, convictions of peer encouragement and acceptance, more accurate understanding of each other's perspectives, feelings of success and self-esteem, and expectation of rewarding future interactions." [Johnson 1983]

VR allows unique capabilities. It is a powerful context, in which you 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; VR enables children to practice this skill in ways we cannot achieve in the physical world.

"We know the world in different ways, from different stances, and each of the ways in which we know it produces different structures or representations, or, indeed, realities...We become increasingly adept at seeing the same set of events from multiple perspectives or stances and at entertaining the results as, so to speak, alternative possible worlds. The child is less adept at achieving such multiple perspectives...There is every reason to insist that this capacity must be present in some workable form in order for the child to master understanding." [Bruner 1986]

VR provides a developmentally flexible, interdisciplinary learning environment. A single *intraface* provides teachers and trainers with an enormous variety and supply of virtual learning "materials" that do not break or wear out. VR focuses our attention on the tasks and elements at hand, excluding extraneous information and reducing distraction.

The virtual environment allows safe experiences of distant or dangerous locations and processes. We can tele-exist in a nuclear reactor or under the sea, experiment with virtual chemistry and biology, and inhabit macro- and micro-cosmic systems scaled for human participation.

Creative expression is given a new medium, allowing students to instantiate their imaginations in multi-sensory contexts, participating in experiential worlds of art, music, theater, and literature. Presentation skills are exercised in new ways; students can demonstrate what they learn and communicate their ideas through virtual experiences that can be shared with teachers, parents, and peers.

VR can be tailored to individuals. Teachers can represent information in forms that are most compatible with a student's particular learning style, selecting interactivity options that match student performance characteristics. Tools for movement and manipulation within the virtual world can be configured to the physical needs of the individual and the requirements of the task.

In VR, we adopt a virtual body for group interaction. What forms will children choose, and what will those choices tell us? Gender, age, social status, physical attributes, and the cultural expectations associated with them, can be left behind when we enter a virtual world. By what criteria will students learn to evaluate each other if appearance is arbitrary?

Challenges

Using VR in schools and for training introduces both technical and cultural challenges. I consider cost, usability of software and interface devices, and fears about the technology.

Cost: Today, commercial VR systems that are sophisticated enough to offer complex models and diverse functionality are expensive relative to personal computers. About a quarter of a million dollars will get you the basics for a very small network of worlds. However, increasingly powerful computers are becoming more affordable each year, and low-end VR systems are being developed in the United States, Japan, and the United Kingdom.

Tomorrow, communications experts envision VR as a public utility with powerful centralized processing that allows anyone low-cost access to internationally networked virtual worlds [Elias 1991].

As a former teacher and administrator, I am well aware that inadequate teacher salaries and overcrowded classrooms take precedence over new technology in the minds of most educators. Serious funding for placing VR in schools will be predicated on two things. First, we need conclusive demonstrations of educational effectiveness, measured by substantial learning and performance increases directly attributable to VR technology. Second, we need to identify sources of funding that do not call on the severely limited resources of educational institutions.

The burden of cost is appropriately assumed by those with the highest vested interest in a successful educational system. Inadequate education not only affects families, schools, and government: business and industry spend $25 *billion* yearly to train/retrain their employees. "Learning has become the single most critical determinant of national economic competitiveness." [Perelman 1990] The decreasing competence of entering employees is motivating many corporations to invest in educational change.

"The necessity of technology in schools is clear. However, bringing these critical tools to the classroom presents a challenge that must be met by the business community in partnership with government." [Gardner 1990]

Usability: A crucial issue for integrating VR into classrooms is system usability -- by students of various ages, by teachers, and by curriculum developers. The following comments are not intended as product reviews but are my assessment of how well current VR tools work, based on the systems I've used to build virtual worlds and on my teaching experience in classrooms from kindergarten through college.

Designing virtual learning environments is substantially different from both traditional interface design [M. Bricken 1991] and traditional curriculum design. Because the whole learner is engaged in virtual activity, we must design at many levels, considering multi-sensory representation of information, multiple methods of interaction, physiologically appropriate virtual contexts, and the choice and structure of the content to be explored.

