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Virtual Environments As a Tool for Academic Learning

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1. INTRODUCTION

This chapter concerns itself with the use of virtual environments (VEs) for learning of the kind expected to occur in schools, colleges and universities, that is, the acquisition of general problem-solving skills, mastery of facts and concepts, and improvement of the learning process itself. The chapter systematically explores the potential of VE for education as well as potential obstacles to its use. As of mid-2001, there are no commercially available VE systems deployed for regular instructional use in K–12 or university education, so this review relies on research projects for insight. In analyzing the major experiments thus far carried out, one can discern various combinations of three basic educational approaches to VE: *exploration, world building*, and *world sharing*. This chapter is not a general survey of VE-based educational research. Rather, it examines in some detail six research projects, focusing on two of these projects to explore each of the approaches above. An excellent survey of the educational use of VE technology can be found in Youngblut (1998).

2. USE OF VE TECHNOLOGY IN EDUCATION

2.1 What Is VE?

Virtual environments denote a real-time graphical simulation with which the user interacts via some form of analog control, within a spatial frame of reference and with user control of the viewpoint's motion and view direction. This basic definition is often extended by provision for multimedia stimuli (sound, force feedback, etc.) by consideration of immersive displays (i.e., displays that monopolize one or more senses), and by the involvement of multiple users in a shared simulation. However, many interesting educational systems involve only the core definition.

2.2 Why Might VE Matter to Education?

Ever since the first computers, people have been suggesting that well-designed simulations could provide access to learning experiences that are simply unavailable via normal means. Virtual field trips consume no jet fuel; simulated laboratories do not explode; virtual dissection kills no animals. Many personal computer (PC)–based simulations have pursued this dream, with varying results (Weller, 1996). Virtual simulations add the specific requirements of a spatial metaphor and free viewpoint motion. Why is it believed that this structure would be superior to a more abstract presentation?

Consider a chemical experiment presented via a two-dimensional (2-D) schematic graphical rendering on a computer screen. An Erlenmeyer flask contains a basic liquid solution. As the student clicks on-screen button controls, a calibrated pipette drips acid into the flask until the dye changes color, indicating neutralization. Quantities are noted and calculations performed.

The same experiment in a virtual laboratory would be located on a realistic, perhaps scarred and beat-up countertop. The user is free to look and move around the lab. Perhaps the user has to find the Erlenmeyer flask in a drawer, set it up properly, use correct safety procedures with the acid and basic solutions, and run the risk of breaking equipment if it is handled too abruptly. In short, the virtual laboratory (like a real laboratory) is intended to teach the culture of the experience, whereas the 2-D schematic laboratory teaches the conceptual core of the experience. The culture consists of the collection of constraints, risks, and procedures that a real chemist must consider in doing the job. Real-life lab experience is usually complemented by classroom instruction to provide the concepts, precisely because the cultural lab experience is so information rich that the conceptual core is obscured.

The story about the chemistry experiment obviously added more than free viewpoint motion to the abstract example. It added a world worth moving through, a context in which the user has choices. These options range from the simple selection of the correct glassware, to the decision to wander away from the lab counter and see what else is in the virtual world.

In a real lab, students make some choices based on learning styles (Gardner, 1993). Some students need to experience direct consequences of manual actions to grasp causal relationships. Others need to say what they see. Still others need to hear or read explanations. The virtual lab is intended to provide a rich set of such choices and to make them accessible in natural ways.

But if all this could be accomplished, would it actually improve education?

2.3 Why Might VE Be a Red Herring for Education?

There are two essential obstacles to the rosy vision described above: design and pedagogy. Let us assume the existence of affordable, reliable VE software and hardware. The creation of richly detailed virtual worlds must still somehow be supported, in which the glassware clinks, the wooden desktop thunks, and, most importantly, when a users does something unexpected (e.g., drops a paper clip into a beaker of liquid), something plausible happens. There are several dilemmas:

- Building richly detailed worlds is very expensive (see chaps. 12–13, this volume). Commercial video games currently cost over $1 million to produce, and they set the standard by which kids will judge virtual worlds.
- If a fascinating, complex world is built, is it actually helping or hindering the kids' learning? Is all this intriguing simulation really bribery, or does it pay its way?

There are those (e.g., Postman, 1985) who stoutly assert that television, even the best educational television, is destroying our kids' ability to deal with abstraction. The written word requires a continuous positive act of the imagination as one reads. Television, and possibly high-fidelity VE as well, do most of the work for you. Thus, Postman would probably assert that the better (and more appealing) a design gets, the further one moves from an ideal learning environment. From a slightly different perspective, Wickens (1992) argues that natural and easy-to-use interactions may reduce a student's retention because less effort is expended.

On the other hand, there is a substantial body of scholarship (described below in more detail) that asserts the value of "situated learning," of providing tasks within a realistic story, with appealing characters and situations. Humans emulate heroes and want to be admired as new heroes. Virtual environments may provide enough story structure and detail to enable learners to remain engaged with tasks, which they would have abandoned in other forms. It may empower learners whose cognitive styles will never resonate with traditional, linear book culture. Active engagement with rich simulated worlds may help students to construct their own mental models.

