VR as Instructional Technology – The CAVE as Classroom

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Introduction

Kathy Madura is teaching her students at Abraham Lincoln elementary school in Oak Park, IL about the human heart. Part of the lesson is taught using traditional paper drawings, and plastic models. Part of the lesson is taught on the gym floor that has been laid out as various chambers of the heart and lungs where the students grab red dodge balls and move around the gym floor through the 'heart' and 'lungs' to learn how the entire system functions. The lesson is also taught using virtual reality equipment installed at the school. Kathy and three or four students wearing special glasses stand in front of an ImmersaDesk, a drafting-table shaped VR device with a large 6′ by 4′ stereo-image screen where a 3D model of a human heart floats. The students can watch the heart pumping and follow the path of blood flowing through the heart and lungs. The students can stick their head into the various chambers and look around, or they can use a virtual 'cutting plane' to see the internal structure of the heart and lungs from any viewpoint.

At the Foundation of the Hellenic World, a museum dedicated to Hellenic culture in Athens Greece, children within a virtual reality room walk daily through the ancient city of Miletus on the coast of Asia Minor as it stood two thousand years ago. This room is 10′ wide, 10′ tall, and 10′ deep, with three walls and the floor being large projection screens showing stereo-image computer graphics. When the students put on the special glasses, the city of Miletus surrounds them in 3D. The large display screens allow the students to walk through Miletus and see all of the buildings full-scale. A human tour guide leads them on a tour of this virtual city in the same way they would tour a real physical place.

These are just two examples of virtual reality (VR) technology being used to enhance conceptual learning in real educational settings. In this essay I will talk about some of the work being done to explore VR's potential to create effective learning environments.

What VR means to us

Many people have different definitions of 'virtual reality.' The broadest and simplest definition is virtual reality allows the user to immerse himself or herself in another world. This definition includes 'old' technologies such as books, plays, films, and orchestra recitals, as well as new technologies such as chat rooms, videoconferences, and video games.

However, for people doing research in the area of virtual reality, the definition is more specific. Virtual Reality needs stereo visuals (to see the world in 3D), wide field of view (the difference between seeing a film in a theatre and on TV), a viewer-centered perspective (as you move your head or body your perspective changes), ways to interact with the world, audio and perhaps the sense of touch. The idea is to recreate the experience of being a person in a space, except in VR that space is an artificial world generated by a computer. For different goals, all of these components (stereo-visuals, tracking, wide field of view, interactivity, audio, touch) might not be required, and a major part of the research right now is seeing which components are valuable for which learning goals.

When most people think of 'virtual reality,' the common image is a head-mounted display, for which the user wears a helmet that covers their eyes and ears. We take a different approach and use large projection screens instead so the user is not isolated from the real world, and more importantly is not isolated from friends and colleagues who are standing nearby. The large screens allow multiple people to share the same experience, which can be very valuable in educational situations where small groups are working as a team. This is also an advantage over standard computer monitors.

There are currently hundreds of VR rooms, and drafting-table sized displays in use around the world. They are most commonly used in research labs for scientific visualization, and in companies such as General Motors for design and evaluation of products in full scale. There are also history museums using them to look at historically significant sites, and several art museums such as Ars Electronica in Austria and NTT's InterCommunication Center in Tokyo have installed these devices to explore their potential as a new art medium. Other researchers are looking at skill acquisition and training, especially in medicine. Our work focuses on the application of these kinds of devices in conceptual learning from elementary school through college. I will describe this further in the next section.

How VR fits into the learning process

We believe that VR can be a valuable tool for conceptual learning. Unlike a textbook or video that presents material in a certain order, in VR the subject matter can be experienced in any order. Unlike a static drawing or photograph, the student can see how the system changes over time, or manipulate the system to see what effect those changes will have. Finally, immersion gives the student the feeling that he or she is directly experiencing and interacting with the subject matter.

Of course, this freedom may lead to confusion if the students explore on their own. The teacher is still the most important person in these educational worlds. The teacher guides the student through the virtual experience in the most appropriate way given his/her experience with the subject matter and the student. We see virtual reality as just another tool that the teacher can employ when it is appropriate. Just like textbooks, filmstrips, videos, guest speakers, and plastic models, virtual reality technology will be good at helping learn certain concepts. We are investigating where it can be useful.

