THE DEVELOPMENT AND ASSESSMENT OF A VIRTUAL WORLD FOR TEACHING ALGEBRA

William Winn, University of Washington College of Education
William Bricken
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Virtual Reality (VR) refers to a new computational paradigm that fundamentally redefines the interface between humans and computers. It includes the body of techniques that tightly couple natural human behavior to computationally generated environments, creating electronically mediated experience. The participant in VR interacts with hardware which senses natural behavior and displays from a subjective perspective. The action-consequence loop is real-time, creating the sensation of direct participation in an environment.

Currently, our understanding of VR techniques has evolved sufficiently to ask questions concerning the application of virtual environments to education and to science and mathematics curricula. We propose to develop a VR testbed for educational applications, to design and evaluate selected mathematics curricula in VR, and to place the experimental materials in the hands of secondary teachers and students in school systems.

Virtual Reality in Education

During the last forty years, educators have eagerly adopted a number of technologies, expecting them to improve the quantity and quality of what students learn. However, programmed instruction, film, radio, television and computers have failed to live up to educators' expectations. This has had two consequences. First, educators have become somewhat jaded in their attitude towards technology. Second, technologists have learned a great deal about the role of technology in education. In particular, it is now clear that technologies themselves do not improve education. Any improvements ensue from the instructional methods that are used with the technologies (Clark, 1983, 1985, 1985b). It is also clear that educators must be involved in the development of new technologies from their inception, that a great deal of effort must be spent on curriculum and instructional development before technologies can become effective, and that technologies work best when they are not forced into the mold of traditional instructional practice.

This project takes these lessons very seriously. In order to avoid the pitfalls encountered when other technologies have been introduced to Education, we propose:

-- to develop a variety of instructional strategies and instructional management procedures likely to be effective with VR,

-- to develop innovative curriculum that takes advantage of the unique characteristics of VR,

-- to develop virtual worlds that embody these instructional strategies, and to formatively evaluate and revise these worlds in a rigorous manner,

-- to assess the effectiveness of these strategies and curriculum, and

-- to enlist the close cooperation of teachers in schools receptive to innovation.

Expected Advantages of VR

VR continues in the tradition of using technology to promote learning within a constructivist paradigm (Bransford, 1990, 1991; Scardamalia, 1991; Spiro, 1990, 1991). Until now, the success of instructional technologies has been severely constrained by their lack of ability to engage students and by very limited interactivity which provides only vicarious instructional experiences. The keyboard and the mouse put distance between the student and the program.

VR has two very obvious advantages. First, it is entirely engaging. Students are totally immersed in virtual worlds. They cannot "look away" as they can when working from a computer monitor. They can take on any role, sharing the perspective of another person or of an object. Second, the experience is immediate. There is no interface to get in the way. Students interact directly with the virtual world as they would with the real world, by looking around, by moving through it, by picking up objects in order to examine or manipulate them.

The engagement and immediacy of VR suggest two areas where it can be used effectively in education. The first is providing access to real but inaccessible or dangerous worlds. Here, the student might explore the seabed, fly a plane, or swim through an artery. The second is the creation of virtual worlds that embody abstract concepts and principles. For example, mathematical theorems do not exist in any physical sense. For this reason, many students have difficulty understanding them and learn them poorly if they learn them at all. Yet a virtual world can be constructed in which the concepts and principles of algebra or geometry are represented experientially. In such a world, a student might manipulate a mathematical function directly, immediately experiencing the result.

The promise of VR includes:

-- a deeper, more natural interaction with computational and symbolic information,

-- a new kind of laboratory experience, one in which interactive experience in virtual worlds replaces specialized physical equipment

-- a new kind of "textbook" in which multimedia experiences are direct, first-person, and as-if-real

-- a capacity of learning through first-hand observation and experience in computationally responsive, programmable environments.

The purpose of this project is to assess the feasibility of building useable virtual worlds that instantiate concepts and rules of algebra and to assess the advantages of these worlds for learning algebra. The engagement and immediacy of VR lead us to expect that:

-- effective virtual worlds can be constructed to contain manipulable objects that represent aspects of algebra,

-- students who experience a virtual world which embodies selected concepts and principles of algebra will learn them,

-- students who have difficulty learning the content from more traditional instructional techniques will learn more easily from VR, and

-- students will enjoy learning more from VR than from traditional instruction.

We are eager to assess students' ability to transfer what they learn in VR to other settings. This means two things for our project. First, instructional strategies will be developed that teach for transfer (Butterfield & Nelson, 1989). This will require the development of a virtual world that provides a sufficient variety of experiences to permit generalization from what is learned. Second, we will structure a research program to test for transfer. We are interested in transfer to tasks typically required in school, assessed by mastery tests and standardized tests of mathematical ability. We are also interested in transfer to practical problems with solutions which require the application of knowledge learned in VR.