The following section establishes some essential principles and terminology for discussing kinds of learning, and educational theories such as constructivism and situated learning. Sections 4 through 6 explore, respectively, the following domains:

- Exploration of prebuilt worlds as a *constructivist* learning activity
- Creation or modification of worlds as a *constructionist* learning activity
- Role-playing by multiple participants as a *situated learning* activity.

Each section includes a description of two experimental projects. A final section then summarizes the state of knowledge and poses challenges for the future.

3. A CONCEPTUAL FRAMEWORK

A commonly cited taxonomy for learning (Gagne, Briggs, & Wager, 1988), describes five categories of learning outcomes:

- Intellectual skills and procedural knowledge
- Verbal information
- Cognitive strategies
- Motor skills
- Attitudes

The Gagne taxonomy is one of the standard tools for instructional design; its structure reflects the traditional academic focus on reading and writing. Others give more attention to nonverbal domains. Gardner (1993) describes seven kinds of intelligence (among many):

- Verbal
- Mathematical–logical
- Spatial
- Kinesthetic
- Musical
- Interpersonal (dealing with others)
- Intrapsychic (dealing with one's own self)

These two classification systems are not easily compared. For instance, Gagne's "motor skills" denotes specific behaviors such as typing or playing golf, whereas Gardner's "kinesthetic intelligence" refers to a way of understanding systems of concepts that is based on physically manipulating and interacting with objects. For instance, Papert (1980) describes a childhood epiphany in which his manipulation of the differential axle of a toy vehicle revealed to him the nature of functional relationships.

And where in Gagne's terminology does one account for knowledge of the fact that Germany lies north and east of France? Calling this "verbal information" reflects a behaviorist focus on the traditional means of reporting knowledge by writing, but students are often asked to draw maps or otherwise indicate their mastery of spatial information. It seems necessary to generalize Gagne's category of verbal information by renaming it as "factual information."

Multisensory integration (see chaps. 14, 21–22, this volume) is integral to VE's affordances for learning and motivates many of the projects discussed below. To deal with this issue, an attempt is made to use both Gagne's and Gardner's terms to describe the kind of learning under study in each project.

3.1 Constructivism, Constructionism, Situated Learning, and Role-playing

The concepts of constructivism, constructionism, and situated learning drive many innovations and experiments in education, ranging from individual lesson modules to entire school reform movements (Cusick, 1997; Wang, 1998). Role-playing can serve as an intense form of situated learning. In most of the experiments in VE for education, several of these learning strategies are involved. For the purposes of this chapter, two research projects have been selected to highlight each concept.

3.1.1 Constructivism

A substantial body of literature (Dede, 1995; Duffy & Jonassen, 1992; Windschitl, 1998) has established the principle that students actively build their internal models of the world rather than passively accepting data. In constructivist theory, all useful knowledge is procedural knowledge. Thus, constructivism serves as a theoretical justification for discovery learning and exploratory systems. Section 4 below explores two constructivist VE projects: ScienceSpace and the Virtual Gorilla Exhibit.

3.1.2 Constructionism

Constructionism is an extension of constructivism, that latter of which is usually associated with MIT's S. Papert (Harel & Papert, 1991; Kafai & Resnick, 1996), in which students must actively create artifacts—preferably interactive ones—to fully integrate their models of the world. Papert invented the well-known LOGO language for children and continues to evangelize the doctrine of constructionism. Not all authors use Papert's terminology; the creation of virtual worlds is sometimes referred to as constructivist activity. We find the distinction useful. Section 5 reviews two constructionist VE projects the VRRV project, and the NICE virtual gardening project.

3.1.3 Situated Learning

Situated learning (Cognition and Technology Group at Vanderbilt, 1993) is oriented around the idea that learning takes place best in story-based, human-centered circumstances. Rather than just computing the area of a triangle, learners are asked to help characters in a story solve an extended problem such as building a house. Many individual problems naturally arise in such a story; their solution is motivated by the normal needs of the characters in the story.

Role-playing takes situated learning one step further by involving multiple learners who are identified with specific characters in the story. Simulated situations may be competitive, cooperative, or both. Introducing multiple learners raises many challenging problems of synchronization, tasking, discipline, and resource management, but offers the potential of unleashing for educational use one of the most powerful forces in the human psyche: social interaction. Section 6 profiles two role-playing experiments, the Round Earth Project and ExploreNet.

4. PREBUILT WORLDS, DISCOVERY LEARNING, AND CONSTRUCTIVISM

4.1 ScienceSpace

One of the most thorough and extensive studies of VE in education has been underway since 1994. Led by C. Dede of George Mason University (Now at Harvard University) and B. Loftin of the University of Houston (Now at Old Dominion University), the ScienceSpace project (Dede, Salzman, Loftin, & Ash, 1999a, Dede, Salzman, Loftin, & Sprague, 1999b; Salzman, Dede, Loftin, & Ash, 1998; Salzman, Dede, Loftin, & Chen, 1999) has used high performance technology to examine the educational potential of immersive VE systems. Loftin created and directs the University of Houston's Virtual Environment Technology Laboratory, and so had access to state-of-the-art VE technology used in astronaut training programs.