Virtual reality should be beneficial for investigating 3D objects (such as the human heart) or walking through 3D places (such as Miletus or Virtual Harlem). It allows us to visit places that are too remote, too dangerous, or simply impossible to visit because they no longer exist or do not yet exist. Paintings, photographs, and videotapes are less exotic ways to visit such places. However, unlike photographs or paintings, VR allows the student to see the context of the image—what lies outside the frame, what is behind the camera. For example, we have worked with researchers at Northwestern University to create a virtual world that allows people to walk into the caves in the Mogoa Grottoes of Dunhuang China on the Silk Road. These caves are in a remote location, and access is limited because of their fragility. The interiors of these caves are covered with murals, and while photographs are good tools for seeing individual murals in detail, VR is a good tool for allowing someone living on the other side of the planet to "virtually" stand inside these caves, surrounded by the murals, and to see how the murals relate to each other. Unlike videotape, we have control over where we move and where we choose to focus our attention.

VR is effective because the user can learn by manipulating the virtual object or scene and seeing the resulting effect. VR allows us to see at a more appropriate scale; the streets and buildings of Virtual Harlem at full scale; ants or atoms on a scale large enough to observe; or our solar system reduced to encompass our field of vision. VR allows the user to 'become' someone or something else with different abilities and characteristics – such as a bird that can fly, a red blood cell flowing through the bloodstream, a person with a vision problem, or someone from a certain ethnic and social background in Harlem. We have the ability to connect these VR devices together, linking students around the country or around the world. We also gain the ability to record students' interactions: where they went, and what they interacted with. This allows the developers to improve the virtual environment, but it also allows the teacher to see where the students spent their time and what they experienced, which can be difficult in the real world. This form of embedded assessment may be very useful in gauging learning effectiveness.

Since this technology will remain exotic for a while, we need to determine a method that will allow students to take something tangible from the virtual experience, such as an artifact, to aid in reflection. Drawings they made based on their observations in the virtual space or pictures taken within the virtual environment could be constructive learning tools. We could also generate less technical versions of the virtual experience, for example by producing a video of what a typical user would see in the environment, or by taking snapshots of what that typical user saw in the environment and making those available on the internet or on CD-ROM. This would allow us to link together a museum experience, a school experience, and the home experience. Conversely, we would like the students to be able to leave artifacts within the virtual environment (see Bricken, 1993). In Virtual Harlem the students can leave annotations in the space, which become another ‘character’ in the virtual world [see Kyoung, Leigh, Johnson in this volume].

Technologically speaking, this is possible today. However, it is important for us to learn from the lessons of past attempts at integrating technology into educational settings, most of which have been unsuccessful. We must address the needs of the individual learners while respecting the constraints (financial, time, and space) imposed by the educational context where learning occurs; those constraints are very different between an elementary school, a museum and a university. It is not enough to demonstrate that the technology functions. For it to be truly useful, we need to show that it is valuable in real educational settings with real students and real teachers. The next section will describe some of the research that we are doing in those real settings.

Current projects

There are several different groups doing research on the use of virtual reality in conceptual learning in museums, universities, and K-12 classrooms (Youngblut, 1998), (Dede, 1996), (Rose, 1995), (Gay, 1994), (Allison, 1997). Much work has been done in this area, and many different approaches are being tested. In this chapter, I will concentrate on the work that I am most familiar with: At the Electronic Visualization Laboratory at the University of Illinois at Chicago, we have been focusing on assessing the impact of VR in an elementary school and are preparing projects for museums and university courses. This work is a large collaborative effort; the main faculty members involved are Tom Moher and myself from Computer Science, and Stellan Ohlsson from Cognitive Psychology.

One of the difficulties in assessing the impact of these VR learning experiences is that it is difficult to separate the virtual world from the technology that delivers it. Ideally, we want the student to focus on the lesson to be learned, not the big screen or the 3D glasses; we want the technology to fade into the background. However, the novelty effect of VR technology is quite strong because it is exotic. Only through repeated use will the technology become ‘invisible.’ One of the main reasons that we have moved an ImmersaDesk into Abraham Lincoln elementary school was to try to avoid the novelty effect by giving the students multiple lessons using the VR technology over several years. Of the current children at Lincoln Elementary, roughly all of the 1st, 2nd, 4th, and 6th graders and one fourth of the 3rd graders (over 425 students total) have had at least one VR experience over the past three years. Over 100 students have had two or three experiences over the last three years.