For example, in the physical world we can play a game of catch and know that the ball will bounce off the surface of the ground, that it will sound one way when it hits cement and another when it hits grass, and that it will travel with fairly predictable speed in the direction we throw it. The virtual world contains *nothing* we do not intentionally include; a virtual ball can go through any surface, or not, with whatever behaviors and sounds we decide on. The first design challenge is to shape the wild possibilities of VR into a coherent form. The conceptual design of a virtual world defines what you do there, how you do it, what elements and behaviors you include, and the context of the experience.

Modeling Software: Virtual worlds that run on commercially available systems are limited in size and complexity. The graphical models are simple, constrained on different systems to between 500 and 10,000 polygons (sides of objects). We can locate four channels of sound in the world and link them to graphical objects. We can achieve somewhat more complex environments by linking worlds together, but each world is experienced separately.

We can model a virtual world that includes a helicopter like the HITL/Boeing VSX [Esposito 1991, M. Bricken 1990], which has interesting functionality and flies through a simple terrain. But we can't even come close to expanding this world to include an airport or the people in it, much less the luggage or vending machines or the printed pages of tickets. As it is, the VSX pushes system limits at 10,000 polygons, and has a noticeably sluggish frame-rate. (60+ Hertz [frames per second] is optimal, 20-30 Hz. is acceptable; the VSX runs at about 6 Hz.) Designing useful worlds within present limitations is possible, but expanding these limits is prerequisite to building the complex environments that can be envisioned for education.

Virtual worlds are presently created on the computer screen. You can model worlds with one of several 3-D graphics design products. This modelling software varies widely in ease of use and capability. I've had the most experience with Swivel 3-D™, making worlds that run on the VPL RB1™ system. The maximum scale of Swivel worlds is approximately 20 foot square in physical space; if our virtual body was rendered at its real size, we would be immense giants in Virtual Seattle [M. Bricken 1990], which is at maximum scale. We need modeling software with refined metrics that allow us to create large worlds scaled to human proportion.

It is easy to interact with objects in Swivel; even young children can learn how to get primitives on the screen, rotate and translate them, and link them together. But creating asymmetric forms requires skill and patience. Accurately naming, aligning, and linking objects to form multiple-component forms requires looking at each intersection from several angles and distances, frequently unlinking, repositioning, and relinking objects relative to each other. The VSX took me weeks to model, and there are still things I should change. (I've found that virtual worlds are never done. Changes and refinements continually suggest themselves: virtual worlds are a process, not a product.) If extensive low-polygon object libraries were included with modelling software, useful worlds would be relatively straightforward for teachers and students to assemble.

3-D modeling packages with more sophisticated functionality, such as Alias™ and Wavefront™, are proportionally more difficult to learn. Some of the most powerful features of these modelers (multiple light sources, radiosity, mirror surfaces, shading options, and batch animation capabilities) are presently unusable for real-time rendering. Also, the object linking mechanisms are not as flexible as they need to be.

I did some conceptual design in AutoCAD™ for a PC-based VR prototype system that could render small (500 polygon) models. It was great training for minimalist world design, but after working with larger models, I've concluded that 500 polygons just isn't enough to stock a dynamic, surprising world with interesting objects. AutoCAD provided me with the most useful architectural design capabilities, but once again, its complex functionality requires more learning time than most teachers and students have available.

The software that HITL uses to model 3-D sound is an extension of FocalPoint™. While I have only begun to integrate sound into virtual worlds, it is clearly a compelling component of the environment. Using vision-only systems in schools would not be doing VR; the multi-modality of the experience is an essential feature for educational applications.

Dynamics Programming Software: After you model a world, you program the dynamics of the environment, adding viewpoint control, command structures, collision detection for manipulating objects, movement constraints, animations, and object behaviors.

Body Electric™ is VPL's dynamics software. Although successive versions of this complex package are increasingly streamlined, effective use requires a clear understanding of interface device functionality, of the network of system components, of the model's structure, and of the intention of the design. You program using a visual data flow network that converts raw data input into virtual behavior.

HITL's dynamics software, VEOS (Virtual Environment Operating Shell), is a platform-independent Unix network that allows multiple concurrent worlds and as many users as you have equipment for [W. Bricken 1990b]. VEOS worlds are specified in a language which combines elements of LISP and Linda programming styles. The ability to program object behavior allows more life-like dynamics in a virtual environment. In Body Electric, I can put a bird on a fixed flight path through the world. In VEOS, I can program the bird to seek out food, prefer some foods to others, avoid cats, and come when its called. Our current interface build will provide first generation tools for the public domain.