4.1.1 Purpose

The focal purpose of ScienceSpace was to identify the key affordances of immersive VE and evaluate their effectiveness as means of learning complex, abstract concepts such as mass, density, and momentum. Three key affordances were of principal concern:

- Immersion
- Use of multiple frames of reference
- Multisensory cues

4.1.2 Setup

Immersion was provided by the use of a state-of-the-art Silicon Graphics RealityEngine2 image generation system, a Virtual Research VR4 head-mounted display (HMD), and Crystal River audio localization equipment. Multiple frames of reference were provided by a variety of means, the principal one being that students could either move through the world coordinate system with the object whose behavior was being studied or remain fixed in the world coordinate system, and observe the phenomena. Multisensory cues were provided by the sound system and also by the use of a special vest. The vest, originally designed for multiplayer "shoot-em" games, was capable of delivering a vibrating stimulation to the user's chest. The learner held a control device in one hand and a reference device in the other hand; both were tracked by 6 degrees-of-freedom magnetic trackers.

4.1.3 Experiments

The ScienceSpace experiments consisted of three phases. The first phase (Newton World) represented basic Newtonian mechanics. The second phase (Maxwell World) concerned electrostatic forces and fields. The third phase (Pauli World) concerned quantum phenomena. During each phase, a series of experiments began with simple pilot activities and continued through formal evaluations of learning effects. Detailed documentation is available on the first two experiments, and so they are described here.

Newton World focused on the motion of spherical masses along a one-dimensional axis. The axis was visualized as a corridor passing between two rows of columns. The columns were used in a variety of ways to help the user measure and perceive the motion of masses. For instance, the columns might change color as a mass passed by, or sounds might occur. Students controlled the action in the world using three-dimensional (3-D) tracking devices or a voice control system.

When studying energy, it was necessary to devise means of concretely rendering the quantities of kinetic and potential energy. A coiled spring was used to represent potential energy; when it was compressed, vibration in the vest increased. An artificial shadow of the mass was used to represent kinetic energy; the shadow's area represented the amount of kinetic energy the object currently possessed with respect to the fixed reference frame. (The radius of the shadow would therefore be proportional to the velocity.) Learners could either travel with one of the moving masses or view the motion from various points outside or within the corridor.

A pilot experiment yielded a series of improvements in the user interface and experimental technique. It was discovered that the affordance of multiple viewpoints was crucial to learning success. A variety of methods of selecting the next action were used (e.g., picking from menus attached to the fixed reference frame, attached to the user's other hand, or via voice commands). Voice selection was found to be the most preferred means of control. Users liked the multisensory feedback modalities and found the world easier to use when multisensory feedback was presented (see chaps. 14, 21–22, this volume).

In a second experiment, 30 high school students helped to evaluate Newton World's potential for learning. The students were pretested, and it was found that most of them confused the concepts of velocity and acceleration, and that most had trouble predicting what would happen when two masses collided.

msd

After a session of approximately an hour's use of Newton World, students' conceptual understanding was again tested. No significant improvement was measured, suggesting that a single visit to Newton World was insufficient to transform users' mental models. However, multiple improvements in experimental technique and virtual world design were carried forward to the next phase.

In the Maxwell World experiments, learners again had the opportunity to use multiple frames of reference and multisensory feedback. Learners could see electrostatic fields in the form of equipotential lines. A "force meter" represented the magnitude and direction of force that would be applied to a charge at any point in the field as the student moved the force meter around. Using the meter, a user could release a charge and watch it move through space, or "become" the charge and go for a ride.

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In the first experiments, students' length of exposure to the system was increased. Fourteen students had from one to three sessions, each of 2 hours duration. As a control, a 2-D commercially developed educational software system, EMfield, was taught. The features of Maxwell World were restricted to correspond to those available in EMfield. Pre- and posttesting indicated that users of Maxwell World developed significantly better understanding of electric fields' 3-D aspects than users of EMfield. In 2-D tests (such as the drawing of sketches related to potentials) the results were mixed. However, the overall results for Maxwell World were significantly better than those for EMfield.

4.1.4 Experimenters' Conclusions

In the later experiments, significantly more learning occurred with VE than without it. Students in all the systems were enthusiastic about their use and remained motivated throughout the experiments. However, motivation did not turn out in the statistical analyses to be a predictor of learning. Some simulator sickness (see chap. 30, this volume) was experienced, with incidence and severity increasing with the longer exposures used in Maxwell World.

4.1.5 Analysis

In terms of the learning taxonomies, ScienceSpace provided a new experiential domain in which students were expected to develop novel cognitive strategies in order to establish procedural knowledge about spatial and mathematical–logical relationships in physics. Despite the lack of force feedback, the investigators hoped that kinesthetic learning would contribute to students' development of physical intuition.

The project made substantial progress in determining how to build effective virtual learning environments for physics, how to enrich multisensory feedback, and how much exposure was necessary to achieve measurable effects.

4.2 The Virtual Reality Gorilla Exhibit

A team of researchers at Georgia Tech developed a VE simulation of a new gorilla habitat at Zoo Atlanta. A basic dimension of this project is a concern with how a virtual experience must be coupled with background information, reflection, and various forms of information accessible during the simulation itself in order to achieve useful educational outcomes.

4.2.1 Purpose

The initial experiments (Allison, Willis, Bowman, Wireman, & Hodges 1997) were designed to teach middle school students about gorilla's social interactions by letting the students play the role of an adolescent gorilla. Subsequent experiments (Bowman, Wireman, Hodges, & Allison, 1999) focused on the design of the zoo's gorilla habitat, with the intention of teaching college students about principles of design.