Our main topic of study in the elementary school is the coordination of multiple representations, both within the virtual worlds and between the virtual world and other media. In order to truly learn a concept, students need to make the appropriate mappings between representations given in different media and different representations within the same media. As described above, VR allows us the opportunity to utilize more appropriate representations in certain domains. How do we help the student correctly map between those representations? In our work with the elementary students, we are investigating this through three tracks of research: the 'Round Earth' track, the 'Virtual Ambients' track, and the 'Quick Worlds' track (Johnson, 2001).

In the 'Round Earth' track we are trying to help 1st and 2nd graders learn about the shape of the Earth and create the mapping from the apparently 'flat' Earth they walk on and the 'round' Earth seen from space. This is more than being able to say that the Earth is 'round' or has the shape of a sphere. It also means knowing about the ability to circumnavigate the Earth, the relativity of up and down, the lack of support for the Earth, and how the Earth's terrain occludes things on the surface that are far away. These things are hard to learn on the small patch of the surface that we commonly walk on every day, and in fact that experience gets in the way of trying to learn about the true shape of the Earth. Instead of converting their existing flat model into a spherical one, we use VR to take the children to a small round asteroid, like the one Antoine de Saint-Exupery's Little Prince lived on. VR helps the kids learn what it is like to walk on this small asteroid around a small spherical body. Then with the help of a small Styrofoam model and an Earth globe, we talk to them individually about how the Earth is the same, only larger (Ohlsson, 2000).

In the 'Virtual Ambients' track, we try to teach students about the scientific method by giving them a virtual field to explore and tools to collect data. This gives them an experience similar to going to a nearby field and collecting rocks or insects, but here the teacher has control over what they find; therefore, we can use easier words for younger children and progressively more complex words for older children. This is similar to an archeological dig my class did in the 6th grade in a nearby field. Of course, the teachers prepared the environment six months earlier with the broken objects we would later 'find.' In our virtual field, the children can learn how to survey a space and collect data for analysis. Accordingly, they should be able to repeat the same tasks in the real world with more skill. The mapping we are concerned with in this situation is the mapping between objects/phenomena (plants, rocks, animals) and their abstract form as data (points, numbers, symbols). We believe that going through the act of collecting the data (in our case surveying a virtual field and taking measurements on the plants found there) makes it easier to follow that data through the analysis process, rather than just starting with a set of numbers which is already an abstraction. Small groups of three or four students spend about 30 minutes collecting data in VR; the rest of the lesson (planning the data collection, integrating the data, analyzing the data) is

Figure 1. Sixth grade teacher Kevin Harris watches as three of his students explore and collect data from a virtual field.

done as a whole-class activity over several hours (Moher, 2000). [See figure 1.]

In the 'Quick Worlds' track, we are looking at how this technology can be easily integrated into existing curricular units. The teachers ask us for simple virtual worlds and we build them; for example, the beating human heart and lungs described in the introduction, or an ant with internal organs, or the solar system – things where VR should be useful in learning the concept. We want to observe how the teachers, such as Kathy Madura, relate their traditional methods of teaching to what can be experienced through VR (Johnson, 2000). [See figure 2.]

In Virtual Harlem, we are dealing with similar issues of coordinating multiple perspectives. The students are already learning different perspectives from the various authors they are reading, the photographs they are seeing, and the music they are listening to. The virtual environment gives them another perspective – richer in some ways, poorer in others. Like the Round Earth work, we are trying to immerse the students in another environment by taking them out of the classroom and into the streets of Harlem 80 years ago. As in the Virtual Ambients track, we give them a world to explore, a place that encourages them to ask questions about the people and places of the Harlem Renaissance. Like the Quick

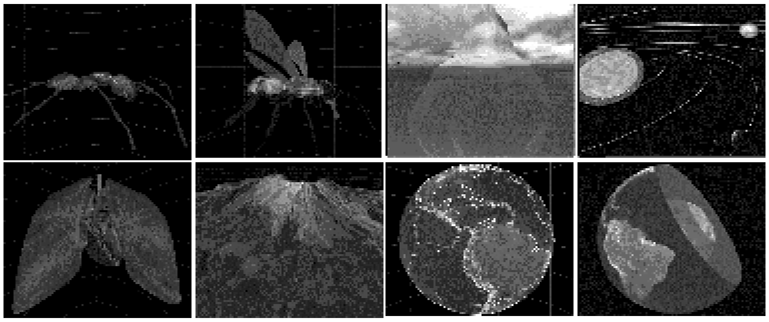

Figure 2. A selection of Quick Worlds that we have developed for the teachers at Abraham Lincoln elementary school – clockwise from top left: an ant, bee, iceberg, solar system, interior of the earth, earthquakes and plates, Mt. St. Helens, and a human heart and lungs.