We need software that is intended specifically for creating virtual worlds, that provides straightforward methods for modelling, modifying, and assigning behaviors to elements of the environment. Ideally, we should be able to use the same basic set of tools both on screen and inside VR. I expect that several iterations of design will be necessary before a simple, reliable VR software toolkit is available for classroom use.

Interface devices: A variety of head-mounted displays (HMDs) have been developed by the Air Force and by NASA. Others are marketed by companies such as VPL, W-Industries, LEEP Optics, and Arvis. They are all based on aerial imaging technology, in which we view a picture focused at infinity that is projected in front of our eyes. This is, of course, not the way we see objects in the real world, where our focus changes to converge on objects located at different distances from us. Although binocular viewing does give us a feeling of three-dimensionality, it is difficult to judge the relative location of objects in aerial displays without redundant cues such as familiar size, occlusion and parallax. Alternative display technologies, such as direct retinal scanning, are being investigated [Furness 1990].

Current HMDs are bulky, heavy and fairly fragile. Present displays are very low-resolution, making small objects and details of virtual worlds difficult to see. Some distort vision with a fish-eye effect and others do not show color. Most do not include audio capacity. All HMDs have cables which restrict our movement. A rugged, lightweight, high-resolution audio-visual HMD that can tolerate the daily use of rambunctious students is prerequisite for classroom VR.

Position sensing and tracking devices translate our movements into data streams that the computer uses to update display images and sounds according to our location. Both the Polhemus Isotrack™ and the Bird™ generate a local electro-magnetic field and track the movement of receptors within it. By placing the receptors on our head and hand, the rotation and translation of those parts of our physical body are mapped onto our virtual body. We need to stay within the generated field and we are attached to the tracking devices with wires. Passive video tracking is used in artificial reality systems such as Mandala™, and could be used for some applications of inclusive VR. The challenge is to improve the technology for wider range, wireless communication, faster update rate, and greater accuracy.

We interact with elements of the virtual world using 6-D control devices such as the VPL DataGlove™, the SimGraphics Bat™, and the Spatial Systems SpaceBall™. The DataGlove has gotten enough use so that we have some information about how it works as an interface device. Getting our hand into the virtual environment increases our sense of presence and allows us to manipulate virtual objects in a more natural, efficient and intuitive way [Sturman 1989]. However, gesture commands are limited by the number of finger positions that can be defined as unique, mutually exclusive, and comfortable. Gestures can require a degree of manual dexterity that many people do not have.

I have found that pointing to fly gets mixed reviews; a lot of people find it an endless source of fun, but other people report tired arms and motion sickness. When moving by pointing, directional accuracy is approximate, stopping exactly where you want to can be difficult, and speed control is awkward. Inadvertent gestures can trigger unintentional commands; for example, when people first use the buttons on the control panel of the VSX, they extend their index finger to press the button and fly right through their target. There are proprietary issues regarding the use of computerized gloves which will affect their price, performance and availability.

The Bat is a 6-D mouse, which can select and move objects in 3-space. The SpaceBall is a 6-D pressure-sensitive track-ball which can be used to select and manipulate objects or control viewpoint. Moving your viewpoint through a virtual world with a Ball is very smooth. Unlike a glove, it can be used to tumble and swivel. This capacity is very useful for object manipulation, but moving your viewpoint with unconstrained freedom can be very disorienting.

The challenge is to determine which interface devices are appropriate for particular tasks and individuals.

Fears: Educators are concerned that more technology that they aren't trained to use will be dropped into the classroom, and that it won't really help them to teach more effectively. On a broader level, there is anxiety about the misuse of VR and fear that the technology may have some inherently negative attributes (see the collected abstracts of the Second International Conference on Cyberspace, Santa Cruz CA, 1991).

Brenda Laurel [Laurel 1990] addresses the fear of computer technology and identifies its components:

- the archtypical taboo on presuming to imitate God
- the fear of fallibility: intelligent software entities may turn out to be crude, lifeless representations, or we may create monsters -- war, environmental destruction -- with computer technology
- the fear of loosing identity: becoming dependent "slaves of cybernetic symbiosis"
- the fear of loosing control to alien life: software entities may *not* be crude and lifeless -- new, improved sentience may emerge and take over.