4.2.2 Setup

The experiment is hosted on Silicon Graphics equipment, using a Virtual Research HMD and Polhemus tracking equipment. A single user experiences the simulation and interacts with the exhibit via a "stylus and tablet" virtual control device. Motion is controlled either by pointing the stylus in the direction of intended travel or by dragging a dot on a map displayed on the tablet. Software was implemented using the Simple Virtual Environment (SVE) software system developed at Georgia Tech (Kessler, Kooper, & Hodges, 1998). Animal sounds are provided through external speakers.

4.2.3 Experiments

In the first series of experiments, students were provided with an experience that could be dangerous in real life, taking middle school students on a visit inside a functioning goilla society. After initially viewing simulated gorillas through a simulated viewport, the learner "moves inside" the habitat and takes up the role of an adolescent gorilla. When the learner moves about, the other gorillas react by moving away or by watching the visitor. If the visitor moves too close to a male silverback (dominant individual) or stares too long at it, the silverback becomes annoyed and will ultimately carry out a "bluff charge" and beat on his chest.

The experimenters observed that most students needed help to understand the gorilla's behavior. Initially a live human guide would stand next to the student and explain what was happening; subsequently explanatory material was built into the audio portion of the experience, The system was also modified to include explicit "mood indicator" icons to show the emotional state of each gorilla.

The second series of experiments concerned teaching college students about habitat design. The design profession is based on well-established principles and also includes a substantial aesthetic component. The experimenters' intention was to provide a series of design examples, with annotation, somewhat like a guided visit to a Frank Lloyd Wright project. A series of audio clips are embedded in the virtual gorilla exhibit. Annotations are marked by cubical signs that play the audio annotation when selected. A few fixed signs occur,in places where signs might appear in a real zoo habitat.

The map that is displayed on the virtual tablet (corresponding to the real tablet the user is holding) provides additional spatial information. The map situates the exhibit among several others in the zoo and teaches the principle of bioclimatic zones, by which exhibits from similar climates and ecosystems are located close to one another. The exhibit also includes photographs of gorillas in locations they typically occupy. These help the viewer to establish the scale of the exhibit. The virtual gorillas are not active in the design experiment because their behaviors would distract from the design lesson being taught. Also, the gorilla's automated behaviors do not include the full spectrum of activities (eating, sleeping, mating, etc.) that must be accounted for in habitat design.

4.2.4 Experimenter's Conclusions

In the first series of experiments with schoolchildren, the principal lessons learned concerned the user interface and the need for explanatory support. Students tended to be concerned with specifics of navigation (see chap. 24, this volume) and could be overwhelmed by the sights and sounds of the simulated animals. The experimenters found it necessary to provide a live gorilla expert to comment on what the students were experiencing.

The system was subsequently used in a Georgia Tech class on the psychology of environmental design. The system was found easy to use. However, students did not strongly relate the audio material to the environment as was intended. As expected, the groups that used the system performed as well as or better than a control group. However, the differences were not significant, probably due to the small size of the samples. A group that experienced the annotated VE without a corresponding lecture received very little benefit.

4.2.5 Analysis

This project aimed to develop factual and procedural knowledge about how gorillas live and interact, as well as about how to design habitats for zoos. It used visual, verbal, and kinesthetic modes of interaction.

The experiences with schoolchildren (needing a live expert to facilitate their learning) and with the university students (needing a lecture to exhibit measurable learning) serve as a strong cautionary note to advocates of VE as a primary means of instruction. The Georgia Tech team advocates VE as a supplementary tool to be used alongside other means of teaching.

5. BUILDING VIRTUAL WORLDS AS A CONSTRUCTIONIST ACTIVITY

In this section two projects are described in which the learner's major activity is to construct or extend the features of a virtual world.

5.1 The VRRV Project

At the University of Washington's HIT Lab (Human Interface Technology Laboratory), a team led by William Winn carried out an extensive project titled VRRV (Virtual Reality Recreational Vehicle). The basic premise was to have students in schools participate in extended world-building exercises using conventional computers. Then an "RV" (originally intended to be a motor home or recreational vehicle, but actually a van) visited the school with immersive VE equipment, so the students could experience the worlds they built. The project is described in Winn et al. (1999). This report describes one component of the VRRV project.

5.1.1 Purpose

The VRRV Project was intended to explore the educational utility of students' building virtual worlds within the constructionist paradigm. The investigators analyzed several previous constructionist VE projects in order to choose experimental parameters. The key questions concerned:

- How students would choose to represent objects and processes
- How students would design spaces to help their peers understand subject matter

5.1.2 Setup

Teachers from 14 schools volunteered their elementary, middle, and high schools as test sites. The teachers were trained in the use of Macromodel software, and it was concluded that the software was too difficult for elementary and some middle school students. Consequently, it was decided to have the project staff build a common world and let the younger students construct auxiliary but nonessential objects. Most of the middle schools and all the high schools designed and built worlds. In these cases the students modeled the objects and specified how they should fit into the world and interact. Project programmers then assembled the worlds and programmed necessary interactions.