Research Methods

The project is not a controlled experiment. Its purpose is to evaluate the potential of VR for teaching algebra using a variety of instructional strategies. Given the newness of VR, this means that our evaluation will be largely formative. To assess the effectiveness of VR, data will be gathered through pre- and post-tests of achievement. To determine the degree of engagement, video records will be made of all sessions, think-aloud protocols (Ericsson & Simon, 1980) will be gathered from students inside a virtual environment, and students will be thoroughly debriefed. The project description follows:

PHASE I: INSTRUCTIONAL DESIGN (2 months)

1. Identify collaborating teachers and schools.
2. With teachers, identify a specific area within algebra which can be addressed by VR techniques.
3. Identify and develop a range of instructional strategies, including free exploration, guided discovery, and problem solving.
4. Identify instructional methods for comparison groups. Develop testing materials.

PHASE II: VIRTUAL WORLD DESIGN (4 months, overlapping Phase I)

1. Identify the relevant components of the virtual environment operating system and associated software and hardware.
2. With teachers, design the virtual algebra world. Identify the unique instructional aspects of virtual world.
3. Implement the virtual algebra world, iterating development to meet instructional objectives.

PHASE III: EVALUATION (8 months)

1. Select sample of students, pretest for algebra achievement and aptitude.
2. Place students in virtual algebra world.
    a. Familiarize student with VR experience and with thinking aloud.
    b. Free exploration of the world.
    c. Assign a task, depending on the instructional strategy
    d. Gather video, computational traces of activity, and think-aloud data.
3. Administer post and transfer tests. Debrief student.
4. Analyze data for content mastery and success relative to aptitude.
5. Iteration from task 2, modifying instructional strategies and world design.
6. Test for transfer to academic and "real-world" knowledge and skills.
7. Compare results from VR experiences to comparison groups.

Phases I through III are designed as one year of research. A second year of study would include replication the first year work in three additional classrooms, extension of the domain of study to other algebra applications, and broadening of the virtual world to include multiple participants.

Outcomes

We expect that the project will provide a great deal of information about the use of VR for teaching abstract content. In particular, the project will indicate:

-- the extent to which students enjoy VR,

-- the ways which students interact with virtual manifestations of abstract ideas,

-- the degree to which what students learn in VR can be used outside VR,

-- how students take advantage of the manipulability of objects in the virtual world, and

-- the degree to which students need to be guided when they work in the virtual world.

The project will also tell us whether it is feasible to use VR with typical students to learn content prescribed by a standard curriculum. Teachers' reactions will also be collected, permitting an estimate of the degree to which more extensive use of the technology will require school reorganization. Finally, it is expected that this initial assessment of VR will lead to the development of testable hypotheses that will permit a more accurate evaluation of the educational effectiveness of VR.

Once the benefits of virtual instruction have been established, we would like to begin a more substantial project designing and implementing a set of software tools for experiential mathematics. The idea is that a student would enter a virtual world which posed the curriculum in terms of interactive problems. The student could select virtual tools, such as virtual measuring devices, graph generators, or even mathematical theorems, which could literally be applied to problems. To empower teachers, we would then like to construct "authoring tools" for in school development of mathematics experiences and interactive problems. These virtual mathematics worlds could be associated with virtual physics worlds, permitting an integration of technical mathematical techniques with science curricula.

Investigators

The co-Principal Investigators for this project are Dr. William Winn and Dr. William Bricken.

Dr. Winn is Professor in the College of Education at the University of Washington. He works in the Educational Technology program in Curriculum and Instruction with a cross-appointment in Educational Psychology. His research is in two areas. The first is the development of prescriptive instructional theory and instructional design theory based on research and theory in cognition. The second is the empirical study of how students perceive, understand and use information presented in graphics. He teaches courses in instructional design, educational technology, computer graphics and instructional theory. Prior to his appointment at the University of Washington, Dr. Winn worked at the University of Calgary. Here, he headed a project which developed the technology and curriculum for using computer graphics in distance education. He also worked on educational aspects of the PISCES project, an extensive simulation of economic systems developed in the College of Engineering. Dr. Winn holds a PhD in Instructional Systems and Educational Psychology from Indiana University, a Masters degree in Comparative Literature and a Bachelors degree in French and German from Oxford University, England. He was formerly editor of Educational Communication and Technology Journal, the major research journal in the Educational Technology field.

Dr. Bricken is the Principal Scientist of the Human Interface Technology Laboratory and a Research Associate Professor of Industrial Engineering at the University of Washington. His current work includes development of a mathematical foundation for virtual reality, design of VR software architectures, implementation of experiential mathematics, and simulation of unreality. He is the chief architect of the Virtual Environment Operating System which interconnects VR interface devices, construction and simulation software, and display hardware. Formerly, Dr. Bricken was Director of the Autodesk Research Lab and Principal Scientist at Advanced Decision Systems, where he pioneered innovations in parallel inference techniques for AI, visual programming languages, and intelligent computer interfaces. He was an Assistant Professor of Education and Social Psychology at Monash (Australia) and at the University of Hawaii. Dr. Bricken holds a multidisciplinary PhD in Education, Computer Science, and Research Methodology (Stanford), an MS in Statistics (Stanford), and a Diploma of Education (Monash). His dissertation was an exploration of unique errors of novice algebra students, for the purpose of developing Intelligent Tutoring Systems. He is currently an associate editor of Presence, the principal technical journal for virtual environment research.

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