New fears have emerged about VR in particular:

- fear of loosing control to others -- invisible hackers, masked tricksters, faceless corporate/governmental manipulators: how do we know who a virtual person really is, how are individual rights established, how are conflicts managed, who is in control?
- fear of denied access: whatever kind of place VR turns out to be, everyone should have the right to be there; who gets in and how?
- fear of confusion: what if we can't distinguish between a refined virtual world and physical reality, how do we know if virtual representations of information are being distorted?
- fear of abandonment: what if VR is so compelling that people don't want to come out, who will mind reality? If I don't get virtual, will I be left all alone?

Fear of the technology may be both the most subtle and the most important challenge to public acceptance of VR as a suitable medium for children. Once we acknowledge this fear, we can address it rationally. Of course, fear is not rational, it is emotional and not easily assuaged. However, I will suggest three approaches to reducing VR technophobia:

Accurate Information: We need first to understand what VR is and is not. We must separate science from fiction; VR is not a novel by William Gibson, it is an interface technique that now allows us more immediate access to a subset of what computers already do. We need to supplant speculation with experience, by making VR software available in the public domain for widespread exploration and evaluation. VR is a new information medium, and like any media, can be used to disseminate propaganda, advertisement, and misinformation. Curriculum that addresses the use and misuse of media exists in most schools and can be expanded to include computer-mediated information space.

Research and Co-development: By sharing our experiences as we continue to explore, observe, evaluate, and refine VR, we increase professional and public understanding of the technology. Developers are presenting progress reports on their systems in professional and public conferences internationally. Educators are initiating formal research on VR issues such as transfer of learning, appropriate curriculum implementation, elements of effective virtual world design, multi-sensory work-load distribution in VR, and the psychological and social impact of the technology's use.

Interface experts stress the value of involving end-users in the development of computer technology during the design phase. Given evidence that VR is safe and useful, we can refine learning applications along with the technology itself by establishing a dialogue between developers and the educational community to determine the appropriate use of VR in schools and in training.

Historical perspective: People, individually and collectively, learn from mistakes. The big lesson of the Twentieth Century is that careless implementation of technology can cause large-scale and lasting negative effects. It is difficult to reverse the momentum of old mistakes, but it is easier to avoid new ones. We can choose how we use new technology.

Issues of power, control, and access in VR are being addressed in the context of Constitutional rights: the Electronic Frontier Foundation exists to encourage the legal extension of First Amendment assurances of freedom and privacy into electronically mediated environments.

Worrying about humanity seems to be an inevitable component of social consciousness. "Plato banned the art of drama from his republic because he thought that humans were in danger of confusing art and life." [Laurel 1990] People are notoriously suspicious of "alternate" realities;

the very name Virtual Reality is enough to raise the hackles of those who fear that other people can't make distinctions between different kinds of experience. My own feeling, after watching hundreds of people of all ages explore virtual worlds, is that they know exactly what they're doing. Perhaps we just don't give people enough credit for common sense. I believe that children are far more likely to mistake Disneyland for reality than they are to confuse VR and the real world.

Summary

New technology obviously needs thoughtful introduction into classrooms. Technology does not, by itself, improve education. Even the most promising educational innovation needs appropriate application to be effective. But, there is clearly the potential that VR learning environments can provide powerful educational experiences.

The significance of VR to education may be wider than particular learning applications. VR provides a testbed for exploring the very foundations of education. What we teach our children springs from our assumptions about how the world works and what is valuable. Our methods of teaching are based on our understanding of the role of the mind in learning. Educators are re-examining the philosophical foundations of education [Goodman 1984] by comparing the implications of objectivism to those of constructivism:

"Objectivism and Constructivism represent alternative conceptions of learning and thinking...Objectivism assumes that the role of mental activities is to represent the real world...and that the role of education is to help students learn about the world and replicate its content and structure in their thinking. Constructivism, on the other hand, claims that we construct our own reality through interpreting perceptual experiences...that reality is in the mind of the knower rather than in the object of our knowing. Constructivists, rather than prescribing learning outcomes, focus on tools and environments for helping learners interpret the multiple perspectives of the world in creating their own." [Jonassen 1990]

By making VR tools and environments available to educators, we may discover more about the very process of learning. By participating in the development of VR, educators can guide the growth of the technology and perhaps influence the course of educational change. As we test and refine this unique learning environment together, we might even hope that VR really will help us to teach more effectively, and that we will see more often that bright light of understanding in our students' eyes.

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