Portable (PC-based) VE equipment built by Division was brought to each school so that the students could visit their own worlds. The systems included Division HMDs and magnetic tracking equipment. The project involved 365 students.

5.1.3 Experiments

Except for the elementary schools and one middle school, each school designed and implemented its own world. During the planning phase, students worked in groups. They selected content, specified objects and metaphors to represent invisible objects and relationships. During the modeling phase, students drew their objects on paper and then built them with the Macromodel software. Project staff assembled the worlds and programmed behaviors. The elementary children explored and manipulated a prebuilt world, to which they had contributed some auxiliary objects. Finally, students visited the worlds they had created, performed specified tasks, and filled out questionnaires about the experience.

In a few schools, the projects related to academic subjects being studied in the schools. Thus, data was gathered to see if VE students had better knowledge of the subject matter than students in other non-VE-supported classes.

5.1.4 The Worlds

Tree World (shared by the elementary schools) consisted of a tree that needed sunlight, water, and nutrients. Students pushed aside a virtual cloud to let in sunlight, pushed aside a boulder to let in a river, and fed a cow so that its manure would fertilize the tree. Students provided insects, squirrels, and birds. In this world, the students' activities could be described as constructivist but not constructionist. The purpose was to make the tree look healthier by providing for its needs, and thus to learn about biological resource cycles.

Here a few typical constructionist worlds are described. Medieval Castle World represented a number of rooms of a classic castle, with a drawbridge. Rain Forest World tells a story in which bulldozers destroy the forest; cattle are introduced and become hamburgers. Finally, the earth is replaced by a big dollar sign. Endangered Species World has animals that turn into skeletons when handled. Washington World presented a maplike visitable model of the state, with many correctly located features that revealed textual annotations when selected. Tide World was intended to show how the sun and moon produce tides.

5.1.5 Experimenter's Conclusions

The authors observed two kinds of metaphor in use: objects could stand for other objects or for invisible objects or processes. Hamburgers stood for the end product of clearing the forest. Skeletons stood for the (unobservable) process of extinction. Students showed the ability to construct valid metaphors but tended to undergeneralize principles. For instance, the elementary students, when asked about plant nutrients, reported that they came from cow poop.

Similarly, students showed the ability to define processes, but when asked about the underlying principles would often cite the process itself (e.g., hamburgers are not the problem, habitat destruction is). The Washington World and Tide World showed mastery of spatial relations and of scale as a dimension of design.

Student designers had to anticipate the need for interactions (e.g., feedback for successful actions) and specify them. This required that students anticipate the errors of others.

Numerical results of posttests were analyzed to investigate enjoyment, ability to navigate, and VE sickness, as well as correlations among these measures. Those who found it easy to navigate also enjoyed the experience. Separate (teacher-designed) testing of knowledge of content indicated that less able students learned a significant amount about the world's subject matter from the VE-building experience, whereas higher performing students did not.

5.1.6 Analysis

VRRV's constructionist experiments spanned a wide range of subject matter and included both factual knowledge and procedural knowledge . The procedural knowledge involved phenomena within the simulation (such as flow of resources through the nutrient cycles of the tree) and processes involved in building virtual worlds. The principal cognitive strategy involved was meta-learning (thinking about the learning process itself), in the form of explicit instructional design for the benefit of other students.

In Gardner's terms, mathematical–logical (causal loops), spatial, and kinesthetic intelligences were involved in the project. Of course, verbal skills had an essential role in planning and specifying the worlds before they were built.

In common with most other VE based projects, the VRRV experiments increased the authors' understanding of the user interface and didactic issues involved, but exhibited relatively little in the way of measurable learning.

5.2 The NICE Project

At the University of Illinois at Chicago, the Electronic Visualization Laboratory has developed a unique immersive VE system called the CAVE (Cave Automatic Virtual Environment;

Cruz-Neira, Sandin, DeFanti, Kenyon, & Hart, 1992; see chap. 11, this volume). Rather than using an opaque HMD, the CAVE uses large projected images on three walls and the floor. A viewer wearing stereographic glasses and a tracking device has the experience of being inside a high-resolution virtual space, but without most of the motion sickness problems (see chap. 30, this volume) associated with head-mounted displays. A handheld control device is also provided. Multiple users can simultaneously see images, although only the one with the tracking device has correct perspective and parallax.

5.2.1 Purpose

Using the CAVE, the NICE (Narrative Immersive Constructionist/Collaborative Environments) project explored both constructionism and collaboration by having students design, build, and "nurture" a virtual garden (Roussos et al., 1997, 1999). In this review, the focus is on the constructionist aspects of the project. The specific learning outcomes being sought were an increased understanding of the relationships between environmental conditions and plant growth. In addition, the experimenters focused attention on the suitability of the CAVE user interface for learning by children of various ages.

5.2.2 Setup

Software was provided that supported the simulation of plant life in a garden. Using a handheld controller, or "wand," students dropped a seed and a plant grew on that spot. If the plants were too close together they would not grow well. Students could grab a rain cloud, "water" a plant, or provide sunlight. Weeds could be removed to a compost heap. The garden continued to evolve, with weeds growing and animals eating plants, even if no users were present. NICE is accessible not only through the CAVE, but also through desktop 3-D VE systems and a 2-D Web-accessible interface.