Worlds track, we want to integrate this new technology into existing curricula where appropriate to see what benefits it may have.

What we are learning from these studies

By placing this technology in real world setting, we can see what works and how to adapt our procedures when things do not work. This section will discuss some of the broader lessons we have learned from these deployments at Lincoln.

Usability has not been a problem, especially for children; first grade children can successfully use the technology. In general, younger students are more comfortable with the technology. They are already familiar with videogame controllers, and they are less inhibited when it comes to exploring the virtual worlds. This familiarity can be good or bad. The children are motivated to explore the virtual world, but it is easy for them to treat the virtual world as a game, and often they do not stay focused on the learning goals. The guides and teachers need to keep the students focused and engaged not just with the superficial aspects of the environment, but with the deeper lessons the environments convey.

While children move through and see what they can discover in the virtual world, adults tend to remain stationary and move about the environment very little. Adults tend to be less comfortable with this technology. This can be a problem in college classrooms where we may need to provide an equivalent experience for students who do not want to participate in the VR experience. In this situation, it may be helpful to have less technical versions of the virtual worlds available.

We have found that it is hard to measure changes in the students' knowledge. This should not be a revelation since there is little agreement in the education community on how to assess learning. We pretest and posttest the students in the Round Earth track, and we not only give them a written test, but we also talk to them and try and probe for the rationale behind their answers. We talk to the teachers in the Quick Worlds track. We videotape the classroom discussions and the VR experiences in the Virtual Ambients track. We have found that the Round Earth experience does bring the students who did not have a solid grasp of the spherical nature of the Earth up to the level of their classmates who did. We are still investigating if this is a condition of the VR and or an effect of teacher interaction with the children. Our initial results suggest that the VR asteroid is better at helping children gain some concepts, while the Styrofoam asteroid helps them gain others. Each gives the students a different view of the material as well as different affordances. VR helps the children understand occlusion by curvature since the children can move forward and backward on the surface and watch tall objects appear and disappear over the horizon top-first as they move. The physical model helps them learn about circumnavigation since they can physically hold and turn the asteroid model in their hands while moving a small astronaut figure around its surface.

The most important lesson has been about accessibility. If the technology is not easily accessible, then it will not be used. In the elementary school, we have found that its not enough to be situated in the school: we need to be in individual classrooms. In museums, this is not a problem, but it can be problematic at a university. Typically, these high-end VR devices are located in research labs, not in lecture centers, so instructors need to move their classes to a different area in order to make use of the technology (as was the case for the Harlem Renaissance classes at UIC in the spring of 2001). We also need to investigate what is the most appropriate technology for individual situations. Should students interact individually, in small groups, or as a whole class? The larger the class, the more likely it is that students will participate, but participation seems currently driven by the exotic nature of the technology.

Right now, this kind of VR equipment is still very expensive, but as with all computer technology, the power increases as the cost decreases. A few years ago, we would have used a $250,000 computer to create our virtual worlds; we can now get fairly good performance from a $5,000 computer, which brings the cost of a large screen VR display (including tracking) down to $25,000. This allows us to build systems like the AGAVE for the in-class Virtual Harlem demonstrations, as well as a portable plasma panel that we roll between classrooms at Lincoln. [See figure 3.] The cost is decreasing at the same time that most universities are wiring up their lecture halls as multimedia rooms; the technology is converging nicely.

Thus far, our investigations of VR as a conceptual learning tool

Figure 3. Three students at Lincoln elementary work with a lower-cost version of the technology, a 50″ plasma panel driven by a consumer-level PC rolled into their classroom for a week.

are encouraging. We believe it is helping the children at the elementary school, and, perhaps more importantly, the teachers and principal believe that it is helping. We have just begun to evaluate how Virtual Harlem can be beneficial. We are also learning how to make better virtual environments, and better educational interventions that take advantage of VR.

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