Two features of VE technology of particular educational interest are its ability to reveal hidden phenomena and help users interpret them. In NICE, for instance, users can go underground to see what is happening there as well as control the flow of time. In addition, a plant that is receiving too much water is shown holding an umbrella.

An unusual feature of the NICE system is that a story is automatically constructed, which describes each action of the learner. This story is expressed in simple English sentences, with some words (e.g., sun) replaced by colorful icons. The story is printed for the child to take home.

5.2.3 Experiments

The basic premise of NICE was to allow self-directed exploratory activities and to carefully observe and analyze what happened. There was some guidance provided by teachers who helped students stay on task and contain their excitement. The experimenters gathered observations in five areas:

- Technical: usability of the interface, system hardware and software
- Orientation: navigation, presence
- Affective: engagement, confidence, interest level
- Cognitive: improvement of knowledge and understanding
- Pedagogical: how did student–student and student–teacher collaboration work?

Fifty-two students between 6 and 10 years old participated in the NICE experiments. The usual experimental setup was to have two groups of four students using two CAVE systems, coupled by a bidirectional audio link. In each group, a leader was designated to wear the tracking device and to appear in the NICE world as an avatar. The other team's avatar, and that of a third person (actually a teacher), appeared in the world to act as a guide.

Each group planned a garden before they entered the CAVE. The group then directed their leader as he or she carried out the design. The group could see the other group's avatar. Sessions lasted about 40 minutes; they were preceded by a set of pretest questions, and followed by interview questions. Students then made drawings and wrote essays.

5.2.4 Experimenter's Conclusions

With regard to usability: the stereo glasses and control wand, being adult-sized, did not work optimally for smaller children. Fatigue (see chap. 41, this volume) and simulator sickness (see chap. 30, this volume) were minimal, but some difficulty with orientation (see chap. 24, this volume) was reported. With regard to affective issues, students enjoyed the activity and particularly liked reading the stories that chronicled their adventures. The student leaders were more engaged with the learning task than the passive observers; the observers were more engaged with the medium itself. Improvement of knowledge and understanding was correlated with control; that is, the students who directly controlled the environment learned more than the passive observers.

Before the experience, 12% of the participants had a good understanding of environmental concepts; afterward, 35% met the same criterion. Most (73%) of the successful students were group leaders.

The project team plans to develop scalable models so that younger children can experience simplified biological phenomena and older ones can explore a richer set of interactions.

5.2.5 Analysis

In Gagne's terms, the NICE experiment helped students build their "procedural knowledge" about caring for plants and their "verbal information" about how plants live. In Gardner's terms, the project was directed at helping students develop their understanding of "mathematical–logical" and "spatial" relationships between growing plants and their environment.

The experiment's cognitive measures would seem to indicate that the educational efficacy of passive observation/participation in VE is limited. Interestingly, such passive conveyance is also attributed to higher levels of sickness (see chap. 30, this volume).

6. ROLE-PLAYING AND SITUATED LEARNING IN SHARED VIRTUAL WORLDS

Several of the projects already described were designed with explicit social dimensions. VRRV had students work together to design and build worlds, and NICE had groups of students sharing a CAVE system. In fact, NICE had two CAVE systems in use at once, with a network so that each user could see the other's avatar. However, the presence of specific characters inside the virtual world, with differentiated capabilities and assigned roles, was not central to the instructional design of those projects.

It can be argued that virtual worlds without specific, visible, differentiated characters (avatars, see chap. 15, this volume) and roles are of an essentially different nature than worlds built around avatars. There is a spectrum of abstraction in simulation-based learning. At the most abstract are simulations with no situational information, just the essence of the phenomenon at hand. Less abstract are simple simulations that are situated within a simulated world, but which are used, so to speak, "through a window." When an immersive system with free motion of viewpoint is used, the situation gets even more concrete, but the learner is still free to behave in a godlike fashion. The *behavioral schema* is oriented toward objects, and there is nothing but the simulated world's own rules to constrain one's behavior.

As soon as human forms appear in the world and begin to plausibly interact with the user, behavioral schema shift and become oriented toward shared experience. This may be the least content friendly of all forms of simulation; social interaction can be a powerful distractor from reflective thought. But students can and do learn from shared experiences. They explain things to one another and observe the result of others' experiments (Johnson & Johnson, 1987).

With younger children, one possible distraction is that they may begin to compete rather than cooperate. Instructional designers sometimes optimistically assume that activities originally conceived of as cooperative tasks will naturally be treated that way by students, but students may see the simulation as a me-win/you-lose game. The social schema must be carefully constructed so that learners can take advantage of known ways of interacting. Roles such as leader/follower, teacher/student, or allies/adversaries are obvious possibilities. Both the projects to be described below have carefully designed roles for participants.

6.1 The Round Earth Project

Like the NICE Project, the Round Earth Project was carried out by the Electronic Visualization Laboratory at the University of Illinois at Chicago. The same CAVE equipment was used. However, in the Round Earth Project, the interaction of two students within a shared virtual world is essential to the instructional design. The work is described in Johnson, Moher, Ohlsson, & Gillingham (1999).

6.1.1 Purpose

The experimenters wanted to select a problem that met the following criteria: Learning goals must be important and hard, and VE must offer some plausible enhancement to the learning process. The concept of the earth as a sphere was selected because it is in standard elementary science curricula and is known to be hard for many children to grasp.

The actual purpose of the experiment was to investigate how VE could teach concepts that are inconsistent with a user's current mental model. It is necessary both to establish the new phenomenon (in this case, the experience that "down" points toward the center of a sphere rather than perpendicular to an infinite ground-plane) and to link this knowledge to one's prior mental model. Two theories of deep learning, "transformationist" and "displacement" approaches, were investigated.

6.1.2 Setup

One CAVE and one ImmersaDesk system were used. An ImmersaDesk is a single-projector system arranged like a large drawing table, in contrast with the CAVE's four viewing surfaces arranged as three walls and a floor. Stereo glasses are used by both participants, and a bidirectional audio link is provided.

Two treatments were provided: Astronaut World and Earth World. Astronaut world was intended to provide a clean break from the current flat-earth experience, with an astronaut-avatar walking around a tiny spherical asteroid while the other learner observed and directed his actions from a command module. To enhance collaboration, the task (picking up fuel cells) was designed so that the observer had knowledge of what was essential for the astronaut's success. The students alternated roles so that each experienced both the god's-eye view and the immersive view.

Earth World involves a satellite mission in Earth orbit. Thus the learners experience the transition between the "flat earth" as seen before launch and the spherical planet with a curved horizon.

6.1.3 *Experiments*

In three successive pilot studies, a total of 17 pairs of children were used. The children were predominantly African-American third graders from a Chicago school in which 93% of students' families are below the poverty line. An initial pilot study led to improvements in the user interface and controls. Students were introduced to the system and then spent 10 minutes on each task twice: for instance, mission controller, astronaut, mission controller, astronaut. The children were usually actively talking to one another. They focused on the task of finding and collecting fuel cells and did not pay much attention to the issues of up and down, gravity, and so forth. A group debriefing in front of the ImmersaDesk occurred after the interactive session.

Pre- and posttests were initially done using 2-D pictures and open-ended questions. When these showed little learning, a Play-Doh 3-D model was used with interview-style questions. It quickly became apparent that little conceptual learning was taking place. For the third pilot study, the approach was modified to focus more attention on the concepts. Only Asteroid World was used. The introductory activity was extended so that the students were given a guided tour around the asteroid. Students' hands-on time was decreased from 40 to 20 minutes. The group ImmersaDesk debriefing was replaced by individual guided inquiry with a physical globe and model of the asteroid.

6.1.4 *Experimenter's Conclusions*

Some clear instances of learning occurred, but there was no large and consistent effect. The use of young children from a challenged population and away from their schools imposed severe logistical strains. The experimenters plan to refine the virtual world and experimental approach and analysis.

6.1.5 *Analysis*

The experiment was designed to use the interaction between two children as the focus of learning. The concept of the round earth would presumably fall into Gagne's category of "factual knowledge." The observer was expected to notice and remark on the fact that the explorer was "upside-down." In the experiments, however, the observer was usually so focused on the task of helping the explorer to navigate that abstract concept formation seldom occurred.

Experimenters were surprised by how difficult it was to convey abstract information to children from deprived backgrounds, and (like the Virtual Gorilla Exhibit project) found themselves adding traditional teaching methods such as tangible 3-D models to their experiment.

6.2 ExploreNet

Not all virtual worlds are three-dimensional. Since 1994, Charles Hughes and Michael Moshell at the University of Central Florida have been exploring the educational utility of shared virtual worlds by using a relatively simple 2-D cartoonlike system called ExploreNet, which was inspired by the Habitat role-playing system (Morningstar & Farmer, 1991). Moshell and Hughes have conducted a series of experiments in various learning contexts, and developed an instructional model built around role-playing and improvisational drama.

6.2.1 *Setup*

ExploreNet is a Windows application, running on ordinary PCs with Internet connectivity. A group of two to eight computers are set up with identical software. One of the computers is designated as a server, but also remains available for student use as a workstation. The users select a shared world and then choose the avatars or characters they will control during the simulation. One station can control one or several characters by taking turns.

Characters move by walking or flying to the location where a mouse-cursor is clicked. If the user clicks on a character or a "prop" (a noncharacter object) in the scene, a menu displays the actions that object can exhibit. If the user types the words appear over the head of the avatar currently controlled by that user on all workstations currently viewing the scene.

The principal expected advantage of ExploreNet's 2-D user interface over 3-D virtual worlds was its ease of world construction and use. ExploreNet's limited repertoire of simple behaviors allowed students to concentrate on the tasks at hand. However, there were a number of user interface problems that emerged as studies continued. Scenes are static and "hot spots" at the edge of scenes are used to move between scenes. When a character steps on a hot spot it disappears from the scene and finds itself in another scene. This proved quite confusing for many users. Ultimately it was found necessary to provide "mentor characters," which control student characters' ability to leave the scene of an intended action. Similar problems arose in dealing with the control of props, particularly when several props were close together.

6.2.2 Experiments

Three worlds were built and tested between 1994 and 1997. Zora's World was based on stories in the autobiography of Zora Neale Hurston, an African-American writer from Eatonville, Florida, and tested in Eatonville's Hungerford Elementary School. Dinosaur World was built in cooperation with students at Maitland Middle School and tested there. AutoLand was built to specifications provided by third grade teachers in the U.S. Department of Defense Dependents' Schools in Germany and tested there. These experiments are described in Moshell (1996) and Hughes (1996, 1997).

The key questions being investigated in these worlds were:

- How should the roles played by different students be differentiated?
- How many students can profitably interact within a simulation?
- How can "free play" and a story line, with educational goals, be reconciled?
- How can the learning experience be managed?

Owl
dog

6.2.2.1 Zora's World. In the first experiment, two *mentor characters*, an owl and a dog, were provided. Other students controlled auxiliary characters (i.e., chickens and a cat). The students controlling the mentor and auxiliary characters were referred to as *cast members*. In addition, two pairs of *guest characters* were provided. The objective of the guests was to get eggs from the barn, build a fire in the back yard, and cook the eggs. But the chickens did not want to give up their eggs. Solving this problem required cooperative behavior between two guests. The mentor characters were trained to give hints as needed without giving away the entire story at once.

The cast members knew how the story was supposed to come out; they were responsible for the experience of the guests, much as uniformed staffs are responsible for the experience of guests in a theme park. Thus the entire experience involved eight students, four guests and four cast members. Usually, six computers were used, with two guests and two cast members sharing computers.

Like the Round Earth Project, Zora's World focused its experiments on underprivileged children. However, the experiments were conducted in the children's own school; in fact, they were situated in the classroom alongside the rest of the class. The six computers were set up with their screens facing the wall, so only the eight participating students could see what was going on. The other 16 children in the class knew that their turns would come; they were supposed to work on other projects in small groups while the current crew explored Zora's World.

Various age pairings were tried, with fourth-, fifth-, and sixth-grade children playing the roles of cast members and guests. It was found that sixth-grade students acting as cast members had the best chance of retaining control of the learning situation and achieving desired outcomes. Younger children would lose track of the fact that they were supposed to be managing others' learning experience and would play the game themselves. However, in general the younger children acting as guests successfully completed the game as often as the older ones.

All students viewed the game as a competitive one, though it had been designed as a cooperative experience. Students would hoard resources (firewood for instance) and bring the game to a standstill until a mentor character could convince them to share.

6.2.2.2 DinoLand. In this world, four individual guests represented different dinosaur species, two herbivores, a carnivore, and an egg-eating species. The only cast member played a managerial role in charge of invoking a day–night cycle. Every night represented a new generation of dinosaurs in which those species that successfully laid and defended their eggs in the previous round became stronger.

The students were extremely motivated by the competitive aspects of predator–prey relationships. One carnivore-player discovered that he could collect all the plants and starve the herbivores into submission. The use of four rather than eight characters proved to declutter the screen and keep interactions focused.

6.2.2.3 AutoLand. AutoLand was designed as a collaborative constructionist activity in which four guests had to find raw materials, assemble them, and create the components of an automobile. Unlike the previous two worlds, this lesson was created on the basis of a textbook chapter (specified by third grade teachers) and was provided to the teachers along with worksheets and paper maps. Because participating students were third graders and could not type, they were allowed to interact verbally (by talking to the students on adjacent computers). Instead of on-screen mentors, each student had a "shoulder buddy" who had previously been through the experience. A teacher served this role for the first group.

According to the teachers, Autoland was very successful as a supplementary classroom activity. In testing by 50 children in two classrooms, over 90% of the four-person teams succeeded in constructing the automobile within the allotted 40-minute period. A formal external evaluation was provided for, but due to transatlantic logistical difficulties was not completed.

6.2.3 Experimenter's Conclusions

The succession of experiments led the project away from the use of in-world cast members and toward a close correlation with subject matter that was of interest to teachers. The provision of external reading materials and in-class activities provided necessary a priori knowledge (e.g., of where in the United States one might find iron ore, coal, etc.) so that the virtual experience could serve to transform abstract concepts like north and south into real experiences.

6.2.4 Analysis

The ExploreNet experiments were intended to teach "attitudes" (cooperation) and "cognitive strategies" in Gagne's terms, or "interpersonal and intrapsychic" skills, in Gardner's terms. In AutoLand there were also goals related to factual information (where cars come from).

Lessons were learned about techniques for using one group of students (cast members) to guide the experience of other students, and about how to build materials that teachers would willingly use.

7. THE FUTURE OF VE TECHNOLOGY IN EDUCATION

From the six projects analyzed in this chapter, some common themes emerge. The most striking of them is that no project achieved significant, measurable learning in its first attempt at using VE technology, and most had not achieved clear results even after several experimental revisions. Among many possible reasons, the most plausible seem to be:

- System complexity and novelty consumed most of the students' and experimenters' attention.
- Evaluations that measure factual knowledge in traditional ways may not be very sensitive to the kinds of procedural knowledge and cognitive strategies that might develop in VE.
- The process of instructional design for virtual worlds is very immature. Tools for constructing 3-D geometric models require specialized technical knowledge and are generally difficult to use.

The explosive growth of video game technology means that the technical and cost barriers to high-performance 3-D computer graphics are disappearing. Interactive software will become easier to build, though it is difficult to predict how fast or far this trend will go. It seems likely that many more experiments will be conducted in the use of interactive simulation for learning. The authors hope that the lessons learned from the pioneering projects reported in this chapter can make the way easier for those who follow.

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